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Playing the Devil's Advocate in Facilitated System Dynamics Modelling Processes: The Case of the UK Retrofit System

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Abstract

One of the most important emitters of CO_2 is the building stock, in particular the residential one. Although technical potential to increase buildings' energy efficiency is available, a gap between actual and potential implementation persists and policymakers worldwide continuously try to explore new tools to support the retrofit uptake. Within this context, the UK committed itself to ambitious carbon emission reductions by 2050 and there the housing stock is believed responsible for about 29% of total emissions. The main instruments used by British policymakers were energy obligations schemes and despite these policies performed relatively well, they were not able to substantially support the deep retrofit uptake necessary to reach 2050 targets. In late 2012, a new market-based policy, called the Green Deal, was launched with the goal to substitute all the previous mechanisms and support the uptake of millions of retrofit measures, but it was a huge failure. The causes were partially identified in the lack of knowledge available on the dynamics involved. Moreover, British policymakers began to explore two new financial policies, stamp duty rebate and green mortgages, which systemic impact was never assessed. Hence, the objectives of the present dissertation were to uncover these dynamics related to British homeowners retrofit uptake, to evaluate the impacts of the two new policies, and, since the study was conducted a participatory system dynamics approach, to test if an adaptation of the traditional Devil's Advocate script, in which the facilitators left their neutral role and act as the missing stakeholders, would be a successful way to tackle homogeneity in participatory workshops. This last was formulated since the research context posed this methodological challenge. The study was conducted in a joint project between University College London and the Department for Business, Energy and Industrial Strategy in which only policymakers could attend the workshops because of the confidentiality and time constraints, creating a situation of homogeneity that could had undermined outcomes' quality. In the literature there were not techniques available to overtake the problem, therefore the new setting was developed and used. Although playing the Devil's Advocate appeared to be challenging to facilitators, it proved to be successful and increased the heterogeneity in the room. The research resulted in a quantified model that depicted the dynamics related to British homeowner retrofit uptake. The study highlighted affordability as a necessary condition but not enough to raise retrofit: popularity and non-financial attractiveness are two factors that deeply drive measures uptake. The two tested policies showed low direct impacts on the system since they target a small segment of population. Nonetheless, indirect effects related to additional financial benefits may increase policies' impact, although these effects are strongly dependent on the time markets need to perceived policy changes. No silver bullets are available in policymakers' toolbox and a combination of policy instruments is necessary. Specifically, financial policies need to be integrated with interventions aimed to increase popularity and non-financial attractiveness of retrofit measures.

Key words: *housing stock, energy efficiency, retrofit, United Kingdom policymaking, system dynamics, participatory system dynamics, group model building, facilitation, homogeneity, Devil's Advocate*

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"… We need to really shake this up, to get it moving and we get this feedback! […] what you need to do is give the system a serious shock, not just play around with a few incentives; you need to change this really quickly …"

- Workshop participant

1. Introduction

1.1. Background and relevance

Having a roof over the head is a primordial human need. For this reason, human beings have always built edifices, shelters and especially dwellings. This necessity is so widely recognized that providing all the citizens a decent place to live became in the last century one of the principal objectives of national governments (e.g. social housing) (Malpass, 2014). Until the pre-industrial era the whole building stock was not a source of any major threat to the environment, but, unfortunately, this has changed with the advent of the industrial revolution (IPCC, 2014). Modern factories took place and started to massively consume energy and pollute. Then, this condition extended to all the type of edifices. Among all the types of pollutants emitted by the building stock over time, greenhouse gasses (GHG), such as carbon dioxide (CO_2), became one of the most menacing. Anthropogenic GHG emissions are the main responsible for one of the major threats to human society today: *Climate Change* (IPCC, 2014). While at the beginning the housing stock wasn't playing a big role, as time went on its share of GHG emissions increased. Wealth diffusion, development of technologies (appliances), decrease in the household average size combined with an increasing population are all factors that made the housing stock consuming energy and become an crucial GHG emitter (Ürge-Vorsatz et al., 2012). At the moment, there are plenty of functional and cost-effective technologies available, and new options are likely to come from the developments of research (Ürge-Vorsatz, Harvey, Mirasgedis, & Levine, 2007). Nevertheless, achieving future with lower carbon emission from the housing stock will require very significant efforts to build up programs and policies aiming to do so, far beyond what it is happening today. Therefore, nowadays, policymakers all around the world are faced with this difficult contraposition in which a basic human need, such as having a dwelling, is causing a major threat to whole humanity. One of the main strategies they identified in order to tackle the issue is to decrease the energy efficiency of the housing stock (Kelly, 2009). On top of that, increasing the dwellings retrofit extent, the improving of existing buildings structure with energy efficiency equipment, has become a desirable goal also because achieving this objective could lead to additional co-benefits (e.g. green growth, poverty alleviation, energy security, etc.) that are really appreciated by citizens and politicians (Ryan & Campbell, 2012).

United Kingdom (UK) is no exception to this situation. The country committed itself to the very ambitious pledges of carbon emission reduction of the 80% below 1990 levels by 2050 (Parliament of the United Kingdom, 2008) in order to do its part to 'fight' climate change. However, although the UK has done fairly well so far, with current trends the CO_2 abatement targets will be missed (Committee for Climate Change, 2015; Kelly, 2009). Within this context, the housing sector represents a big share of UK energy consumption (Waters, 2016) and therefore it is getting British policymakers' special attention. Owing the low replacement rate, the majority of the UK dwellings will be still in existence in 2050; therefore, retrofit has been identified

as one of the principal ways to tackle dwelling emissions. In the country, many technical measures for energy efficiency are potentially available. Nevertheless, the upgrading rate for energy efficiency installments is still limited and insufficient to meet national objectives (BEIS, 2017b; DECC, 2016b). Moreover, pursuing these goals has become important not only from an environmental perspective but also for other reasons. First, these improvements will help the government to tackle the widespread social problem of fuel poverty (households that can not afford to maintain properly warm their home at a fair cost; DECC, 2015). But also it has been observed that retrofitting housing stock would lead to greater energy security (Kelly, 2009), avoid energy grid structural enhancements (Erbach, 2015; Poudineh & Jamasb, 2014), foster green growth (Ryan & Campbell, 2012). Considering the importance of achieving efficiency in UK dwellings, policymakers started almost 20 years ago to implement policies aiming to support retrofit uptake rate among households (Rosenow, 2012). Since the first governmental interventions, almost all the policies had been based on a logic of subsidy (e.g. CERT, ECC1 and 2, ECO) for the households on the retrofit measure (Rosenow, 2012). Over time the schemes targets have progressively raised and these interventions delivered the promised carbon reduction in a relatively satisfactory way. However, the subsidies' mechanism worked well for the UK short term pledges (Committee for Climate Change, 2015) until these types of policy structures became 'unsustainable' for two reasons. First, these schemes were not able to support a retrofit uptake high enough to meet the long-term national targets. Second, in a difficult economic situation in which the country is going through, it was becoming more and more challenging to defend this system of subsidies to the retrofit market. Energy efficiency was not necessarily perceived as a priority and therefore maintaining these financial aids was getting expensive in terms of political capital. Therefore, in 2013, the *Green Deal* scheme was launched in grand style and it became the Government's flagship green policy. It was based on innovative economic incentives on bills and it was intended to deliver energy efficiency retrofits at scale. It was expected to support millions of retrofit installations, but instead the scheme was undertake only by few thousands of households (Morse, 2016; Rosenow & Eyre, 2016) resulting in a resounding policy failure (Bishoff, 2013; Gosden, 2016; Syal, 2016; Vaughan, 2015). There are multiple reasons for this failure (Bonfield, 2016; Morse, 2016; Rosenow & Eyre, 2016). However, one of the main causes was the poor design of the policy (complicated and not economically attractive) that forgot to take into account the complex dynamics involved in the homeowners retrofit uptake (Eker & Zimmermann, 2016; Macmillan et al., 2016) and ended up misjudging households behaviour and overlooking to many policy resistances and unintended consequences (Collins & Dempsey, 2017; Shrubsole, Macmillan, Davies, & May, 2014). Now, new policies are under examination by policymakers in order to fill the gap left by the Green Deal fiasco. The main direction is towards the creation of financial and fiscal instruments and two policies are being considered. First, a *green mortgage policy*, in which it is assumed that lenders starting to offer preferential mortgages for improving fabric energy efficiency or providing better conditions to home buyers that purchase houses with high efficiency standards, will stimulate the retrofit uptake. Second, it is a direct *stamp duty rebate*, namely a

discount on the fees to pay when a house is acquired if the dwelling under transaction is energetic efficient or if the buyer is committed to retrofit the property.

Unfortunately, scientific sounded knowledge on this issue is lacking. There have been multiple studies on the homeowner decision-making process for the retrofit uptake (Wilson, Crane, & Chryssochoidis, 2015) but they are very specific and narrow focused on small sectors or portions of the retrofit system. Conversely, there are no studies that capture and explain the dynamics involved in the homeowners retrofit uptake rate in UK. In other words, there is not a robust knowledge from a more holistic perspective understanding loops, barriers, drivers and interaction between different actors and their decision-making processes related to the homeowner retrofit demand are still unknown. Moreover, the possible impacts of the two policies under investigation by policymakers have not been assessed and their effects on the retrofit market explored in scientific literature.

1.2. Research context and setup

To conduct this study System Dynamics (SD) methodology (Forrester, 1961; Sterman, 2000) was considered an optimal tool to improve our understanding over the issue through the use of causal maps and quantified models. Moreover, it was decided to use this method in its participatory form (Stave, 2010; Vennix, 1996). This approach is usually called Participatory System Dynamics Modelling (PSDM) and it directly involves stakeholders and experts in the process of map or model construction. This choice was made for two main reasons. First because including stakeholders and experts in the conceptualization and modelling phase may dramatically improve the quality of the outcomes and support possible implementation (Scott, Cavana, & Cameron, 2016). Second with respect of the relation between housing stock and energy efficiency, there have been many calls by scientist to use more PSDM to understand what are the dynamics involved (Eker & Zimmermann, 2016; Shrubsole et al., 2014) and to use this approach to concretely support policymakers in the decision process (Macmillan et al., 2016; Xing, Lannon, & Malcolm, 2014) with quantified SD models.

A joint project between the Department of Business, Energy and Industrial Strategy (BEIS), the former Department for Energy and Climate Change (DECC), and the University College London (UCL) Institute for Environmental Design and Engineering (IEDE) offered the right context to conduct this investigation. Between March and April 2017, in London, a PSDM project was performed with policymakers from BEIS with the support of UCL researchers and in collaboration with Valerio Cappuccio, a fellow Erasmus Master in System Dynamics (EMSD) student. The project aimed to improve the departmental understanding of the dynamics involved in the homeowners retrofit uptake and to preliminary assess the likely outcomes of the green mortgage policy and of the stamp duty rebate. Unfortunately, the project took place in 'pressure-cooker' situation (Gerrits & Vaandrager, 2017). The time span for the research on the field was very short compared to usual PSDM approaches because the Department needed to have some preliminary insights very quickly.

In addition, due to the short time to arrange the participatory sessions and to the confidentiality of the issues discussed (the two policies were not publicly disclosed yet), only policymakers attended the sessions while all the other stakeholders were excluded. As a result, this condition of homogeneity in the participants' group, not so uncommon in PSDM projects, could have decreased the quality of the outcomes (Gerrits & Vaandrager, 2017). Therefore, the study posed interesting methodological challenges. In response to this situation a new facilitation approach was prepared upfront, in line with the objectives of the dissertation, and developed as a possible way to overcome the problem. It consisted an adaptation of the traditional Devil's Advocate in a new setting, in which facilitators leave their neutral roles and try to act like the missing stakeholder would do in the attempt to bring their mental models into the room.

1.3. Research objectives and contribution

Consequently to the gaps in literature identified above, the questions this dissertation tries to answer are the following:

1) What are the dynamics involved in the homeowners retrofit uptake rate in UK? Specifically, what are the loops, barriers, drivers and interactions between different actors and their decision-making processes related to the homeowner retrofit demand?

2) What will the impact on the uptake rate of financial policies, such as a *green mortgage policy* or a *stamp duty rebate,* be? Would they be effective from a dynamic perspective, namely would they be able to trigger virtuous feedback loops?

In addition to these objectives, this thesis aims also to explore the effectiveness of the adapted and new Devil's Advocate script as a tool to overcome homogeneity in a PSDM group of participant. Therefore, it tries to give a response to the following demand:

3) In a PSDM case in which relevant stakeholders cannot be involved in the participatory process and homogeneity is present in the group of participants, how can missing stakeholders' point of view be brought inside the PSDM sessions? What is the effectiveness of the adaptation of the Devil's Advocate script presented in this thesis?

The pursuit of these research objectives and the resulting insights are expected to improve our understanding of the retrofit system in the UK and to preliminary evaluate the impacts of financial policies under consideration in BEIS. Providing an answer to the last question could contribute to enrich the set of instruments in the toolbox of SD practitioners, since homogeneity issues are not uncommon in PSDM and robust solutions to overcome this issue are lacking.

1.4. Dissertation structure

This dissertation is structured as follows. In the second chapter, a review is conducted on the literature discussing the environmental issues posed by the buildings' stock (with an eye to the housing one) and the different methods and policies for their mitigation. In the third chapter, the specifics and peculiarities of the UK case are presented, such as: the challenges to policymakers, the knowledge gaps undermining previous policy efforts, an overview on the methods used before on this topic and on the related SD researches. Then in the fourth chapter, it is outlined the PSDM method developed and used to perform the study. Here it is also explained why a new approach to tackle homogeneity in groups in PSDM project is needed and how the new Devil's advocate (DA) setting is structured. Subsequently, the fifth chapter describes and discusses the results of the research: first, the process and outcome products are shown, then the results of the new DA are analyzed, and later the simulations runs and policy tests performed through the model are shown and policy implications are discussed. Here there will not be a very detailed description of the model since this will be deeply disclosed in the dissertation of Valerio Cappuccio, the EMSD colleague the model has been built with. The last chapter, the sixth one, reports the main insights gained regarding the three research questions introduced before and indicates possible future pathways for additional studies on the subjects. Fig 1-1 illustrates the thesis chapters unfolding and the different level of analysis.

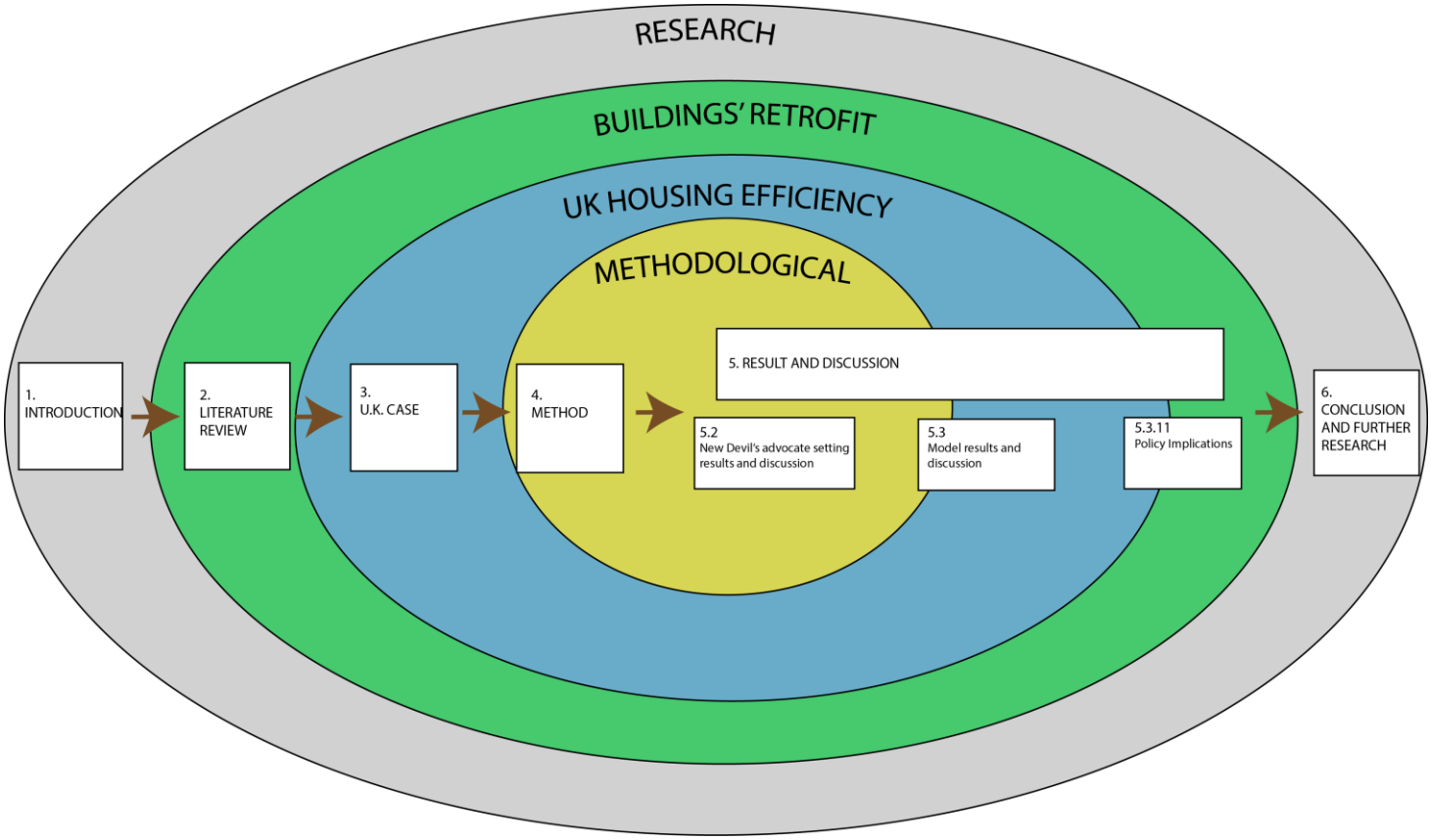


Figure 1-1: Dissertation structure

Source: conceived by the author

2. Buildings' stock and sustainability

2.1. Buildings stock: a source of sustainability concerns

Starting from the ground-breaking message of the book *Limits to Growth* (Meadows, Meadows, & Randers, 1972), mankind has began to consider environmental *sustainability* as a potential obstruction to human prosperity. Sustainably is a complex and wide concept that offers an umbrella for a wide array of issues (ocean acidification, natural resources management, land use, etc.) and due to this variety and complexity it has been discussed for long time (Hopwood, Mellor, & O'Brien, 2005). Nevertheless, nowadays, despite some few skeptical niche-groups that remain, anthropogenic climate change has been almost definitely acknowledged as one of the major future sustainability threats to humanity. Greenhouse gasses (GHG) emissions, mostly in form of carbon-dioxide (CO_2), can be pointed as the most important cause of this threat (IPCC, 2014). That has pushed human community (scientists, policy makers, etc.) to look at the sources of GHG in order to try to decrease their emission. What emerged is that the existing building stock is one of the most important responsible CO_2 releaser worldwide (Allwood, Cullen, & Milford, 2010; Ürge-Vorsatz et al., 2012; Ürge-Vorsatz, Harvey, Mirasgedis, & Levine, 2007) as it is possible to see in Figure 2-1.

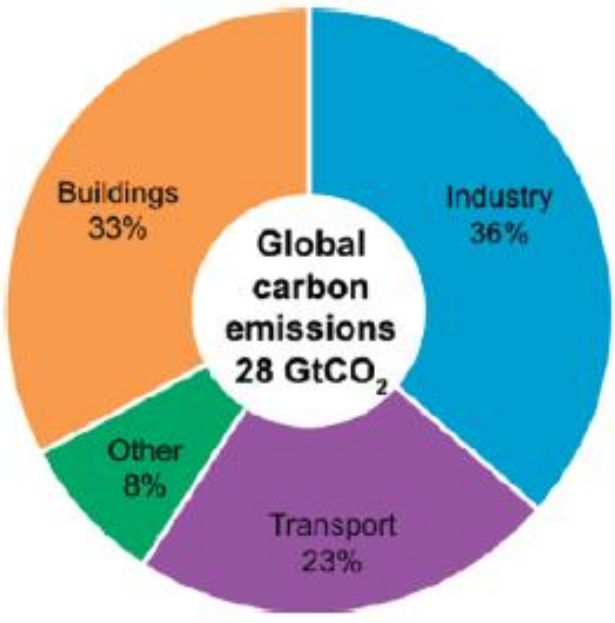


Figure 2-1: Global anthropogenic CO_2 emissions sources (2006)

Source: Source: Allwood et al., 2010 p.1

Ürge-Vorsatz et al. (2007) estimated that, in 2002, the building sector was 'blameworthy' of 7.85 Gt of carbon emission, accounting for 33% of the total. Since then, the situation hasn't changed much at a global level as a later appraisal made by Ürge-Vorsatz et al. (2012) reports that the building stock is still responsible of a third of energy related carbon emissions. In addition to that, it contributes with roughly 1.5 Gt CO_2 (Ürge-

Vorsatz et al., 2007) equivalent emissions of halocarbons (type of gasses responsible not only of increasing global greenhouse effect but also of decreasing the thickness of the ozone layer), approximately two thirds of the total emission (Ürge-Vorsatz et al., 2012), as well as around 25-33% of black carbon emissions (Ürge-Vorsatz et al., 2012). It has also projected that by 2030 there will be a growth in building absolute emissions reaching a range between 11 and 15.6 Gt/year, with the share of the sector remaining around one third of the total (Ürge-Vorsatz et al., 2007). However, other studies state that the building energy use and related CO_2 emissions may even double or possibly triple by 2050 because of many tendencies (Lucon et al., 2014). These trends are connected to the fact that an increasingly number of people in developing countries will access to adequate housing, electricity, and improved cooking facilities from today to mid-century (Lucon et al., 2014). Moreover, households size changes (decreasing number of people per households) and variations in wealth level and lifestyle habits (e.g., rise in the average number of appliances per household) all around the world will contribute to increase building energy use (Lucon et al., 2014). In this context, residential buildings play a key role since they are responsible for the nearly 18% of direct CO_2 emissions (World Health Organization, 2011). This generates a very challenging contrast, where on one side housing is a basic human necessity and right (United Nations, 1948) and on the other one housing is a major contributor to Climate Change, one of the most important threats to humanity. However, the residential stock can become also part of the solution to the problem. Housing have been described by the IPPC (2014) to have one of the greatest potential compared to other sectors (i.e., industry, transport, , waste generation, energy supply, forestry) for reducing GHG emissions in a cost-effectively way, in short time and using mature available technologies (World Health Organization, 2011) compared to other sectors. Providing some numbers can help to understand the magnitude of the phenomena: for example, reductions in heating energy requirements of 50 to 75 % in single-family housing that can even increase up reaching peaks close to 90 % in multi-family housing for average costs of approximately 100-400 $US\$_{(2010)}/m^2$ (Harvey, 2013).

Kelly (2009), in line with Lucon et al. (2014) and Ürge-Vorsatz et al. (2007), has identified mainly four ways by which carbon emission can be cut down from the existing buildings and housing stock:

- *re-engineering the fabric of the buildings*
- *improving the energy efficiency of appliances used in houses and offices*
- *decarbonizing the sources of energy to the home*
- *and changes in personal behaviour*

The last point involves social and psychological aspects and regards population educational processes more than edifices themselves. Also the decarbonisation of the energy sources (through the decarbonized grid and use of local or distant renewable sources of energy) is more related to the way energy consumed by edifices

than directly to how the building consumes energy. Whilst the first two ways, re-engineering the fabric of the edifices and improving the performance of appliances at parity of energy consumption, directly regard the action to close the buildings and housing energy efficiency gap and this will be the focus from now on.

2.2. Energy efficiency gap: a complex system

The energy efficiency gap has been defined as the "*discrepancy between optimal and actual implementation of energy efficient technologies*" (Backlund, Thollander, Palm, & Ottosson, 2012). At the moment, there is a wide set of relatively accessible and cost-effective technologies that could decrease buildings energy consumption by a notable extent that have not been broadly adopted (Ürge-Vorsatz et al., 2007). In this respect, Yang (2012) reports that the International Energy Agency (IEA) calculated the potential for energy efficiency improvements to range approximately between 20% and 50% of the total energy consumption. Other estimations show that closing the general energy efficiency gap would help to save around the 20% of the total final energy consumption from 2010 to 2030 in OECD countries and of that increased energy efficiency in buildings will account for around 34% (Jollands et al., 2010) (Fig 2-2). This seems to be in line with the IEA estimations (Yang, 2012). Moreover, in developing countries the potential can be considered even larger since there are more low-cost energy efficiency opportunities in these nations that have not been tackled yet and because of the diffused use of inefficient technologies (Yang, 2012).

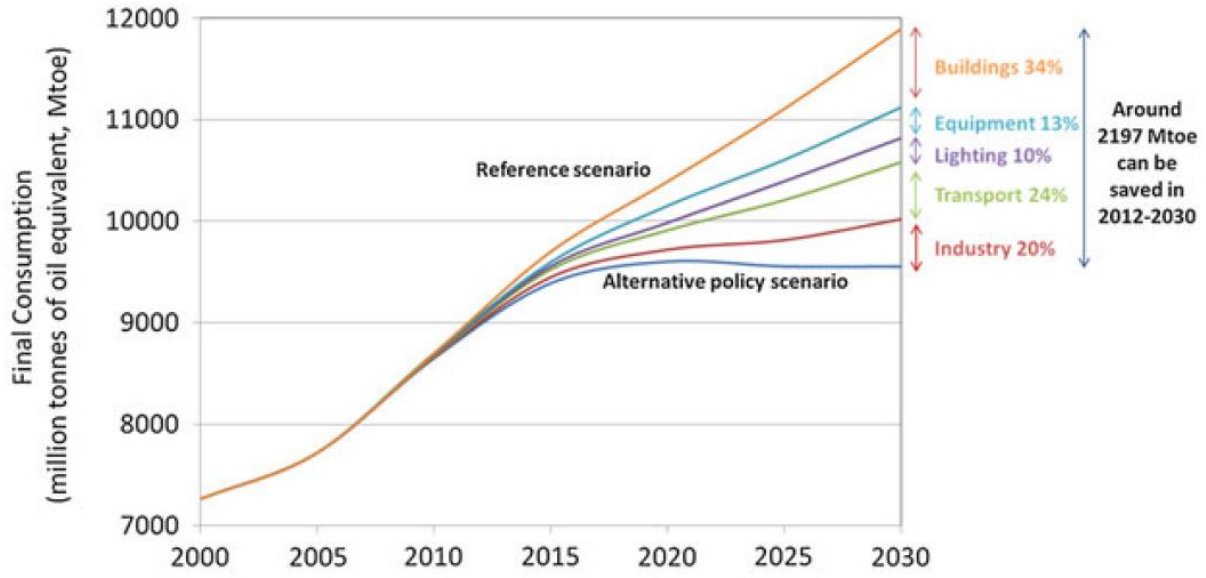


Figure 2-2: Impact of energy policy on world energy consumption (2000–2030)

Source: Yang, 2012 p.11

Another useful way to look at the energy efficiency gap is as the "*difference between the actual level of energy efficiency and the higher level that would be cost-effective from an individual's or firm's point of view*" (Yang,

2012). From the economical point of view this implies it is possible to produce greater economic output using less energy and from a societal one that people do a highly inefficient use of energy (Lovins, 1976 cited in Yang, 2012, p. 11). Despite the clear benefits energy efficiency leads to, as it was shown, this gap is far to be close even though it seems potentially to be cost-effective. The causes of this situation have been identified in the presence of multiple barriers (financial, informational, behavioural, geographical, technological etc.) that inhibit the uptake rate of energy efficiency measures (Blok et al., 2007; Dowson, Poole, Harrison, & Susman, 2012; Lucon et al., 2014; Santangelo & Tondelli, 2017; Tuominen, Klobut, Tolman, Adjei, & De Best-Waldhober, 2012; Ürge-Vorsatz, Koeppel, & Mirasgedis, 2007; Wilson et al., 2015; Yang, 2012). These obstacles, act also as market barriers since hinder the growth of the energy efficiency businesses, act on several levels of society, such as on households, on firms, on regional governments, on nations (Lucon et al., 2014; Yang, 2012), pushing government and international bodies (e.g. United Nations Framework for Climate Change, IEA, etc.) for policy interventions (Yang, 2012). Due to this multiplicity, the understanding of these obstacles comes from several disciplines, including economics, engineering, sociology, anthropology, and psychology. Nonetheless the many forces employed, there is still no consensus about the nature, origin and interrelations of these barriers and there are different opinions about which policy interventions are indispensable and effective (Yang, 2012). The effort needed to close the gap is massive, if we consider that IEA has projected that the world will require around 96 billion US$/year to address the energy efficiency gap between 2012 and 2030, in all sectors of society (Yang, 2012). To make things even more complex, increasing energy efficiency is not always a straightforward process because it can generate unintended consequences. This is especially true with respect of increasing the efficiency level of dwellings (Collins & Dempsey, 2017; Shrubsole et al., 2014) that can impact negatively households living there.

Therefore, energy efficiency appears to be a very complex system, affecting several domains (economic, social, and environmental), with high stakes involved (e.g. high investments required, increasing need to mitigate climate change), in which multiple actors are present (people, firms, policymakers, etc.) at a different levels (local, national, regional, global), with barriers and unintended consequence.

2.3. Energy efficiency co-benefits: multiple interests

In addition to mitigate climate change, improving buildings and housing retrofit extent can lead to important direct and indirect *co-benefits* other than energy savings. Co-benefits are defined as "*the positive effects that a policy or measure aimed at one objective might have on other objectives, without yet evaluating the net effect on overall social welfare. Co-benefits are often subject to uncertainty and depend on, among others, local circumstances and implementation practices*" (Clifford & Prasad, 2016). In the case of energy efficiency, it is possible to consider as co-benefits all the socioeconomic outcomes that may arise aside to climate change mitigation (Ryan & Campbell, 2012). These co-benefits seem to be many (Fig 1-2) and they have been listed

by a multitude of researchers (Blok et al., 2007; Kelly, 2009; Lucon et al., 2014; Ryan & Campbell, 2012; Ürge-Vorsatz, Danny Harvey, et al., 2007).

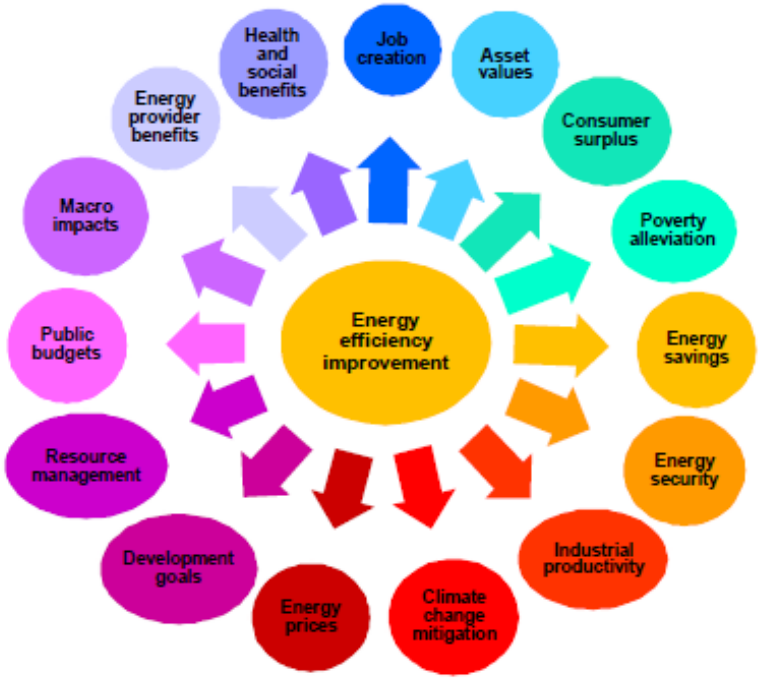


Figure 2-3: The multiple benefits of energy efficiency

Source: Ryan & Campbell, 2012 p.8

Understanding the co-benefits related to energy efficiency is crucial in order to comprehend the relevance that closing the energy efficiency gap is gaining among policymakers around the world. In this respect, Ryan & Campbell (2012) provide an interesting framework to understand these co-benefits. They assume that society is a multilayer entity and state that energy efficiency related benefits impact on many of them. The authors identify four main levels that can potentially be affected: *individual, sectoral, national* and *international*.

At *individual* level (people, households, enterprises, etc.) several co-benefits have been highlighted. First, health and wellbeing improvements were observed in public health as result of improved heating, cooling and air quality. Then, augmenting energy efficiency can lead to increased energy affordability and access, alleviating poverty. If energy efficiency raises energy demand is reduced at parity of consumption (namely there is not rebound effect). This translates in reduced bills and it might make the difference especially for the low-income classes, making them able to acquire all the energy services they need without renouncing to other primary needs as well as free up income to spend to satisfy other needs. However, the last concept is valid not just for the poor but for all income level classes.

At a *sectoral* level, namely on the economic sectors of the society (industrial, transport, residential and commercial) improved energy efficiency can increase industrial productivity and competitiveness. This because it reduces the consumption of resources and pollution (lowering the costs of buying resources, depleting waste or compensating for externalities), and it improves firms capacity utilization leading to smaller operational and maintenance costs. Moreover, increased energy efficiency may help energy providers to supply better energy services to their customers, to decrease operating costs and to increase their profit margins. In addition, it alleviates the pressure on the energy grid, reducing the peak demand and providing an alternative solution to grid capacity enhancements (Erbach, 2015; Poudineh & Jamasb, 2014) that are at the moment very costly and technically difficult to make. Lastly, evidences start to show an increase in the number of investors willing to pay a premium for properties with higher energy performance (Fuerst, McAllister, Nanda, & Wyatt, 2013). Therefore, energy efficiency may also increase asset values.

At a *national* level there might be multiple co-benefits related to energy efficiency. First, investments in energy efficiency can lead to new jobs in energetic and other sectors. This could be in line with governments' green growth strategies and macroeconomics objectives of GDP increase. Then, it reduces the energy-related public expenditures, for example, it lowers energy consumption in government agencies and public utilities due to the decreased fuel purchase costs. For countries with energy consumption subsidies (usually in attempt to fight fuel poverty), improving energy efficiency means decreasing the public disbursements to 'feed' these subsidies (Ryan & Campbell, 2012). In countries where fuels are imported, energy efficiency can lower the pressure on currency reserves (better trade balance) and in energy-exporting ones it can free up even more fuel to export (Ryan & Campbell, 2012). Another very important co-benefit for policymakers in governments is that a reduced energy demand can improve the security of national energy systems crosswise the four dimensions of risks (Kruyt, van Vuuren, de Vries, & Groenenberg, 2009): "*fuel availability (geological), accessibility (geopolitical), affordability (economic) and acceptability (environmental and social)".*

Lastly, at *international* level there may be several positive additional impacts too. If energy demand decreases in multiple markets it may lead to a reduced energy price on a regional scale (Ryan & Campbell, 2012) and consequently this can increase energy affordability help to raise the disposable income of individuals and enterprises. In addition, lower demand can reduce pressure on natural resources (e.g. oil, coal, gas) with potential benefits for the environment and ecosystems. Improved energy efficiency can be significant in achieving economic and social goals in developing countries such as better access to energy services, poverty eradications, improved environmental sustainability and economic progress (Ryan & Campbell, 2012).

However, as mentioned above, this is only one of the framework that can be used to understand the multiplicity of the energy efficiency related co-benefits. Usually, other authors tend to categorize these co-benefits based on the domain they impact or challenge they tackle, for an example look at what Kelly (2009)

propose. Integrating these two different ways of interpreting energy efficiency co-benefits may help to understand better how wide the range of these co-benefits is. This is done in in Table 1-1. Here, in vertical the co-benefits levels of impact proposed by Ryan & Campbell (2012) are combine horizontally with an adaptation of the three domain of impact used by Kelly (2009).

Table 2-1: Energy-efficiency related co-benefits level and domain of impact

Domain / ***Level***	*Energy security*	*Long-term sustainability*	*Welfare*
Individual	improving energy affordability and access	None	ameliorating health and wellbeing; increasing disposable income
Sectoral	None	reducing costs for energy providers and energy peak	higher industrial productivity and competiveness; bigger assets values; increasing GDP
National	improving national energy security;	None	creating jobs
International	moderating energy prices regionally;	reducing the extraction of natural resources; meeting development goals;	moderating energy prices regionally; meeting development goals

Compiled and conceived by the author

The world is facing challenges on multiple levels and domains. Improving energy efficiency for attacking one of these challenges means to attack all the others. It follows that someone may be skeptical on some of the challenges but not on all of them. This is why energy efficiency is widely recognized as a desired and appealing goal. Although these co-benefits are often not all quantified or identified by policymakers, the impacts listed above can still have a key role in making energy efficiency a priority for policymakers and then prompt them to implement policies that also mitigate GHG emissions (Blok et al., 2007). This is particularly true in countries where environmentalism does not have a strong tradition or a priority role in political agenda or occupies daily concerns of citizens. (Blok et al., 2007). In conclusion, in the light of what has been discussed so far, the buildings' stock seems to be a major player in "*both causes and solutions of these challenges*" (Kelly 2009).

2.4. Closing the energy efficiency gap: retrofit

As it was shown, there are mainly two ways to reduce the energy efficiency in buildings: re-engineering the fabric of the buildings and improving the energy efficiency of appliances used in offices and, in particularly, houses.

For what concerns buildings' appliances, evidence suggests that in a wide number of countries devices and machines energy efficiency has increased in the last years (IPCC, 2014), even three times more than underlying rate of technological improvement (Lane, 2015). This substantial improvement has translated into energy saving and therefore in carbon emissions reduction. For example, in the countries in which robust actions have been taken to improve appliances performance at a lower energy cost, it has been estimated it saved between 10% and 15% of national or sectoral energy utilization (Lane, 2015). Moreover, the issues related to the expensiveness of efficient appliances acting as barrier for the low income households uptake, i.e. Faberi, Mebane, & Presutto (2001), it has been resolved by a 'natural' decrease in purchase prices (see economy of scale and learning curves effects). This means that policies that have been undertaken (e.g. labelling[1]) worked relatively well. Even if there still room for improvements in the appliances' efficiency, where it seems that much needs to be done regards the building fabric (Ürge-Vorsatz et al., 2007). To increase the energy efficiency of the building stock means to diminish the quantity of energy consumed during their life-long (in particularly the energy required for indoor heating). There are principally two ways. The first one is to construct new buildings in a more efficient way and support the depletion rate of high inefficient buildings. The second is to *retrofit* the existing stock (the operation of improving the energetic performance of a building*)*. Acting on the new constructions is easier for policymakers than increasing the retrofit uptake rate, since setting efficient standards for new edifices is relatively straightforward process (although, implementation may raise several issues), while operating on existing building, especially on the houses people live in, is considered a very sensitive subject due to the high sentiment people project in their home (Soo, 2015).

Unfortunately, due to the low replacing rate, most of the existing building stock will still be present in 2050 in most countries (IPCC, 2014), especially in the developed ones, e.g. in Europe it has been predicted that 80% of the actual stock will still be there (Serghides, Dimitriou, & Katafygiotou, 2016). The replacement time is a key concept that needs to be understood in order to comprehend the necessity of retrofit. The replacement time of appliances is relatively much shorter than the buildings' one. This means that it is not necessary to act on the appliances in use in order to meet the reduction goals in that sector, but producing and commercializing efficient ones and wait for the natural replacement of old and broken devices can be

[1] A practical example of labelling policy is the one put in place by European Union and can be found at the following link. https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficient-products

enough in order to meet the targets on time (Blok et al., 2007). Conversely, this is not true for the building stock. That is why retrofit is necessary at this stage.

At the moment there is a plethora of ways thorough which is possible to retrofit an existing building (Blok et al., 2007; IPCC, 2014). Table 2-2 offers a summary of the measures that will discussed below.

Table 2-2: Summary of the overviewed retrofit measures

Direction of action	*Examples of retrofit measures*
Thermal envelop	Walls insulation, ceiling insulation, basement insulation, doors and windows frames, ventilation system
Building heating system	Solar passive technologies (airflow windows, preheating or pre-cooling buried pipes, solar air collectors, sun-facing glazing)
Space heating system	Condensing boiler, heat pump, passive ventilation mechanisms, customize ventilation
Heating, ventilation and air-conditioning systems (HVAC)	Demand-controlled airflows systems, displaced ventilation
Building energy management	Smart buildings, smart meters, centralized electronic energy management systems
Lighting	Daylight sensors, efficient lightning devices
Solar energy	Devices for capturing solar-thermal energy to heat up water and indoor air

Compiled and conceived by the author

One of the principal retrofit interventions is to act on the *thermal envelop* of the building. Thermal envelop refers to the building shell as a barrier to unwanted heat transfer between inside and outside the edifice. The effectiveness of this envelop depends on (Blok et al., 2007): the insulation levels in the walls, ceiling, loft, basement; the thermic features of doors and windows; and the stream of inside/outside air exchange which depends on the edifice air-tightness, on ventilation (mechanical and non-mechanical) and on external driving forces (e.g. wind, inside-outside temperature or air pressure differences). Improvements in inefficient thermal envelops can have big impacts in reducing energy consumption for heating by a factor from two up to four compare to standard practices at a relatively low cost-effectiveness for both residential and commercial buildings (Hamada, Nakamura, Ochifuji, Yokoyama, & Nagano, 2003; Hastings, 2004 cited in Blok

et al., 2007, p. 395). Moreover, it does not just help to keep the edifice warm in winter, but it also considerably reduce indoor summer temperature thus it lowers the energy used to cool down the fabric. Another option for retrofit is to act on the *building heating system*. It can consist, for example, in implanting solar passive heating technologies (Blok et al., 2007) such as: airflow windows, preheating or pre-cooling air ventilation through buried pipes, solar air collectors (mounted on walls or roofs), extensive sun-facing glazing, etc. Or alternatively, the effort may be towards increasing the efficiency of the *space heating system*: new condensing boilers (in which additional heat is recovered as part of the water vapour in the outlet valve is condensed and reused, see Palmer & Cooper, 2013), heat pumps (a device that uses energy inputs to transfer heat from the outside air or ground in the winter to medium used to distribute heat in a building), etc. Also the cooling effort can be reduced, thorough the use of passive techniques (e.g. fans or pumps that do not require mechanical energy) to meet part of the cooling load, via the increase of cooling equipment performance at parity of energy consumption, and combination of efficient auxiliary systems (e.g. customized and proper ventilation). These have proven to generate significant energy consumption reduction (Blok et al., 2007). This has become a more salient issue considering the recent trends in which the penetration of air conditioning in developing countries is quickly rising and reaching even higher peaks in developed ones (Blok et al., 2007). In line to what has been said, the *heating, ventilation and air-conditioning systems* (HVAC) (namely filtration, humidification, dehumidification, heating and cooling) need to be adjusted and tailored to the fabric of the building and to the situation. This provides massive savings according to Blok et al. (2007). For example installing demand-controlled airflows in which ventilation systems adapts to the change building occupancy can alone save 20-30% of total HVAC energy consumption (Brandemuehl & Braun, 1999 cited in Ürge-Vorsatz et al., 2012, p. 683). Or new systems like displacement ventilation have been reported to reduce HVAC energy use by 30 to 75% (Blok et al., 2007). Another type of retrofit listed by Block et al. (2007) is the improvement of *building energy management* (BEM). BEMSs are control systems for buildings that use computers for monitoring and managing the use of energy. Nowadays, the edifices that implement this type of technology are also known as *smart buildings*. These systems to help avoid energy waste because they support building occupiers to efficiently manage the consumption and also make faults easy to be detected (through *smart meters*). Estimates of the potential savings vary much in literature ranging from 5 to 40% (Blok et al., 2007). Moreover, smart buildings can be easily combined with daylight sensors to dim or switch off lighting, diminishing energy waste. This if integrated with the most efficient *lightning* devices can reduce by 75% up to 90% lightning energy consumption (Blok et al., 2007). Other retrofit opportunities come from the use of *solar energy*. For example, solar-thermal energy can be utilized for heating water and indoor air offering savings on the energy used for warming water and air that range from 10 to 60%, depending on the fabric (Blok et al., 2007).

The measures listed above are not all the measures available. There is a vast literature on that. The idea of this last paragraph was to show the high number of potential measures that are available. Moreover, many of these can be combined when it is time to retrofit a property, offering even a wider range of options and increasing the CO2 savings. Nevertheless, as it was shown, the uptake rate of energy efficiency gap for buildings and housing is far to be at an optimal level.

2.5. Policies to support retrofit uptake rate

Although improvements in energy efficiency evidently reduce buildings and housing energy consumption, as well as providing a broad range of co-benefits, its uptake rate is lower than desired ad the energy efficiency gap discussed above still persists all around the world. The causes of this unfavourable situation have been identified in the presence of decision-making, informational and economical barriers (Wilson et al., 2015) that interfere and hinder people to install retrofit measures in their property (all these obstacles vary from case to case, therefore the ones related to UK will be presented and discussed in detail in chapter 3.4).

Therefore, market forces alone will not lead to the indispensable conversion towards low carbon buildings without external policy intercession (Lucon et al., 2014). However, there is no consensus among policymakers about which strategies are necessary and most effective to overcome the barriers (Yang, 2012). Hence, from this perspective, the greatest challenge is the development of effective intervention for improving the energy efficiency of existing buildings and houses (Ürge-Vorsatz, Koeppel, et al., 2007). The International Panel on Climate Change (IPCC) through the 3rd Working Group (Lucon et al., 2014) to the Fifth Assessment Report (IPCC, 2014) grouped the broad portfolio of policy instruments in six categories. The detailed policies are reported and described in Table 2-3 at the end of this chapter. First, *regulatory measures* seem to be some of the most effective and cost-effective tools. Examples are building codes and appliance standards. However, standards need to be carefully set at proper level and periodically raised in order to avoid to be locked in suboptimal performances. Moreover, enforcement has not always been easy. Second, *information instruments* (e.g. equipment energy labels, building labels and certificates, and mandatory energy audits) are usually implemented as support of other policy interventions, in particular standards. However, they proved to be relatively effective also on their own. Third, *direct market intervention instruments* include public procurement or the development of energy service companies (ESCOs). These interventions in some cases had a real impact in transforming the market. Fourth, *economic instruments* comprehend several options, including tradable permits (tradable white certificates and broader carbon markets), energy carbon taxes, tax rebates (e.g. tax deductions building retrofits, value-added tax exemption, various tax reliefs), and more focussed incentives (low interest loans and incentives). The fifth category are the *voluntary agreements*, for example with industries. However, the effectiveness of these policies is extremely context-dependent and in many cases they need to be accompanied with other policy measures. The sixth and last type includes *advice*

and leadership programmes, such as information campaigns, advice services, and public leadership programmes. The objective of these interventions is to build public awareness and capacity. Although virtually any of these tools can perform very effectively (environmentally and costwise) if adjusted to the context and if implemented and enforced properly, there is a remarkable spread in the policies' performances and results when it comes to reality (Blok et al., 2007; Lucon et al., 2014). What can be safely stated is that one policy alone in most cases appears not to be enough to achieve significant results but combinations of them (policy packages) seem to be the most sounded approach (Lucon et al., 2014). For example, appliances market transformation has been realized through a combination of energy labels, minimum standards, incentives for efficient equipment and communication campaigns (Lucon et al., 2014). Integration with other policy domains (see co-benefits) is particularly effective and energy-efficiency can be pursued more forcefully through other policy goals that occupy higher positions in the political agendas. Thus retrofit may benefit of more resources and of stronger political support than just climate change mitigation (Ryan & Campbell, 2012). Moreover, IPCC state that to obtain the broadest impact possible policymakers should adopt and holistic approach considering the whole life span of the building and to not neglect the fact that a skilled workforce is needed to fulfill the instalments (Lucon et al., 2014). Lastly, policies should be dynamic, namely with periodic revisions to adapt to technical and market changes (especially regulations may need to be strengthened over time).

Up to know, policymakers have mainly focused on technological improvements in energy efficiency (Geller, Harrington, Rosenfeld, Tanishima, & Unander, 2006). However, especially in developed countries, they began to direct their action towards the existing building stock. This because it is extremely large and renewed very slowly, therefore it has been targeted through policies aiming at accelerating rates of energy refurbishment and regulatory building codes (Lucon et al., 2014). Concerning these lasts, in the last years a large number of executives have set or are considering important strengthening of the requirements in these regulations. Moreover, several emerging policy instruments are starting to gain the attention of policymakers. Some of them, started to act on consumer behaviour in order to reduce energy demand. For instance, they recently started to direct their action on the need to change society behaviours towards more sustainable ones (Lucon et al, 2014). Policy tools for capping or discouraging increasing energy use include: personal carbon trading with personal carbon allocations (but this action still have not been introduced yet), property taxation related to CO_2 emission and energy saving feed-in tariff (incentive to reduce energy consumption. In addition, energy efficiency obligation schemes are being diffused in several countries (e.g. some UE states, Brazil, India and Australia). These certificates are also known as suppliers' obligations and their main application has been in regulated markets directed by obligations upon energy companies to save energy (Lucon et al, 2014). This policy instrument was first applied in Europe and it proved to be very effective (Bertoldi, 2012 cited in Lucon et al, 2014, p. 720). However, these certificates have a downside: they are incline to incentivize cheap and

mass market measures rather than massive, expensive and more effective in terms of savings retrofit. This fact has instilled some concerns on the ability of these policies not to be the best suited for high saving targets (Eyre et al., 2009 cited in Lucon et al, 2014, p. 720). Policymakers are also looking at financial tools that could stimulate and support energy efficiency uptake. Several retrofit technologies have shown to be economically convenient and if properly financed the costs are paid back in a relative short time frame by the energy savings. Unfortunately still many potentially attractive investments in energy efficiency are not undertaken because there are not financial products available, because they do not meet short-term financial return criteria or because customers are very initial-cost sensitive. The major causes of this gap have been identified in the lack of relevant finance and of bankable energy efficiency offers. Germany made an innovative attempt to overcome these issues. Through the KfW (Kreditanstalt für Wiederaufbau) development bank, loans for energy efficiency with very low interest rate (compare to the market) making them very attractive for households. Up to now, the scheme has been successful in supporting many building refurbishments (Rosenow, Eyre, Bürger, & Rohde, 2013). Also, UK tried a market-based approach with another innovative policy called 'Green Deal' that unfortunately did not delivered the expected results (it will be discussed in detail in the next chapter). Another financial solution to overcome economic constraints is to involve external investors (e.g. commercial banks, venture capital firms, equity funds, etc.) in contributing to the retrofit and repay their investments through the energy savings. It works best for huge projects (e.g. social housing), since the profits for individual cases are not high enough for the investors (Lucon et al, 2014). Moreover, there is need to guarantee that energy savings are able to repay the investments in order to tempt investors. Lastly, opportunities in financing for green buildings are slowly gathering interests. Japanese financial institutions started to offer products that provide a discount greater than 1% on mortgages and loans for constructing or buying a house, depending on the grade of efficiency received by a public assessment done by the municipality (Murakami et al., 2004 cited in Lucon et al, 2014, p.720). From first evaluations it appears to have contributed to the diffusion of green buildings.

Table 2-3: Retrofit policy portfolio

	Policy	*Description*	*Comments*
Regulatory measures	Building codes	Sets of standards for buildings or building systems determining minimum requirements of energy performance	Traditionally typical low enforcement has resulted in lower than projected savings. Building codes need to be regularly strengthened to be effective
	Appliance standards (MEPS)	Rules or guidelines for a particular product class that set a minimum efficiency level, and usually prohibit the sale of underperforming products	Most OECD countries have adopted MEPS. Voluntary agreements with manufacturers are considered effective alternatives
Information instruments	Energy labelling	The mandatory (or voluntary) provision of information about the energy / other resource use of end-use products at the point of sale.	MEPS and labels are usually co-ordinated policy measures with common technical analysis
	Building labels and certificates	Rating buildings based on their energy performance and provide credible information about it to users/buyers	Building labels could be mandatory (for example in the EU) or voluntary. Labels are beginning to influence market prices
	Mandatory energy audits	Measurements of the energy performance of existing buildings and identify cost-effective improvement potentials	Audits should be mandatory and subsidized and reinforced by incentives or regulations that require the implementation of the cost-effective recommended measures.
Direct market interventions	Sustainable public procurement	The organized purchase by public bodies following pre-set procurement regulations incorporating energy performance / sustainability requirements. Setting a high level of efficiency requirement for products purchased by public sector as well as requiring energy efficient buildings when renting or constructing them.	It can achieve a significant market transformation, because the public sector is responsible for a large share of these purchases and investments
	Promotion of energy services (ESCOs)	It aims to increase the market and quality of energy service offers, in which savings are guaranteed and investment needs are covered from cost savings.	Energy performance contracting (EPC) schemes enable ESCOs or similar
Economic Instruments	Energy Efficiency Obligations and White Certificates	The set, record and prove that a certain amount of energy has been saved at the point of end-use. Schemes may incorporate trading.	In all the White Certificates schemes the targets imposed by governments have been so far exceeded

	Carbon markets	The limit to the total amount of allowed emissions. Carbon emission allowances are then distributed and traded	Carbon cap and trade for the building sector is an emerging policy instrument
	Energy and carbon tax	Taxation levied on fossil fuels or on energy using products, based on their energy demand and/or their carbon content respectively	These fiscal tools can be powerful are expected to cause a decrease in consumption. However, depending on price electricity, the tax typically should be quite substantial to have an effect on behaviour and energy efficiency investments.
	Use of taxation	It can be considered as a type of subsidy, representing a transfer of funds to investors in energy efficiency.	Examples include reduced VAT, accelerated depreciation, tax deductions, feebates etc.
	Grants and subsidies	Economic incentives, in the form of funds transfer.	Incentives (e. g., grants and subsidies) for investments in energy efficiency and building renovation
	Soft loans (including preferential mortgages)	Loans and mortgages given for carbon-reduction measures with low interest rates.	Governmental a fiscal incentive to banks, which offer preferential interest rates to customers and incentives based on the performances achieved, e.g., in Germany (CO2-Rehabilitation Program)
Voluntary agreements	Voluntary and negotiated agreements	Tailored contracts between an authority and another entity, aimed at meeting a predefined level of energy savings.	Voluntary programmes can be also applied in the built environment where housing association and public property owners agree on energy efficiency targets with the government
	Awareness raising and information campaigns	Programs transmitting general messages to the whole population.	Information campaigns to stimulate behavioural changes and investments in energy efficiency technologies
	Individual feedback	Provision of tailored information	New developments for information campaigns are seen in the area of smart metering and direct feedback.
Advice and leadership programmes	Public Leadership Programmes	Public practices going beyond the minimum requirements in order to lead by example and demonstrate good examples.	

Source: adapted by Lucon et al., 2014, p. 717

3. Retrofit policy: the United Kingdom housing efficiency

3.1. UK emissions and targets

Within this global context and following the CO_2 reduction targets set by the EU of a 40% GHG cut by 2030 compare to 1990 levels (Erbach, 2015; European Commission, 2014), the UK thorough the Climate Change Act (Parliament of the United Kingdom, 2008) has committed itself to ambitiously reduce its carbon emission in 2050 80% below 1990 levels. In the UK, around 45% of all CO_2 emissions come from the use of appliances, heating systems, the water and air movement in buildings (Kelly, 2009). The remaining 55% is divided among transport 33%, industrial processes 22% and agriculture with an irrelevant percentage. Therefore, incrementing the building stock efficiency performance is essential in order to reduce consumption and thus emissions, especially because evidence shows that 2050 targets with the current improvement rates will be missed (Climate Change Commitee, 2015; Kelly, 2009). In this regards, Kelly (2009) explicitly says that "*unless there is a deep retrofit of existing buildings to reduce carbon emissions by 60% and probably by 80%, the targets […] will certainly be missed*".

3.2. The UK housing stock: a source of concerns and potential solutions

Of the buildings' stock, dwellings represent a big share of total UK carbon emissions. In 2015 they have been accounted for approximately the 29% of the total CO_2 (Waters, 2016) and it has even increased its weight if we look at the past, considering that Kelly (2009) estimated it to be 27%. Fig 3-1 below, shows how prevalent is the energy consumption made by the housing stock compare with other sectors in British society.

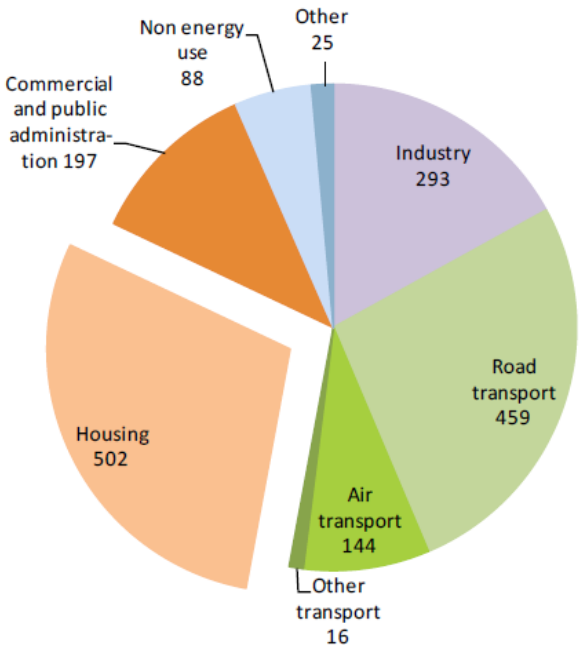


Figure 3-1: Final energy consumption by sector 2012 (UK, TWh, Total 1,724 TWh)

Source: Palmer & Cooper, 2013, p.5

Thus, dwellings have a key part to play in achieving the targeted reductions. It needs to be noted that the UK domestic residential stock is relatively dated compare to most European countries, with many edifices built during the Victorian era (19th century) (Waters, 2016). In consequence, many houses have been built with poor insulation standards and then these properties require additional energy to maintain a basic level of thermal comfort. However, as older houses are progressively substituted with newer and more efficient ones, this will bring to a lower stock energy consumption. But, given the actual low replacement rate, the majority of these dwellings will be in existence in 2050 (Shrubsole et al., 2014) when UK is expected to have met its GHG reduction targets. In 2050, 70-80% of the existing housing are likely to still be there according to Palmer & Cooper (2013), whilst Kelly (2009) calculated this percentage to be even higher, 87%. Therefore, in UK the replacement rate is a long-term trend; houses constructed antecedently 1918 were the 25% of the dwelling stock in 1970, and 44 years later in 2014, they were still a 16% of the total stock, yet a remarkable percentage (Palmer & Cooper, 2013). In this respect, Fig 3-2 offers a clear idea of how the UK housing stock has developed over time and how low the replacement rate of dwellings is. The absolute number of old houses has been fairly constant and the 'real' reason why it decreased in percentage is that the size of the stock increased, making it relatively smaller than before.

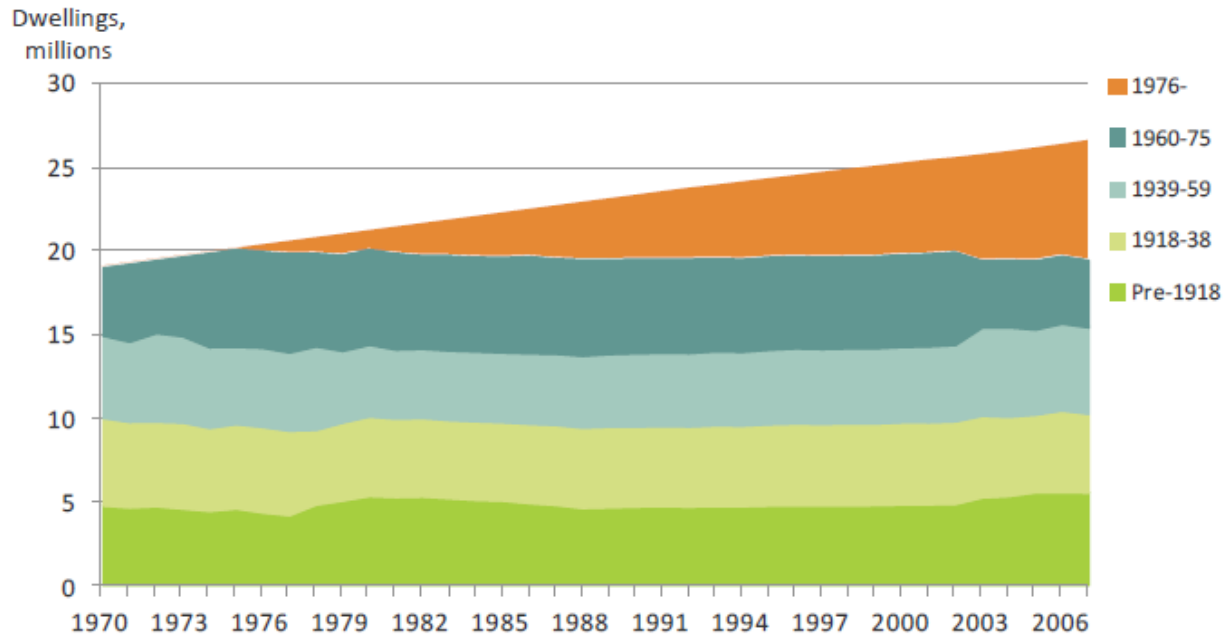


Figure 3-2: Housing stock distribution by age 1970-2006 (millions)

Source: Palmer & Cooper, 2013, p. 24

For that reason, rising the retrofit rate, namely the adoption of domestic energy efficiency measures, is essential in helping the government to stay on track in achieving its pledges.

Moreover, an improvement in the energy efficiency of the housing stock has been intended (Heffner & Campbell, 2011) and expressly indicated as a crucial strategy by the Department of Energy & Climate Change

(DECC, 2015) to tackle *fuel poverty*, a condition faced by a household when its members, given their income, can't afford to maintain properly warm their home at a fair cost. More specifically, households are officially considered to live in fuel poverty when confronted with "*higher than average required fuel costs*" (not just for heating but also for hot water, lights, cooking and appliances) and "*if spending this amount on fuel would push the residual income below the official poverty line*" (Hills, 2012). This definition allows to capture the extent (the number of households in fuel poverty condition) and the depth (namely the fuel poverty gap, defined as the difference between energy bills and what is estimated to a reasonable expenditure threshold for each dweller) of the problem. Figure 3-3 below shows the trends of fuel poor size (grey bars) and the fuel poverty gap (red line). The diffusion of this phenomena slightly reduced overtime from 11.8% of the dweller (around 2.44 million households) in 2003 to the 10.9% (2.39 million households) (Palmer & Cooper, 2013). More recent detections, calculated the households affected by this condition to be 2.38 million, roughly the 10.6% of all total (DECC, 2016a). On the contrary, the fuel poverty gap line highlights that the depth of the problem has raised significantly for these households (especially because in this period the price of energy increased remarkably). This may be due also to the fact that a disproportionate number of low income live in the least energy efficiency dwellings (DECC, 2015). Although it may appear there are little improvements, fuel poverty is still a severe issue in the UK society and much need to be done to solve it.

Figure 3-3: Fuel poverty in England (%) and average fuel poverty gap

Source: Palmer & Cooper, 2013, p.16

Furthermore, increasing the energy efficiency of the existing housing stock is expected to generate other important co-benefits by the British Government. First, it will help to reduce the household's bills, not just for the fuel poor (Ryan & Campbell, 2012). Then it will also alleviate the pressure on the energy grid, reducing the peak demand and providing an alternative solution to grid capacity enhancements (Erbach, 2015; Poudineh & Jamasb, 2014). This is very important because enlarging the grid capacity is an expensive and

technically challenging task. In addition, it is expected to contribute promoting renewable energy and 'green' attitude among the population (Ryan & Campbell, 2012). Energy efficiency also helps to decrease vulnerabilities and external (foreign) dependence in energy sector, concerns that are rising of importance during these uncertain times (Kelly, 2009; Linares & Labandeira, 2010). Especially because, in the last years, the flow of gas between Zeebrugge (the Netherlands) and Harwich (UK) has changed direction. After more than 30 years of exporting gas extracted in the North Sea, the UK became an importer from the Russia. Therefore, significant reduction in energy consumption in the buildings stock could decrease the energy security threat arising from receiving fuel from potentially unreliable sources (Kelly, 2009). This has become even more salient now after the uncertainties related to Brexit and the instabilities in the European – Russian relationship since the war in Crimea (Correljé & van der Linde, 2006; Nelsen, 2014). Last but not the least, expanding the retrofit measure uptake rate is supposed to foster green growth and create new jobs (Ryan & Campbell, 2012), co-benefits that are highly evaluated by British policymakers.

3.3. The state of the stock

The two main ways the UK households can adopt to decrease their dwelling energy consumption are to use highly energy efficiency appliances and to retrofit the fabric of the building. Concerning the appliances, the average number of appliances per household has raised for all kind of devices. It stands out the dramatic increase of electronic devices which has boosted from an average of 2 appliances in 1970 to 13 in 2015 (Waters, 2016). Fig 3-4 illustrates the total number of appliances in by typology per household (vertical bars – left hand axis) and the total domestic electricity consumption (diamonds – right hand axis).

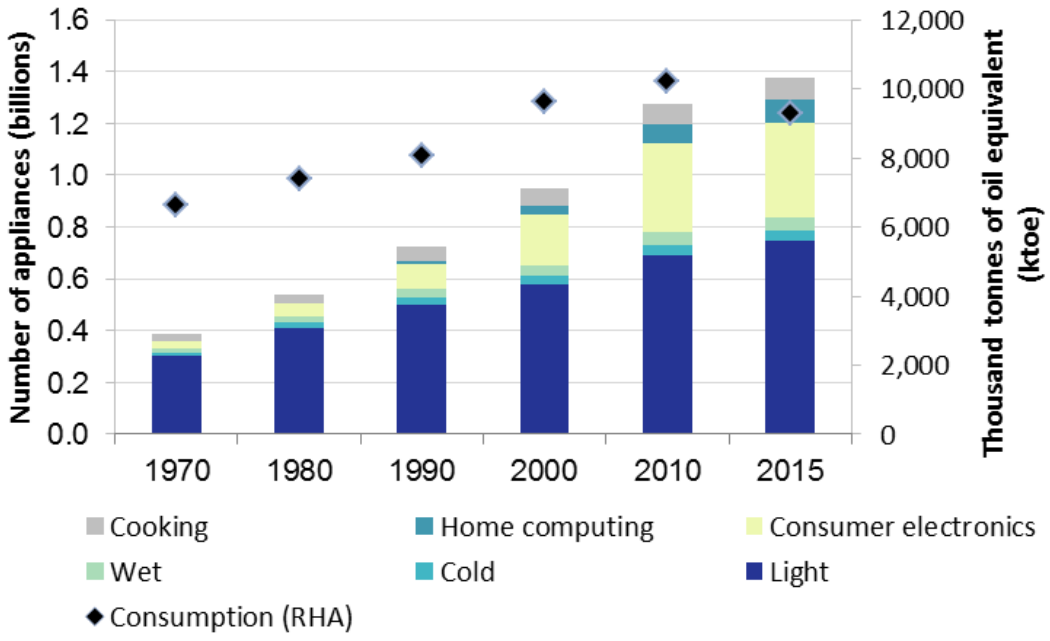


Figure 3-4: Total number of electrical appliances owned by UK households and total domestic electricity consumption

Source: Waters, 2016, p.26

It is clear that over time there has been a notable growth in consumer appliances especially from mid 90s in electronics and lightning. Nevertheless, despite the increasing number of devices, it is also visible a recent drop in electricity consumption. To some extents, it can be explained by an increased efficiency in appliances. Looking at the cold appliances can be emblematic and help to understand the magnitude of the phenomena. The average energy use for new cold appliances has dropped constantly and significantly since 1990 for all devices types (Fig 3-5). During the period 1990-2015, all cold appliances improved by between 58% (fridge-freezers) and 69 per cent (chest freezers) (Waters, 2016).

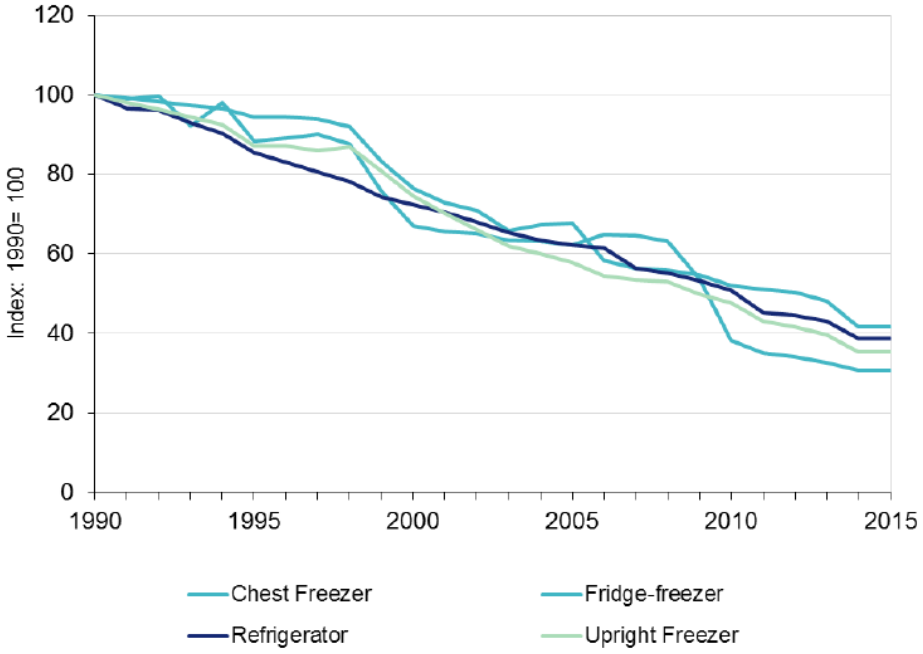


Figure 3-5: Average energy consumption of new cold appliances 1990 to 2015 (index 1990)

Source: Waters, 2016, p.27

However, improvements on average consumption for other appliance types were remarkable too but less dramatic compared to cold ones. For example, concerning wet appliances, between 1990 and 2015 there was an energy efficiency increase of 11% for tumble dryers, while dishwashers' energy utilization fell by 41%, washing machines by 33%, and washer dryers by 20% (Waters, 2016). Moreover, if these outstanding positive trends are combined with the short appliances' replacement time (relatively to housing one), it is reasonable to be optimistic and expect a drop in housing devices electricity consumption.

On the other hand, with respect on the interventions directed to renew the dwelling fabric, it is worth to look closely first at the state of the 27.7 million homes in the UK and the retrofit measures installed. However, at the moment there is a plethora of technologically available measures to retrofit buildings (double-glazing, condensing boiler, cavity wall insulation, solid wall insulation, loft insulation, heat pump, etc.) as it was shown in chapter two and therefore a choice needs to be done in order to focus enough the analysis. With this in

mind, the author has chosen to concentrate on the retrofit measure that are most frequently monitored in the ministerial reports (BEIS, 2017a; DECC, 2016b; Waters, 2016).

The instalment of *double-glazing* is believed to provide a reduction in consumption around 4% (DECC, 2016b). The number of houses in which double-glazing has been installed has considerably raised overtime: in 1983 it was just 9.5% and it became 80% by 2013 (Waters, 2016).

Part of UK dwellings' external walls, 19.2 million (BEIS, 2017a), have been built with external cavity walls. A cavity wall is formed by two thicknesses of brickwork with a hollow space in between them ('cavity') and it was a typical method of construction during 1920s. *Cavity wall insulation* consist in filling this cavity in between with particular material that decreases the exchange of heat among house indoor and outdoor. This type of retrofit has been estimated to reduce consumption by 8.4% (DECC, 2016b) and up to 2015 it was installed by 73% of households against the 3.8% of 1976, with an estimation uncertainty of 2% (Waters, 2016). Other estimates account that 13.3 million homes undergone cavity wall insulation, namely the 69% of potential dwellings (BEIS, 2017a). The two sources slightly differ, however, what is clear is that it has considerably increased overtime, although it still far away reach its full potential (Waters, 2016). Homes without cavity wall have solid walls. This type of construction has no gap in between and let more heath passing through than walls with cavity (in which the air inside provide a first sort of insulation). In this case, it is possible 'to add' additional external (*external wall insulation*) or internal (*internal wall insulation*) layers to decrease the amount of heat exchange with the outdoor environment. These measures can reduce energy consumption by 16% (DECC, 2016b). Despite the high energy savings, only 4% (334,000) dwellings of the potential homes with solid wall, 8.5 million (BEIS, 2017a), have a solid wall insulation (Waters, 2016). *Loft insulation (*namely adding an additional layer of insulating material, such as rock wool, on the loft, attic or flat roof to the loft space) in 1976 was adopted by half of potential UK homes, 23.9 million (BEIS, 2017a), and it reached 90% by 2002 (Palmer & Cooper, 2013) and it is estimated to save 2.1% of energy consumption (DECC, 2016b). However, the majority of these houses have what today is seen to be as an inadequate level of insulation, from 25mm to 100mm (Palmer & Cooper, 2013). Regulations on the matter have changed in 2002 and again in 2006 towards thicker layers of loft insulation. At the moment, according to the new standards, 15.8 million dwellings have a proper loft insulation of at least 125mm (66% of the potential) while 8.1 million houses have an insufficient insulation (lower than 125mm) and only an irrelevant number of properties is estimated to have no loft insulation at all (BEIS, 2017a).

Another retrofit uptake rate that is monitored by policymakers is the *condensing boiler*. As said in the first chapter, condensing boilers recover additional heat from its exhaust gasses that otherwise would be lost (Palmer & Cooper, 2013). Installing a condensing boiler can diminish energy consumption by 8.3% (DECC, 2016b). In 2005 they were only 7% of the total boilers installed but their number dramatically boosted and they have been estimated to be around 50% (Palmer & Cooper, 2013), and it hasn't stop growing.

Unfortunately, although some comforting trends are already in place (e.g. double-glazing, boilers), what alarms British policymakers and experts is that at the current paces UK might fall short to meet the desired national targets on time (Kelly, 2009). This because, despite the availability of options, there is still a remarkable energy efficiency gap that can be close through retrofit (BEIS, 2017a), especially for what concerns solid wall insulation. What is needed to be explored now is the reason why people remain reluctant to introduce retrofit energy saving measures into their properties and lives even though they have been demonstrated to be cost-effective and thus their uptake to be economically convenient (Backlund et al., 2012; Booth & Choudhary, 2013; Frederiks, Stenner, & Hobman, 2015; C Wilson et al., 2015; Yang, 2012).

3.4. Barriers to homeowners uptake and unintended consequences

Before to dig into the different barries obstacolating energy efficiency uptake, it is worth and necessary to look at the housing stock distrubution by tenure. Fig 3-6 shows the historical trend in UK housing ownership. In the 1970s homeowership was around 40%, then it steadly increased and in 2011 more than two thirds of the housings stock belonged to the households living there (Palmer & Cooper, 2013) and, although there has been minor oscillations, this share has been relatively constant up to now over the total 27 million UK dwellings (DCLG, 2016; Office for National Statistics, 2016). On the contrary, the share of social and affordable rented dwellings by Local Authority and Registerd Social Landlords (RSL) had fallen overtime from more than a third in 70s to slightly less than the 20% of now. After strong osclillations, the private rental sector stabilized at similar proportion as the social housing (DCLG, 2016; Palmer & Cooper, 2013).

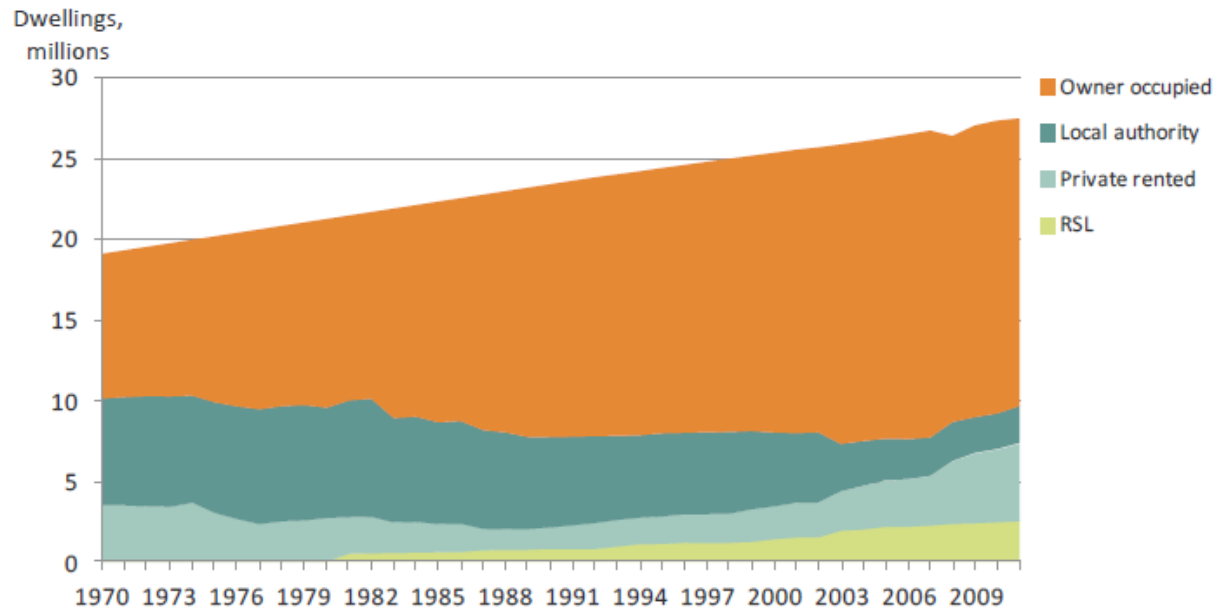


Figure 3-6: housing stock distribution by tenure (millions) up to 2011

Source: Palmer & Cooper, 2013 p.25

This is why to homeowners it has been given a special consideration. It is due to their biggest share of the UK housing stock. Moreover and beacuse historically housings owned by social renters have been more likely to get energy efficiency improvements while conversely private rented and owned houses tended to be less well insulated (DCLG, 2013 cited in Palmer & Cooper, 2013, p. 25). For all these reasons homeowners will be the focus of this study from now on.

Although energy efficiency improvements clearly appear to reduce household energy consumption (DECC, 2016b) as well as provide a wide range of individual benefits, such as thermal comfort and weak increase in assets' values (Fuerst et al., 2013), the retrofit measures uptake rates are stubbornly lower than the projections would suggest (Wilson et al., 2015). Moreover, while studies commonly observe UK households having a positive attitude towards energy efficiency (Skelton, Fernandez, & Fitzgibbons, 2009 cited in Wilson et. al., p.13), it is clear that the energy efficiency gap between the techincal and economic potential and the real adoption is far to be closed. At this point an obvious question arises: *"if there are profits to be made, why do markets not capture these potentials?"* (Blok et al., 2007 cited in Wilson et al., 2015, p. 13). The explanations invoked by researchers and policymakers suggest the presence of several barriers that inhibit cost-effective technology adoption decisions (Backlund et al., 2012; Booth & Choudhary, 2013; Erbach, 2015; Frederiks et al., 2015; Hamilton et al., 2014; Lucon et al., 2014; Rosenow & Eyre, 2016; Ürge-Vorsatz et al., 2012; Ürge-Vorsatz, Danny Harvey, et al., 2007; Weiss, Dunkelberg, & Vogelpohl, 2012; Wilson et al., 2015; Yang, 2012). These obstacles have been identified and describe by many authors. Consequently there are many frameworks used in literature to categorized them from the homeowner perspective. For example Wilson et al. (2015) identify three main barriers' domains to retrofit renovations in owner-occupied houses: decision making, information and finances. However, here an original and broader approach is adopted, that takes into account the aspects considered during the decision-making process for energy efficiency renovation. The reason for that is that it is believe to help the reader to grasp all the nuances and issues related to homeowners' decision making. Therefore, the levels identified and used to frame are following: financial, informational, behavioural, social, trustworthiness and technological.

Financial barriers are mostly related to the initial upfront costs of a measure (Blok et al., 2007; Wilson et al., 2015). The upfront costs vary a lot depending on the measure. For example, a loft insulation usually costs around 400£, while a solid wall insulation can range between 12000 and 18000£[2] depending on the property. These costs require to the homeowners personal available capital (e.g. savings) or access to additional capital (e.g. loans and mortgages). With this respect it needs to be taken into account that at the moment there are not many available financial products tailored on offering credit to homeowners willing to retrofit their property (Bonfield, 2016). On top of that, the majority of UK homeowners are not prone to borrow money

[2] All the prices are retrieve from the Energy Saving Trust http://www.energysavingtrust.org.uk/ . Founded in 1992, it is a governmental organization devoted to promote energy saving in UK

to pay for their renovations. A study performed by the governmental organization Energy Saving Trust (2011) estimated that only 10% of the households undertaking a renovation use any sort of financial product, and this is in line with some research done by private companies (Houzz UK, 2016). However, energy efficiency instalments are usually considered by homeowners as an addition to a renovation for amenity reasons that they are planning to do (Wilson et al., 2015). It has been found that, on average, households are willing to top up their initial budget by 10% for covering an additional retrofit measure (Energy Saving Trust, 2011). Another financial barrier arises from the fact that in several cases it might be more convenient to look for a better deal with the energy supplier than to install a retrofit measure. On the newspaper 'The Guardian', Brignall (2015) reports that it is possible to save on average between 158 and 234£ by only switching energy supplier. Then, governmental fuel subsidies tend to make less salient the need to decrease home energy consumption to households (Alberini, Banfi, & Ramseier, 2013; Blok et al., 2007[3]). Lastly, the presence of subsidies supporting retrofit in previous policies may generate in the households a feeling of subsidies expectations, making them waiting for the moment in which the retrofit measure they want is subsidized at the most and therefore delaying the installation (Alberini et al., 2013; Blok et al., 2007[4]). *Behavioural* barriers relate to the household's inner perception and personal evaluation of energy efficiency. The economic gains provided by the savings on the bill due to reduced energy consumption take time to repay back the initial costs and research has shown that there is a strong aversion in UK homeowners to delayed gains (Behavioural Insights Team, 2011). The reason why has been identified in the fact that homeowners are prone to look for quick and tangible returns from their investments (Wilson et al., 2015). In addition, among households it has been observed that energy costs have a low salience and they are usually misperceived (Sanstad & Howarth, 1994 cited in Wilson et al., 2015, p. 13). This aspect has also been found and verified in other countries, like the Netherlands (Brounen, Kok, & Quigley, 2013). With respect of salience, it is very important to note that dwellers renovate their properties mostly because they want to improve the aesthetics or increase the value of the house and very few of them renovate with the specific purpose of improving the energy efficiency (Wilson, Chryssochoidis, & Crane, 2013). Consequently, the majority of households appraises a lot aesthetic attributes and how much their property can improve when they need to decide whether to retrofit or not. Furthermore, homeowners tend to evaluate a lot the possible hassle factor involved when retrofitting (Wilson et al., 2015; Wilson et al., 2013) . For example, the disruption necessary during the installation processes may be an obstacle for many households. While the disruption, and therefore the hassle generated by that, for a loft or cavity insulation are very low, for a solid wall insulation is very high and it may block people from retrofit. Lastly, there are other behavioural barriers related to the "*cognitive burden (or transaction costs) of making complex and irreversible decisions*" (Phillips, 2012 cited in Wilson et al., 2015 p. 13). Deciding to improve the energy efficiency of your own can be a complex decision, and this complexity

[3] Blok et al. (2007) refer to that as a generic market failure
[4] Blok et al. (2007) refer to that as a generic market failure

can be perceived as overwhelming by some households and prevent them to consider the retrofit option. This type of inhibitory burdens have been repeatedly found in applied behavioural research on energy efficiency in the UK (Wilson et al., 2015), in Europe (Emmert, Van De Lindt, & Luiten, (2010) cited in Wilson et al., 2015 p. 14), and globally (Ürge-Vorsatz et al., 2012). To this, it needs to be added that homeowners have a bounded rationality when they make decisions on energy efficiency (Backlund et al., 2012; Frederiks et al., 2015; Wilson et al., 2015). *Informational* obstacles are related to the knowledge homeowners have on the subject. In detail, information barriers include a perceived absence of credible and available information on energy efficiency (Energy Saving Trust, 2011; Wilson et al., 2015) generating a lack of awareness and familiarity on the subject among the populations (Brounen et al., 2013; Papachristos, 2015). This lack of information is quite wide and regards the measures available, their features, what the benefits are, etc. It makes people less familiar with retrofit processes and thus less prone to undertake them. Moreover, energy efficiency is not perceived yet as an added value to property (Wilson et al., 2015). However, there is discordance in the literature on the topic: in other researches it seems energy efficiency has a low impact on the house value (Fuerst et al., 2013). *Social* barriers refer on how social bonds may affect homeowners' retrofit decisions. Environmental benefits appear to be more for society than for the individual that retrofit (Energy Saving Trust, 2011; Papachristos, 2015). Moreover, due to energy efficiency lack of salience, to energy consumption misperceptions and to the jeopardized and not very high retrofit uptake, there is still not a social pressure to undertake retrofit renovations (Behavioural Insights Team, 2011). *Trustworthiness* barriers can be consider as a special sort of informational obstacles. In this case households do not have enough trust in order to overcome uncertainties about contractor reliability and cost-saving outcomes (Weiss, Dunkelberg, & Vogelpohl, 2012 cited in Wilson et al., 2015, p. 13; Bonfield, 2016). Specifically, homeowners have been reported to not trust the installers and the potential retrofit energy savings declare. In addition, the poor advices provided in the past have increased the magnitude of the problem (Bonfield, 2016; Guertler, Robson, & Royston, 2013; Rosenow & Eyre, 2016). Lastly, the instability coming from the lack of longevity and clarity from the government policies to support retrofit negatively influences the energy efficiency uptake rate of households (Guertler et al., 2013). *Technological* level barriers refer to the physical limitation some measures have. This means that not all the measures can be installed in every home because not all of them are suitable for that property or because there are technical issues that impede to install that measure (Blok et al., 2007). Moreover, due to the installation process and material used, some retrofit measures in particular cases tend to impact negatively the aesthetic value of a property (solid wall insulation done in a Victorian house lowers the beauty of the external part of the edifice) (Roberts, 2008) . Table 3-1 summarises all the barriers listed in this review.

Table 3-1: Barriers to homeowners' retrofit uptake

Aspects	*Types*	*Sources*
Financial	Measure upfront cost	(Blok et al., 2007; Lucon et al., 2014; Wilson et al., 2015)
	Access to finance	(Blok et al., 2007; Bonfield, 2016)
	Reluctance to borrow	(Energy Saving Trust, 2011; Wilson et al., 2015)
	Easier to save by switching supplier	(Brignall, 2015)
	Subsidies expectations	(Alberini et al., 2013; Blok et al., 2007)
	Fuel subsidies	(Alberini et al., 2013; Blok et al., 2007)
Behavioural	Hassle factor	(Blok et al., 2007; Wilson et al., 2015)
	Delayed gains	(Behavioural Insights Team, 2011)
	Lack of tangibility	(Wilson et al., 2015)
	Not salient	(Brounen et al., 2013; Sanstad & Howarth, 1994 cited in Wilson et al., 2015, p. 13)
	Aesthetics	(Wilson et al., 2015; Wilson, Chryssochoidis, & Crane, 2013)
	Cognitive burden	(Phillips, 2012; Wilson et al., 2015; Emmert et al., 2010; Ürge-Vorsatz et al., 2012)
	Bounded rationality	(Backlund et al., 2012; Frederiks et al., 2015; Wilson et al., 2015)
Informational	Lack of knowledge	(Blok et al., 2007; Energy Saving Trust, 2011; Wilson et al., 2015)
	Awareness/ familiarity	(Blok et al., 2007; Brounen et al., 2013; Papachristos, 2015)
	Perceived value of energy efficiency	(Wilson et al., 2015)
Social	Social norms	(Behavioural Insights Team, 2011)
	Benefits appear more to society than individual	(Energy Saving Trust, 2011; Papachristos, 2015)
Trustworthiness	Contractor reliability	(Weiss, Dunkelberg, & Vogelpohl, 2012 cited in Wilson et al., 2015, p. 13; Bonfield, 2016)
	Declared savings reliability	(Weiss, Dunkelberg, & Vogelpohl, 2012 cited in Wilson et al., 2015, p. 13; Bonfield, 2016)
	Lack/poor of tailored advices	(Bonfield, 2016; Guertler et al., 2013; Rosenow & Eyre, 2016)
	Perceived lack of longevity and clarity from government policy influencing investment decisions	(Guertler et al., 2013)
Technological	Lack of potential to apply retrofit measures to some properties	(Blok et al., 2007)
	Some measures impact aesthetic	(Roberts, 2008)

Compiled and conceived by the author

In addition to all the barriers presented above, installing retrofit measures have proven to be not a completely 'safe' process because once a multitude of undesired unintended consequences cause by them have been detected. Detailed descriptions are provided by Collins & Dempsey (2017) and by Shrubsole et al. (2014), especially the last focus on the British housing stock. Energy efficiency measures tend to increase the building airtightness and the building envelope insulation (decreasing the indoor-outdoor exchange of heat). If the measures are not properly installed or do not consider the house 'holistically' (e.g. they take into account the climate condition of the area or the presence of other retrofit measures already installed), these may lead to increase indoor pollutants, radon levels, dust, mites and humidity. If this last is too high it can generate mould on the walls. Usually energy efficiency measures at insulation level of the fabric tend to increase the building permeability, but if not installed properly they may lead to leakages and infiltrations generating mould (this is especially true in the England, since it is a very rainy geographical area). Nevertheless, there are also positive side-effects related to retrofit such as decreasing noise, quieter indoor environment (although even these may have negative impacts on some individuals as increasing anxiety because they feel more disconnected with the external environment). Moreover, retrofit leads to increasing thermal comfort, especially during winter, and with a potential reduction in winter mortality. However, it is even possible that this downturns in summer overheating if the proper ventilation is not installed. In addition, radio signal might result attenuated and it can generate issues with some telecommunication devices.

In conclusion, what appears to be is that there are many drivers and obstacles leading and hindering households retrofit uptake that create a very complex system.

3.5. Past policies: successes, failures and resistances

Starting from 1994, several British government have tried to close the discrepancy between potential and actual implementation of energy efficiency measures in dwellings mainly using financial leverages, such as energy saving obligations, and mandatory regulations (Grimshaw, 2016; Mallaburn & Eyre, 2014; Palmer & Cooper, 2013; Rosenow, 2012; Shrubsole et al., 2014).

Mandatory minimum requirements have demonstrated to work effectively. Two examples can show it: the condensing boiler uptake rate and the 125mm or more loft insulations. Since 2005, all new boilers in UK must be high-efficiency condensing one. Before the regulation the share of this type of boilers made up only 7% of the total. In 2011, six years later they were already almost half of them (Palmer & Cooper, 2013). In 2002 and in 2006 the standards for loft insulation have increased up to 125mm. In 2002, most of the houses with a loft had an insufficient insulation. Over time, with the support of subsidies mechanism EEC and CERT, the number remarkably increased and now it is around two thirds of the total potential (BEIS, 2017a; Palmer & Cooper, 2013).

As for the financial policies, the UK has used a lot this type of policy-tools in the last years in order to support retrofit uptake as many other countries did (Weiss et al., 2012). The key policies schemes have been composed of subsidy mechanisms (Rosenow, 2012). From 1994 to 2002, the Energy Efficiency Standard of Performance (EESoP), the first governmental scheme, was put in place. Then there was the Energy Efficiency Commitment (EEC) from 2002 up to 2005 and next it was substituted with the Community Energy Saving Programme (CERT) until 2011. In 2011, the Energy Company Obligation (ECO) replaced the previous scheme. However, in 2013, the Government tried to integrate ECO with a new market-based financial mechanism without the presence of subsidies. The name of this policy was Green Deal and unfortunately, it did not deliver the energy savings desired and it was rapidly dismissed in 2015 (Guertler et al., 2013). At the moment, only ECO is in place with a reduced funding capacity (Grimshaw, 2016). Fig 3-7 illustrates the main financial instruments introduced in the UK from 2000 up to now.

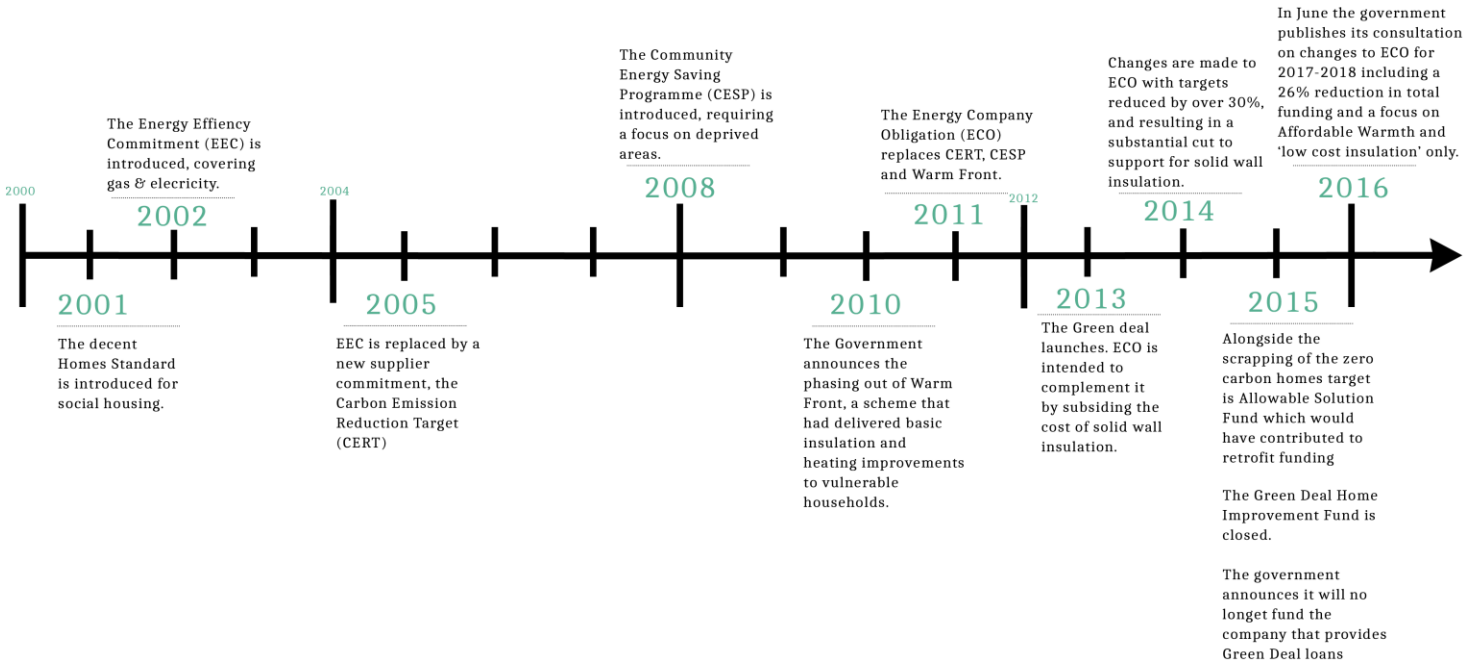


Figure 3-7: UK financial policies from 2000 up to now

Source: adapted from Grimshaw, 2016 p.4

Except the Green Deal, that will be explored in detail later, all the subsidies mechanisms have been working in a similar way. The government sets some targets of energy saving through retrofit for the energy suppliers and they have to economically support the uptake rate of retrofit measures in the UK housing stock in order to meet that targets (Fig 3-8).

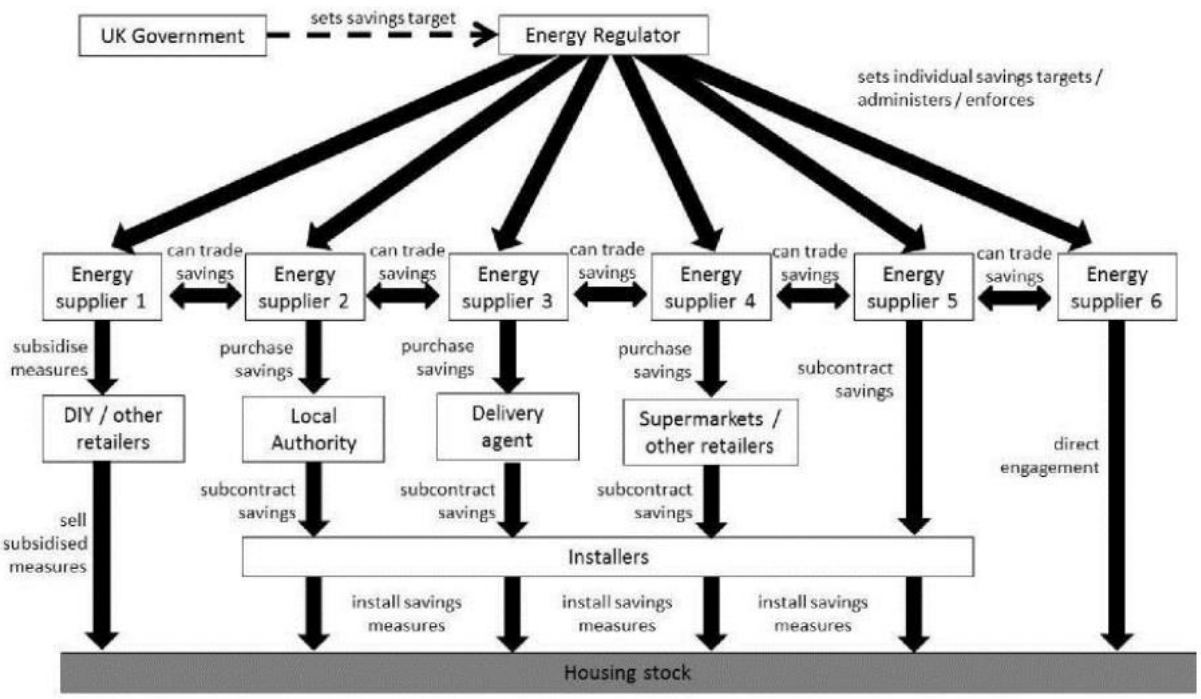


Figure 3-8: UK subsidies policy structure

Source: Rosenow, 2012, p.377

Although the key structure of these policy-tools has been almost the same for all of them, what have changed are the energy saving targets set by the government to the energy suppliers (Rosenow, 2012). Fig 3-9 below shows how these targets increased over time.

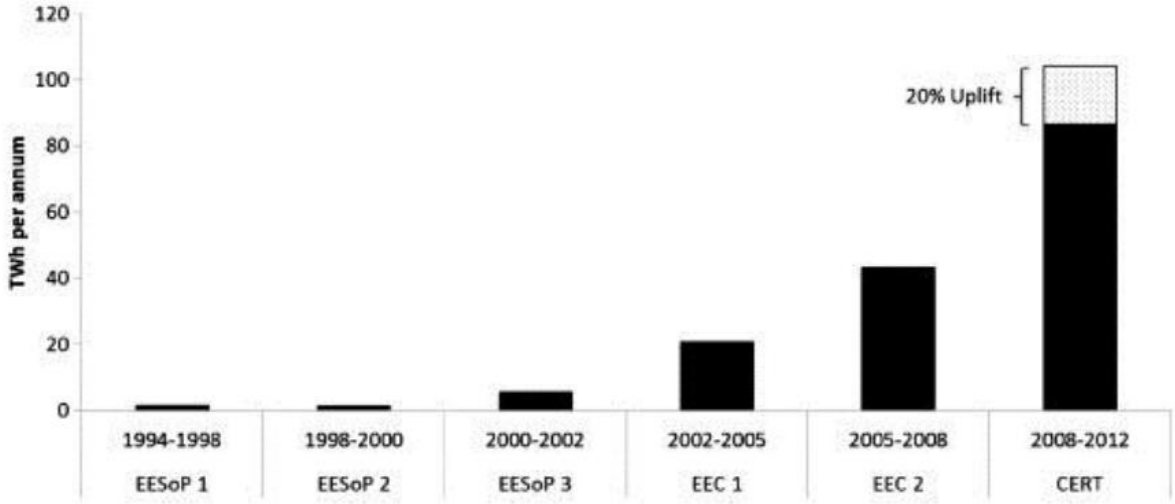


Figure 3-9: UK subsidies schemes energy saving targets

Source: Rosenow, 2012, p.376

Over time policymakers have constantly tried to raise the targets, and therefore the final subsidies to the households, in order to influence even further the retrofit uptake. This subsidies worked so well that the UK

is on track to meet its short term pledges (Committee for Climate Change, 2015). However, as it has been reported above, it is not enough to achieve emission reduction for 2050 (Kelly, 2009). This is the case because energy suppliers are incline to incentivize and support the uptake of light retrofits (isolated upgrades that are generally simple, economic and fast but that tend to not capture high energy savings) rather than deep ones (more expensive and intrusive retrofits that achieve greater energy efficiency and that tend to have a more holistic approach). These are well-known side effects for this type of policy instruments because this policy approach might not be best suited for ambitious future targets (Lucon et al., 2014). With this in mind, it is interesting to look at the solid wall insulation uptake rate (due to its high costs and savings can be to some extends consider a sort of deep retrofit). In 2008 the homes with solid wall insulation were only 67,000 compared to 334,000 homes with that in 2015 and most of these installations are due to the subsidies mechanism, especially ECO (Waters, 2016). Although the uptake has sensibly increased, the policies had a major impact: only the 4% (Waters, 2016) of the potential houses have a solid wall insulation and it clearly is not enough to help the UK to reach its targets.

Thus, policymakers started to look for new approaches than just subsidizing the market for two main reasons. First, because a change in pace was needed to reach the long-term targets. Second because for the political point of view subsidies on energy efficiency were not appealing and not seen as a sustainable way to support retrofit, especially in such a period of economic crisis and constraints. A more market-based policy was indicated as the preferable solution since it could have lead the retrofit market to be self-sustainable and not attached and dependant on governmental help. Based on these principles the Green Deal was developed (Guertler et al., 2013). Unfortunately, the Green Deal was a resounding failing (Bishoff, 2013; Gosden, 2016; Syal, 2016; Vaughan, 2015). Launched in 2013 in grand style, it was the government flagship environmental policy and it was supposed to complement ECO subsidies. It was defined by the conservative minister Barkers as the "*Europe's most innovative and transformational energy efficiency programme*" (Rosenow & Eyre, 2016). Green deal was based on innovative economic incentives on bills and it was intended to deliver energy efficiency retrofits at scale. Specifically, households could have asked for property assessments from a specialized assessor and then, if considered eligible, to enter in the scheme. To be eligible the retrofit measures under consideration have to abide to the *Golden Rule*. The Golder rule requires that projected saving generated by the measure installed to exceed the loan repayments. The candidates could have retrofitted their property through affiliated installers and paid it with a loan at a fixed and conventional interests rate without facing the upfront costs. The pay back process would have been thorough a 'pay-as-you-save' mechanism in their energy bills. Basically, households could have their house retrofitted and they would have paid it back with the saving generated in their bills. Another original aspect was that the payback payment was attached to the house not to the household: therefore, in case the household had moved away, the new dweller would have continued paying the retrofit measure with the saving in the bills (Rosenow &

Eyre, 2016; Rosenow et al., 2013). Green deal was expected to support millions of retrofit installations, precisely it was estimated by the Department for Energy and Climate Change (DECC) that by 2020 it would have facilitate the retrofit of 14 million homes with a rate of about 2 million per year (Rosenow & Eyre, 2016). Instead the scheme was dramatically undertake only by few thousands (Guertler et al., 2013; Morse, 2016; Rosenow & Eyre, 2016): around 6000 homes per year for a total of 14,000 by March 2016. Due to the extremely low impact (it delivered the 0.003% of what was expected to), the new Conservative Government stopped to fund it in July 2015 *de facto* scrapping it (only the houses that have already started the Green Deal process could have used the dedicated funds) (Rosenow & Eyre, 2016). The House of Commons' Energy and Climate Change Committee said "*Green Deal has widely been recognized as be a failure*" (House of Commons Energy and Climate Change Committee, (2016), cited in Rosenow & Eyre, 2016, p. 141) while some scholars went even further defining it as "*the biggest failure in the history of UK energy efficiency policy*" (Rosenow & Eyre, 2016, p. 141). Media did not go easy and condone the mistake (Bishoff, 2013; Gosden, 2016; Syal, 2016; Vaughan, 2015). Not only the Green Deal failed to deliver what was expected but it also slowed down the retrofit uptake rate in British houses (BEIS, 2017b). Rosenow & Eyre (2016) report that by mid-2015 the loft insulation delivery rate dropped by 90%, cavity wall by 62% and solid wall by 57% compared to 2012. And what was done under the government schemes was mostly under ECO (BEIS, 2017b). Therefore, it seems Green Deal even increased the magnitude of the problem instead than solving it.

It is important to look in detail at what has not worked. The interests rates were not competitive since they were higher than other products findable in the market (Guertler et al., 2013; Rosenow & Eyre, 2016). The Green Deal suffered since its born of bad publicity issues (Guertler et al., 2013) and many UK citizens were already skeptical and when the media diffused data and information on the low uptake (Jones, 2013) the situation got even worse. Moreover, given the high interests rates only retrofit measures with high return rates were eligible for the scheme. Thus, usually only relatively cheap and with discrete return, like cavity wall insulation, were fitting the golden rule while major energy efficiency improvements, that were more expensive than simple measures, were excluded. This was a perverse result since more expensive measures appear to be better suited for pay-as-you-save financing mechanisms (Rosenow & Eyre, 2016). Another huge mistake made by policy makers was that they did not engaged enough homeowners. They adopted a top-down marketing approach since they were thinking that solely financial savings would have prompted homeowners to renovate their property (Rosenow & Eyre, 2016). As it was presented previously the reasons why people renovate and retrofit their property are much more complex than that (Wilson et al., 2013). Especially they ignored the fact that people have great aspiration for themselves and their houses than just have savings in their bills and when homeowners undertake renovations look for improvements in their health, wellbeing, house aesthetic, etc. (Macmillan et al., 2016; Rosenow & Eyre, 2016; Wilson et al., 2013). Therefore, policymakers completely failed to take into account this complex narrative and all the other

barriers involved in the retrofit uptake rate. Using a nice metaphor from Rosenow & Eyre (2016), they tried to sell the loan instead the car. If a broader perspective is taken, it is possible to realize that the root causes of this failure were many (Bonfield, 2016; Morse, 2016; Rosenow & Eyre, 2016): the design of the policy itself was poor (complicated and not economically attractive), the behaviour and attitude of households was misjudged and many complexities and policy resistances were overlooked, etc. The main reasons for this poor policy-making process has been identified in underestimation of the complexity of the housing system and in "*a lack of appropriate modelling and decision support tools to aid long term planning for sustainable urban retrofitting*" (Xing et al., 2014). Consequently, these may have led to overlook at the high fragmentation of the policy environment (Eker & Zimmermann, 2016), at huge amount of dynamics involved in the system (Macmillan et al., 2016) and at presence of multiple possible unintended consequences (Collins & Dempsey, 2017; Shrubsole et al., 2014).

3.6. Policy under exploration

Nonetheless, the Department for Business, Energy and Industrial Strategy (BEIS), the former DECC, still has the task to fill the gap left by the Green Deal and to develop other financial policies to support energy efficiency improvements in the housing stock. Furthermore, BEIS wants to foster the energy efficiency sector up to the point in which it is self-sustainable without government subsidies. However, at the moment ECO subsidies are still in place and it has been assessed that without them the market would drop drastically (Morse, 2016). To achieve these goals policymakers in BEIS consider important to make energy efficiency more valuable in the eyes of consumers in order to avoid previous mistakes (especially the ones related to household engagement). At the moment, BEIS is exploring a policy consisting in pushing mortgage lenders to value more energy efficiency (*green mortgage policy*). The logic underlying this policy is that if energy efficiency was weighted more during the lending process, it would be more appreciated also by public and it will prompt homeowners selling or buying a property to consider retrofit because of these financial benefits. This mechanism will be in place through the concession of bigger mortgages depending on the energy efficiency level of the property purchased or through special conditional loans for retrofit an inefficient house that is going to be bought. The goal of BEIS is also to increase the general households' consideration of retrofit and energy efficiency desirability; in order to stimulate demand, support growth and the development of the supply chain (generating new jobs). In addition, policymakers in BEIS are examining another possible policy option: *a stamp duty*[5] *rebate* (stamp duty is a tax in UK that you have to pay when you buy a residential property for more than £125.000, and its amount is oscillating between 2% of property value, for the less expensive houses, to 12% for the most expensive ones). The effects that it is expected to trigger in consumers and in the market are similar to the green mortgage policy. If buyers wanted to buy an efficient property they

[5] More info at the following link https://www.gov.uk/stamp-duty-land-tax/overview

would have a discount on the stamp duty, but also who acquires a non-retrofitted house could benefit of this rebate in case they guaranteed to improve the efficiency of the dwelling. In this last case, the amount of money free up by the discount would support the buyers to pay for the retrofit. Moreover, these changes could send some signals to the market and trigger an increase in the value assigned to the energy efficiency by homeowners.

3.7. Challenges and open questions

After all this overview, it should be clear the complexity of the energy efficiency retrofit system in the UK. High stakes and multiple actors are involved, plenty of barriers decrease the policies' impacts and unintended consequences are behind the corner. Whereas technologies significantly improved during the last years, our understanding of the interrelations between homeowner values, measures' costs, decision making behaviours, policies, installation quality, installers, etc. is still very limited (Ürge-Vorsatz et al., 2007). Moreover, the impact of changes in the energy efficiency system is very complex "*with some changes pushing in one direction and others pushing in another*" (Palmer & Cooper, 2013, p. 26). For instance, the historical rise in home ownership should have meant that homeowners have more stake in their property, so they are more likely to invest in it. However, retrofit improvements have not gained much attention from homeowners: they are more likely to invest in amenity renovations (e.g. new kitchens, better bathrooms) than in insulation (Palmer & Cooper, 2013). It follows that since there is not an understanding of these relations, no quantification of them has been done (Ürge-Vorsatz et al., 2007). Therefore, a holistic understanding of the homeowners' retrofit uptake system is lacking and acquiring it becomes crucial and needed. In the scientific literature, studies on the whole dynamics related to UK homeowners deciding to retrofit their property are completely lacking. Moreover, also the impacts of the financial policies under investigation in BEIS (mortgage policy and stamp duty rebate) have not been explored yet in this context. Knowing them can be noteworthy in order to help policymakers to improve policies design and to assess their effects.

3.8. Previous studies

The homeowner decision process to renovate and retrofit has already been investigated. Wilson et al. (2015) provides a very interesting overview on many studies on this issue. They report that discrete choice models have been widely used to capture household's preferences in energy efficient renovations. In the vast majority of these studies, financial attribute appears to be dominant when homeowners consider to retrofit. Microeconomic research has been also employed to estimate the effect of policy incentives and consumers' willingness-to-pay for retrofit and to calculate discount rates for future energy cost savings. The use of these models stresses a lot the importance of financial influences on energy efficiency decisions. In addition to that, also diffusion models are applied. Wilson et al. (2015) point out that from these models analisys appear that

cost-savings, thermal comfort, compatibiliy, simplicity, visibility and trialability are the most important drivers of a retrofit measure diffusion. Moreover, surveys and statistical analysis are broadely used to investigate homeowners preferenes, specifically if socioeconomic explanatory variables, such as household green attitude or type of property owned, have any correlation with the uptake rate. What is intersting of these modelling efforts is the fact that the type of factors and variables at which researchers are looking at is incresing in getting more diverse respect the traditional financial aspects that are usually considered.

However, these types of models only briefly touch the dynamics involved in the homeowners' decision-making process and in how they are interrelated with the whole system. Moreover, most of these studies have static approach (Meadows, 1980), while what seems to be needed is knowledge of how these relations in a complex system unfold over time. Hence, another method needs to be chosen. Therefore, in order to study the dynamics related to homeowner retrofit uptake rate and the impact of mortgage and stamp duty rebate policies a *Participatory System Dynamics Modelling* approach is adopted. A short description of System Dynamics (SD) and Participatory System Dynamics (PSDM), of the reason why this method was selected and of its applications to similar contexts will be provided in the following sections.

3.9. System Dynamics and Participatory System Dynamics Modelling applications to retrofit systems

System Dynamics (Sterman, 2000) is a methodology invented by J. Forrester in late 50s and early 60s (Forrester, 1961) to study interactions in complex systems. It uses informal maps and formal models combined with computer simulations to understand and alleviate dynamic problems in complex systems such as social, technical and environmental ones. Dynamic problems can be defined as undesired situation changing overtime, in which the problem owners find troubles to solve them despite their effort. SD practitioners believe that a problematic behaviour depends on the structure of the system and that its complexity makes it difficult for people to understand the causes of the problem. SD provides a peculiar, high level and holistic approach to analyze these issues. Through the conceptualization of system as a structure based on accumulating stocks and flows, it tries to uncover the endogenous feedback loops that generate the system behaviour (Sterman, 2000). This holistic perspective of SD allows to see how mental models and decision-making processes influence the system behaviour. Once the underlying structure is understood, SD gives the possibility to test policies and their impact on the system. Therefore, it helps to develop policies for triggering systemic change in complex environments. Initially and usually, it has been employed in an expert mode, namely a system dynamicists collecting information, building a model and then sharing the results. Although interactions with experts on the subject generally take place, in the traditional SD setting they are not directly involved in model or mapping development process. However, from the late 80s and more consistently in the 90s a new mode of modelling emerged in which stakeholders, policymakers and subject

experts were directly involved in the model building process (Vennix, 1996; Vennix, Andersen, Richardson, & Rohrbaugh, 1992). In this case, SD practitioners engage with subject experts, academics, policy-makers, communities and people affected by the problem in a so-called 'group model building' (GMB) (Vennix, 1996) or 'participatory system dynamics modelling' (Stave, 2010) process. Therefore, in GMB or PSDM, the stakeholders' expertise is directly used for building a causal model, e.g. in a (series of) joint workshop(s). Alternatively, stakeholders are involved more broadly in different participatory system dynamics activities, which include not only group model building, but also additional participatory elements such as problem formulation, model validation, etc. (Cappuccio, Cunico, & Zimmermann, 2017). For this reason when SD is utilized with any form of stakeholder participation in addition to during the modelling process, it is usually called PSDM (Stave, 2010; Videira et al., 2003). The attempt to integrate a broader participation into the modelling process has the goal to overcome some limitations related to the traditional expert mode approach. The principal reasons are mainly four. First, stakeholders hold the necessary knowledge on the system to build the model and improve its quality (Vennix, 1996). Thus, a broader participation in the modelling process can tend to improve model quality, since more sources of knowledge are integrated together. Second, participants can improve their understanding of the problem by joining the modelling process (Scott et al., 2016). Attending to workshops tend to generate a learning process among the participants, since they follow step by step the development of the model. Third, PSDM can support the alignment of participants mental models and create shared knowledge among the group (Scott et al., 2016). Discussion during the workshops is facilitated and this helps to create the right context to generate shared learning. Fourth, "*if* [stakeholders] *are involved in the process, they are likely to engage more fully with the results*" (Xing et al., 2014). Traditional approaches has proven to be likely to fail to trigger a sustainable, long term and systemic change (Vennix, 1990). Instead, PSDM supports the implementation phase, since the participants' sense of ownership towards the model is greater than it would be with an expert approach and this make more likely the intervention to have an impact (Rouwette, et al., 2002; et al., 2016; Vennix, 1996). All of this is especially true when models have tried to tackle 'messy problems' (Vennix, 1996), namely issues that have high degree of complexity, a multitude of stakeholders involved and in which uncertainty is high. Moreover, experts and stakeholders involvement and supervision over the model provide a first validation of the quality of the structure of the model. For all these reasons, PSDM has been recognized to have a great potential to contribute to complexity understanding and policy-making. Therefore, PSDM has been chosen as method for this study for the reasons listed above. In the context under study, it can provide great knowledge enhancements. However, the reason why PSDM has been chosen are not just from a scientific purpose of gaining new understanding. It has been selected also because the engagement of stakeholders in the modelling phase can increase the likelihood of the model to trigger a social and sustainable change. That's exactly why Eker & Zimmermann (2016), Shrubsole et al. (2014), Macmillan et al. (2016), Xing et al. (2014) explicitly have called for the use of PSDM in this environment. Said so, it is necessary to look at previous SD

experiences in the retrofit domain looking if there are studies that already covered, at least partially, the dynamics of UK homeowners retrofit uptake and the systemic impact of the two policies under exploration in BEIS and looking for lessons to learn from similar projects.

SD has a long tradition of being applied housing problems. Jay Forrester, the founder of SD, first investigated the dynamics involved in the urban development, discovering how policies in force at that time were contributing to cause undesired behaviours experienced in many major cities in USA (Forrester, 1969). Therefore, it not surprising that SD has already dealt with issues related to housing stock and its energy consumption. There are existing focusing on the housing market dynamics and scenario exploration (Eskinasi, Rouwette, & Vennix, 2011). There are also researches on the diffusion of energy-efficiency measures in the dwelling stock. For example Blumberga et al., (2011), Müller & Ulli-Beer (2010) and Pruyt & Yücel (2011) developed models in an expert mode approach respectively for the Latvian, Swiss and Dutch housing stock. These models explore the main trends in housing stocks, the sensitive system sectors and the main drivers of energy efficiency. However, despite the differences due to the diverse case studies, they all adopt a very aggregate point of view: energy efficiency is not differentiated in different type of measures but they are integrated all together; households decision processes are stylized since they do not take into account most of the barriers and drivers discussed in the literature; and other important sectors of the retrofit system appear to be left outside their analysis boundaries (e.g. supply chain) and consequently their impacts on the homeowner decision are not explored, etc. However, there are also SD studies on the occupants' consumption behaviour conducted in a traditional setting. Papachristos (2015) studies and quantifies the effects of smart meter introduction, increased appliances efficiency and households trends and behaviours (with respect of appliances use) in the Netherlands, finding that the benefits carried by the smart meters diffusions are 'rebounded' by the increase in the number of households and in the average number of appliances per person. Armenia et al. (2009) investigated how households behaviour in terms of comfort and cost can influence the adoption of energy efficiency measures. Although this study is very narrowed in its scope (it accounts only household's comfort and costs and it lack of any connection to the broader system, such as housing stock, supply chain, etc.), it shows that the 'taboo topic' of homeowner behaviour (Armenia et al., 2009, p. 29) can be modelled in a dynamic way and not only with static models as it has been mainly done so far. According to them, this may open to system dynamicists new areas of research in the housing efficiency domain. However, they warn on the difficulty to formalize it. There were also application of PSDM in the housing sustainability system domain. De Gooyert et al. (2016) used it to understand better the persistence of policy resistance in the context of sustainability transition. Their project with 96 participants was considered successful since it showed that the PSDM approach can help overcoming policy resistance by mapping out the structure of the system responsible for such resistances and because it helped to identify leverage points to trigger systemic changes. Elias (2008) conducted a systemic analysis of

the residential sector energy efficiency in New Zealand's residential sector. He gathered 10 stakeholders for a workshop session and the outcomes of that were a qualitative map of the housing stock and a general understanding of how retrofit uptake can be improved from an aggregated perspective. Although the map is not quantified and it lacks of details on the homeowners decision-making process for retrofit uptake and of connections with other important sector of the housing domain (e.g. supply chain), it illustrates how PSDM can be successfully used in the domain of residential energy efficiency.

The UK housing system is not new to be explored with SD. Hong-Minh & Strohhecker (2002), in a traditional expert mode, investigated the British private house building supply chain and built a model able to explore different scenarios for different supply chain performances. However, what can be specifically relevant to the scope of this project is the study Eker & Zimmermann (2016) in which the authors highlighted the high fragmentation degree of the UK housing construction and retrofit environment. After conducting a large set of interviews with stakeholders, they were able to capture and identify the high degree of fragmentation within the housing system. This state of fragmentation seems to arise from the lack of competences and monitoring activities in the actions of designers, constructors and policy-makers, thus generating performance gaps. Therefore, they suggest systems thinking approaches for research and decision-making in order to avoid policy resistances and unintended consequences. Also PSDM was recently applied to specifically study the UK case when participatory group modelling sessions were done with stakeholders and experts with the goal of increasing the understanding of the long-term dynamics of urban retrofit at a city-regional scale (Xing et al., 2014). The result was a causal map that was used to facilitate the discussion among the participating stakeholders at the end of the process. The outcome, although maybe a step behind in terms of refinements, it is very close to what Elias (2008) obtained in New Zealand. In line with this is the work of Macmillan et al., (2016). They involved in over 50 stakeholders from the UK, representing 37 organizations (among which six national government departments), in a series of workshops with the scope of improving the understanding about housing, energy and wellbeing and their complex interconnections. It resulted in a series of Causal Loop Diagrams (CLDs) that helped participant to create a shared understanding of how wellbeing relates to housing and a set of common criteria to assess future policies. The researchers conclude calling for further participatory studies focused on deepening the dynamics involved in the system. Hence, the works of Xing et al (2014) and Macmillan et al. (2016) shows how PSDM can be successfully applied to create system maps in a participatory way with British stakeholders in order to improve the general understanding. Moreover, both of them identify in the policy-makers lack of appropriate modelling and decision support tools for long term sustainable retrofitting one of the key barriers to the energy efficiency uptake.

An overview of the SD relevant studies on the subject has been presented. Although some researches are available, no one have explored so far in a dynamic way and in detail how the homeowners' decision-process

for retrofit and the broader housing system are interrelated in the UK (it wasn't either precisely studied in other countries). On top of that, nobody quantified these dynamics. There are also no study on the dynamics triggered by financial policies such as the mortgage policy and the stamp duty rebate. Therefore, noted the knowledge gaps and the relevance of the challenges arising from these gaps, the scope of this thesis is to study through a PSDM approach the dynamics related to homeowners deciding to retrofit their property and the possible impacts on this system of financial policies such as green mortgages and stamp duty rebate.

4. Methods and Research Process

The method adopted to conduct this research was PSDM based on participatory workshops. Figure 4-1 below outlines how the approach was developed for this research by detailing the activities related to each research step.

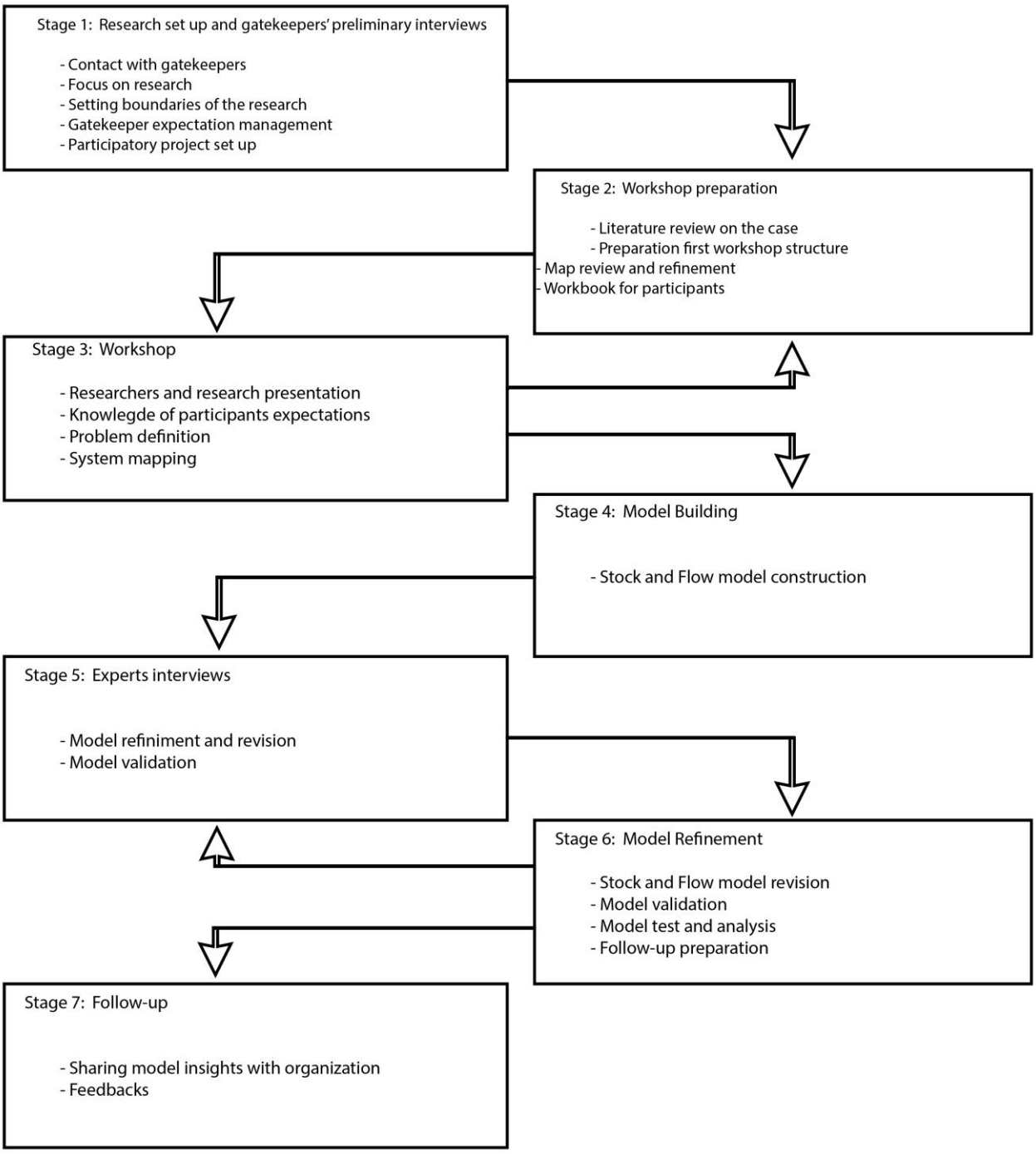


Figure 4-1: The Participatory System Dynamics Modelling process

Source: conceived by the author

In the next paragraphs, an explanation of each step is provided.

4.1. Research steps

4.1.1. Research set up and gatekeepers' preliminary interviews

Since the approach needs the contribution of several participants-stakeholders, it is important to organize some preliminary interviews with the gatekeepers of the organizations involved. There are three main practical reasons for this. First, it serves to familiarise the client with the method and to define clearly the scope, focuses and outcomes. Second, it is important to plan and set-up the whole research process (e.g. workshops, interviews, etc.). Third, it is compelling because it allowed the researchers to get to know what the pressures and constraints that project will face are and to tailor the PSDM approach consequently. The optimal expected results for this step are to obtain primarily a shared process schedule, and then an agreement on the desired outcomes.

4.1.2. Workshop and workshop preparation

Once the process is set up and the workshops planned, these last need to be prepared. First, a literature review on the subject was performed in order to familiarize the researchers with the subject. Then time by time, before each workshop, a detailed plan for the session needed to be developed. To perform this work the traditional guidelines (Vennix, 1996) for participatory SD are followed. Moreover, the workshops are structured in 'chunks', based on scripts, in order to make the session more flexible and increase participants' performance, as literature recommends (Andersen & Richardson, 1997). The outcomes of the sessions are expected to be system maps in form of causal loop diagrams (CLD). The workshop recording is done in order to save on digital format all the discussions that take place. Moreover, at the end of each sessions, participants' feedback are collected. In between the workshops, a workbook with the outcomes of the session is delivered to the group, as Vennix (1996). The purpose of this is to show them what they have done, to make the whole process completely transparent (via letting them know what the research team has been doing behind the scenes) and to try to keep their interest high on the project. Moreover, it served as validation step. The participants are asked to refer back if any inconsistency is found or to bring their concerns directly to the next session. Then the outcomes of a workshop will be used for the preparation of the next one as a starting point. The idea is to continuously build up the new map structure based on the previous one produced. The procedure described is an iterative process that is repeated all the time that a workshop is performed (for this reason in Fig 4-1 there is an arrow going back from stage 3 to stage 2).

4.1.3. Model building

Once the workshops terminate, the quantification phase starts. A stock and flow model (SFD) is constructed based on the resulting system map produced in the last workshop. To build up the structure the lessons provided by Sterman (2000) are followed. The needed data will be firstly retrieved from literature and official

sources (e.g. BEIS, UK Office for National Statistics, etc.). In case the necessary data are not found among these, grey literature will be analyzed.

4.1.4. Experts interviews and model refinement

Near the conclusion of model building process, interviews with experts are done. These serve many scopes. First, meeting the experts can be crucial to clarify some possible uncertain structures of the model. Second, they can provide information and data that might still be needed since not found in literature. These aspects are crucial to refine the model towards a better quality. Third, having the model and the assumption discussed with experts can be considered a form of validation (Barlas, 1996). At the end of this step a more formal model validation will take place based on the examples provided by Barlas (1996) and Sterman (2000).

4.1.5. Follow up

Lastly, once the model is built and validated, the results are presented to the workshop participants. The scope of that is to share with them the insights gained on the system. A possible related outcome for this final step could be that the new insights may cause or support participants mental model changes and/or create commitment towards group solutions. Feedback on the whole process are going to be collected.

4.2. Research context

As already said in the introduction, the Department for Business, Energy and Industrial Strategy (BEIS) is the governmental department responsible for energy efficiency policy. In the direction to avoid the repeat the same mistakes made in past policy-making processes, BEIS began to explore more holistic approaches in order to take into account the complexities involved within the housing system. After the Green Deal failure, to BEIS appeared clear that financial affordability is not the only barrier limiting the retrofit uptake rate in UK dwellings, despite its importance. Accordingly, BEIS decided to improve its understanding of this system, especially with respect of homeowners. Therefore, it started a fruitful collaboration with University College London (UCL) Institute for Environmental Design and Engineering (IEDE) in which PSDM was the adopted approach to conduct research. This has brought to the *Housing, Energy and Wellbeing* (HEW) project[6], described in Macmillan et al. (2016) and reported in the previous chapter. Since, the final maps and the participatory process proved to have an impact in shifting the mental model of a wide number of stakeholder and policymakers in the direction of a more holistic view, BEIS and UCL decided to extend their collaboration further. Therefore, this new project between the two institutions is at the base of the research developed in this thesis. The scope of the project was to explore the dynamics behind the homeowners retrofit uptake and how the policies under investigation in BEIS, namely the mortgage policy and the stamp duty rebate, would trigger systemic change. The scope of the project is in line with the research gap previously identified and

[6] https://www.ucl.ac.uk/bartlett/environmental-design/news/2014/may/housing-energy-and-wellbeing-hew-project

with the objects of this study. Moreover, this project allows us to answer to the many calls that have been made in the scientific literature to use PSDM in the domain of housing energy efficiency in the UK (Eker & Zimmermann, 2016; Shrubsole et al., 2014) and to support policy-makers, with this method (Macmillan et al., 2016; Xing et al., 2014). The project took place between the end of February and April 2017 in London. There was an agreement to conduct the project through interviews and participatory workshops. Unfortunately, only members from different areas of BEIS policymaking team could attend the sessions due to the confidentiality of the subject and because of the high time pressure to conclude the project in a short time making that it was not possible to invite other stakeholders or experts and that there was no room to arrange extra and separate events with them. Therefore, only policymakers could attend the workshops.

4.3. Participatory system dynamics in a 'pressure-cooker'

These setting specifics impose to diverge from the traditional and complete group model building approach exposed by Vennix (1996). However, it is also true that this case is not uncommon in PSDM. Many (if not all) participatory projects needs to deviate from the original prototypes and be adapted to the context in which they take place because sometimes they can not access all the stakeholders or have a reasonable amount of time to follow all the indicated steps. This is exactly one of the reasons why sessions tend to be divided into chunks based on scripts (Andersen & Richardson, 1997): this make them flexible and adaptable to a wide range of situations. Examples of successful projects conducted in short time frame or unorthodox settings already exist. For instance, Videira et al. (2012) were able to achieve satisfactory outcomes thorough only a workshop with twenty-two participants. Nevertheless, the possibility to have only policymakers attending the workshops creates an absolute homogeneity in the mental models brought into the session, and such homogeneity in the participants poses a great methodological challenge. The traditional setting for PSDM requires to include a different variety of stakeholders affecting and affected by the system under analysis into the workshops' participants (Vennix, 1996). The reasons are that this allows to incorporate diverse sources of information into the model, to improve its quality, to avoid group-thinking and ideas redundancy among the participants, to have their assumptions challenged by other stakeholders and thus develop further their understanding, to create shared knowledge among different stakeholders and, lastly, to get commitment on the project results from different actors and consequently to increase the chance of success during the implementation phase. Actually, there are very few script that tries to overcome part of the issues posed by homogeneity. One of them is the '*Devil's Advocate*' (Vennix, 1996). It suggests dividing the participants in two groups, one with the goal of attacking the assumptions made in the model so far and the other with the aim of defending them. However, this strategy has a major limitation: it does not introduce new source of information 'into the workshop room', it just uses the knowledge that is already there. Thus, it is expected to work well only in projects where the participants are heterogeneous. For instance, it may be the case of a workshop group in which heterogeneous participants are facing groupthink or they do not

challenge each other assumptions and the first ideas that pops up is always the one the group opts for. Then, using the Devil's Advocate suggested by Vennix (1996) may stimulate participants to go behind what already discussed.

Therefore, finding a solution to the homogeneity issue that brings 'into the room' new mental models (namely bringing heterogeneity) is a remarkable methodological challenge. However, based on the actual state of the art, a proper methodological solution has not been found. Gerrits & Vaandrager (2017) found themselves in a very similar situation and they report an unsuccessful methodological adaptation they tried in a PSDM process in order to increase the heterogeneity among the group. Policymakers of Rotterdam, a Dutch municipality, asked Gerrits and Vaandrager their help to gain system thinking skills and develop a model "*in oder to assess the extent to which budget cuts could be done whilst keeping the urban system stable*" (Gerrits & Vaandrager, 2017, p. 4). To achieve this scope a particpatory group model building setting was chosen. However, there were two major issues:first, the project needed to be concluded in a time span of two months and second, due to time and external constraints, only a small group of civil servants of Rotterdam municipality attended the project. Therefore, they found themselves working under high time pressure and with a homogenous group of policy-makers as this research did. In reaction to that, they planned "*to negate the homogeneity of the group by instructing the participants to collect data from a wide range of sources and to safeguard the diversity of the data*" (Gerrits & Vaandrager, 2017, p. 5), expecting that these instruction could increase the heterogeneity present in the group. Nevertheless, the adaptation was no successful and therefore it is worth to look closely at what happened. Gerrits and Vaandrager had an initial meeting with the gatekeeper in the organization in which they framed the focus of the project and selected the methodology (PSDM). Then, they hold a presentation to the potential participants in which they presented SD and PSDM features and the scope and plan of the study. During the presentation they noticed that the trust on the use and attainability of the methodolody was not very high, since among the group several people were skeptical towards the methodology. Nevertheless, the project was approved because the municipal chief executive (the gatekeeper) was a supporter of the approach. However, due to time and external constraints mentioned earlier, it was communicated that only people from the same municipality department would attend the project and that it needed to be done in a two month period, and therefore there was room for only two worskshops and a final follow-up meeting. Therefore, with this information, Gerrits and Vaandrager started to design a participatory process and decided to 'compress' the usual GMB approach in order to meet the necessities of the case. The first session began with an introduction of GMB to participants and then they were taught on how to reconstruct mental models from interviews. After that, municipality officials practiced this type data of collection. The participants were requested to perform the role of either the responded or interviewer (and in this last case to try to be as much naïve as possible). Once the problem of the interview was clarified, the interviewers had to repeatedly ask about the causes of the

problem, and then the causes of the causes and so on. Some of the preliminary results after this exercise had recognizable feedback loops even though the concept was not touched by the facilitators yet. So modellers gave to the audience the task of performing these interviews with people outside the organization and the relative model construction in between the two session and to send the results to the research team as soon as possible. Then the modellers would have gathered all the data together and constructed a preliminary model to be discussed and further developed in the second session. The idea was that as the officials got into the 'field', they would confront with many diverse points of view on common themes as waste and cleaning policies. Gerrits and Vaandrager also report that their general impression at the end of the session was that the participants accepted the ideas and the task provided. However, the results started to arrive to the facilitators only very few days before the second workshop. Moreover, the majority of the maps were of a very disappointing quality. Here the words used by Gerrit and Vaandrager are reported in order to fully comprehend the extend of the disappointing outcomes: "*few officials had even taken the effort to actually construct a model. Those who had made an attempt had usually done it incorrectly and, it appeared, in a great hurry. The models were also based on very little but homogeneous information. An important reason for this homogeneity was that, contrary to the instructions, most of the civilservantshad only interviewed direct colleagues at approximately the same hierarchical level. Even if they did interview outside of their own organization, as two did, they were unable to translate those results into anything other than what they themselves understood to be true. In other words, they only recorded and emphasized those views that confirmed their own. In addition to this, normative and factual statements were mixed*" (Gerrits & Vaandrager, 2017, p. 7). Consequentely it was impossible for the modellers to unify the information collected in a preliminary model to be used as a starting point in the next session. Therefore, a change in plan was decided: the modellers built a preliminary model by themselves, presented it to the audience and then used the second session to ask for additional information to the participant in order to compensate the lack of quality. During the second workshop, the participants were divided into subgroups with a topic assigned to each one and, after the group discussion, they were asked to report back to the bigger audience their conclusions. The modellers used these ideas to develop the model further. Their findings were presended in the last meeting. Contrary to the first two workshops, which deeply relied on participants' inputs, this session was more a follow-up in which researchers presented the insights gained. Unfortunately, the meeting was unsatisfactory. The authors report that "*the participants either found it difficult to follow the many loops in the model or, conversely, thought that the model was too generic to reveal anything surprising. Of the latter group, some remained silent out of politeness but were still deeply sceptical. The details of the model and our observations mentioned in the previous section seemed to fall upon deaf ears*" (Gerrits & Vaandrager, 2017, p. 8). The participants claimed they were expecting something far different from the actual outcomes and because of this diffused unsatisfaction among the participants the possibility for further projects and collaborations was cancelled.

Gerrits and Vaandrager tested to what extent they could compress GMB and PSDM more in general. They accepted the challenges posed by a homogeneous group of participants and they thought it would be feasible to train participants to collect mental models and make them do the task and that this would introduce more heterogeneity in the group discussion and subsequently improved the model. Unfortunately, the results were very dissatisfactory. At a group level (increased quality of communication, creation of a shared language, consensus about problem and solution definitions) no improvements were seen. At individual level (positive response to the process, mental model refinement, commitment and behavioural change) only a small portion of participants stated that they appreciated the usefulness of SD while the majority did not respond positively. These last "*were negative about the method mentioned the following weaknesses: the amount of time and other resources required, the skills demanded from the participants, the resulting model that was either self-evident or not clear enough and lack of a clear goal for using the method*" (Gerrits & Vaandrager, 2017, p. 9). Gerrits and Vaandrager got to the conclusion that the adaptations tried need to be rejected as good or promising practice because they could not achieve the client goal, no change in the organization was observed and the organization rejected the method deciding to not continue the collaboration after the sessions. The researchers identified the possible causes of the failure in a combination of factors as the lack of time, no effort from the participants' side, contextual issues (political environment). It is very unusual to see scientific articles reporting on a failed PSDM, but the work of Gerrits and Vaandrager is definitely very instructive to illustrate what may not work in a GMB project. Therefore, a new strategy to try to overcome the homogeneity during a GMB and PSDM in general is still needed. The project at the base of this research provided the right setting to test a new approach. What has been developed is an adaptation of the traditional Devil's Advocate and it makes the facilitators leave their neutral role, becoming participants in order to raise new issue and new mental model into the workshop. It will be fully explained in the following subchapter.

4.4. The 'new' Devil's Advocate setting: a possible way to overcome the homogeneity barrier

The new Devil's Advocate script (DA) is a deep revisitation of the Vennix (1996) script and it takes inspiration from other facilitation techniques, such as the 'Stakeholder role plays' proposed by Bryson (2004), the role play gaming (blue team vs red team) used in cybersecurity (for example: Hannes, 2012; Mirkovic et al., 2008) and the widespread approach of the 'Six thinking hats' (De Bono, 1999). From these approaches, it is possible to note that people in other fields of study already tried to increase heterogeneous thinking among working group. From all these experiences and approaches, one main idea comes out: role-playing games are a successful way to deal with this. For instance, Bryson (2004) makes people impersonate different stakeholder in order to explore how they would behave. It is similar to what is done in cybersecurity: groups responsible of cybersecurity of companies or governments are divided in two teams, the defenders (blue) and the

attackers (red) and they have to play these roles and try to take each other down. This is a way to stress out how effective are the defence mechanisms and to explore how hackers might think. However, to ensure these strategies are effective a reliable knowledge among the game participants on the role they are going to play is needed, otherwise the usefulness of the technique can decline drastically, for instance if the actions of the fictional stakeholder/hackers are not realistic and credible the learning experience suffers. For these reasons, these techniques were evaluated as not the best way to deal with complete homogeneity in a PSDM session. In our project, only policymakers from BEIS were attending the workshops and they were the part of the organization that contributed to develop the failed Green Deal policy. As it was illustrated before, one of the reasons why the policy design was poor, was because policymakers failed to take into account other actors perspective (e.g. homeowners, supply chain). Therefore, from a practical point of view it did not make much sense to ask someone who had proven not to understand the mental model of some specific actors to perform a role play game in which they have to impersonate exactly those actors. Based on all of this the new DA script was developed.

The substantial difference of the new approach suggested here is that who plays the role-play game is not a participant but a facilitator among the research team. One or more members of the team leave their neutral role of facilitators for the entire duration of a session and then impersonate and bring in to the PSDM 'room' the mental models of the missing stakeholders/experts. It may be intended as a sort of new GMB script but actually it is not. With script, it is usually meant a group exercises that is performed for chunk of workshop sessions. Moreover, they are interchangeable and usually practitioners put in series in order to create a session (Andersen & Richardson, 1997). This is not the case for the DA adaptation, since it is not a group task lasting for a certain amount of time and then changed. It is more a setting for a session because it does not involve the actively participants and it does not just last for part of the workshop but for the whole meeting. What are the information that the DA brings into the room? The preparation of the role requires a considerable amount of time. First, the missing stakeholders need to be identified. This can be done based on the group inputs and on the literature on the subject. Once they have been discovered, behind the scenes, scientific and 'grey' literature is read on their point of view, interviews with subject experts are done (paying high attention to not disclose any confidential information on the case) and reports analyzed. Then all the relevant information obtained are organized in tables in which there are indicated: the theme of issue to be raised by the DA, who the related stakeholder is, how to frame the issue during the workshop, a suggestion on how to represent these concepts in form of variable and causal relations and the source of all the information. Table 4-1 shows how the tables provided to the DA look like. The DA is provided with these tables before the workshop in order to give some time to study 'the role'.

Table 4-1: Prototype table with the information provided to the Devil's Advocate

ISSUE TO RAISE	STAKEHOLDER BEARIER OF THAT ISSUE	HOW TO FRAME IT	POSSIBLE VARIABLE RELATED TO	SOURCE
Existing dwellings are likely to represent 70–80% of the 2050 stock. 30% are going to be new houses. In 2016 140,660 houses have been completed. (Legislation "Building Regulations and associated technical guidance", regulation called "Zero carbon emissions" that have been stopped)	Constructors/ other policymakers (Department for communities and local Government)	"At the moment new houses are not relevant in the model. It is a stock outside the core structure. But I think that if we adopt a long term view they can be important and therefore valuable to be taken into account". "Are there any legislative requirements for energy efficiency and GHG emissions from new buildings? ('in which stock is the rate going in?')	"New building rate", "demolition rate",	(Shrubsole, Macmillan, Davies, & May, 2014), (UK Government, 2017)
Top renovation payments methods: 1) Savings/personal finances 85% 2) Cash from home mortgage refinance 14% 3) Credit card – to be paid off over time 14% 4) Gift/inheritance 11% 5) Personal loan from friends/family 4%	Renovation expert	From what I know only 14% of the people that are renovating chose to pay with cash from home mortgage refinance. Is this data realistic according to you? "Do you agree that knowing the magnitude of people paying in this way is important?	"Percentage of people using mortgages refinance for paying renovations"	(Houzz report, 2016)
People in UK are very reluctant in undertaking loans and mortgages	Industry stakeholders/ Households	Households in UK are not very willing to take a loan or refinance their mortgage to pay for their renovations. This can have an impact on the policy.	"Reluctance towards mortgages and loans"→ "Percentage of people using mortgage refinance to pay for renovations"	Esfand Burman, research associate, UCL Institute of Environmental Design and Engineering with long experience in the construction sector
Households distrust Households seems reluctant to accept financial offers coming from other actors	Households	*"Generally, those who chose not to pursue support despite being contacted described being 'put off' by the method of contact. Cold-calls*	"Households trust in financial offers"	DECC Supplier Obligation Consumer Research: Summary Report

Source: compiled and conceived by the author

Once all the information have been collected the whole preparation needed for the setting is completed. The setting can be now used during a workshop. For that session, at least two facilitators are required: one will facilitate the workshop while the other plays the DA. The facilitator needs to introduce the figure of the DA to the workshop participants. It is a very delicate phase since it is the moment in which a member of the facilitation team, that before was neutral, abandons his impartiality and starts to act as a participant. If this setting is not properly explained to the group, it may raise misunderstanding, tension and even conflicts and thus undermine the whole project. It is also a good practice to ask the participants whether they agree with this approach and leave them room to refuse it in case they do not feel comfortable with it, because there is no point in creating pressure on group members. Figure 4-2 provides a guideline on how to introduce the DA to the group.

[Facilitator]:

"As you saw last time, facilitators don't interfere with the content under discussion among the participants. What they can do is to ask question that challenge the participants. Today facilitator X will leave her neutral facilitation role and act as one of the participants for most of the session. The reason why we made this choice is that we want to bring some issue into 'the workshop room' that might be raised by the stakeholders (that unfortunately can't attend the workshop). The idea is to stress the model/map as much as possible in order to increase its truthfully with respect of reality. We expect this process to increase the quality of final output since it can lead to integrate into the model 'things' that were not considered before. However, it is your right to stop it. It means that if you think that this approach is annoying or useless just let us know and say that you do not want that facilitator to be there".

Figure 4-2: Prototype new Devil's Advocate introduction to workshop participants

Source: conceived by the author

Lastly, how does the DA carry out his role during the session? Although he acts as one of the participants, he has to follow some guidelines in order to make his role as smooth as possible. The ideas behind this choice come from the work on human interactions, help and consultation of Schein (1990). Therefore, the behavioural guidelines provided to the DA are the following:

- Sit and stand among the participants and not among the facilitators.
- Suggest links and variable as any participant. Therefore, participate to the nominal group techniques and the modelling phase (suggesting variables, links, arising questions, etc.).
- Do not interfere in the group activity that requires reaching a consensus among participants. You have 'less power'. This because reaching consensus is an internal group process through which the commitment on the model is built and so nobody of the facilitation team should interfere with it. In practice, after every discussion in the modelling phase, in which also the DA can take part, the facilitator usually asks to the participants if they all agree on the suggested item. In this moment the DA should not interact (if something appears to be extremely wrong he can ask clarifications but he cannot put a veto or start a conflict)
- The goal of the DA is to add more perspective to the group and then improve the model quality. Remember that with this adjustment we are exploring to what extent a facilitator can leave his role and intervene on the content and what contribution they can give to the model. To do so, the DA can share his reasoning as a normal participant and the data source these ideas come from. Try to set yourself in an inquiry mode when suggesting variables, etc. An example of bad practice is: "*this is wrong, the literature says this, this and this*" because obviously their reaction would be quite negative towards the workshop setting. Instead an example of good practice could be: "*I see. But, have you ever considered this option described in this source?*" or "*I read some articles. This might be placed here and connected*

to this. Is it useful? Why don't you think so?". In this case, the DA just challenges their ideas and do not impose anything. The burden of thinking about the stimulus from the DA is shifted to the participants since they need to think about it in order to answer the question. Moreover, questions are less 'harmful' in a discussion than statements.

- Ultimately the role of the DA is just posing ideas (backed by sources), explaining the reasoning why these ideas could be relevant and then support the participants to accept them or not. They are the ones who make a decision. The DA should never forget this while conducting his role.
- The issue that DA should pose are studied and analyzed earlier with the research team in order to check and assess their robustness and relevance. All the issues are related to a stakeholder, have a source backing that claim (literature, interview with experts, etc.), have a sentence as guideline on how to present the issue to the other participants and a list of possible variables related to it.

Ultimately, the DA needs to be warned that this is a methodological attempt to adapt PSDM to an undesirable situation. It has never been tried and there could be some aspects that have not been taken into account and something not expected can arise in the workshop. Therefore, to the DA it is requested a high degree of flexibility and adaptation. In conclusion, the DA becomes an 'asynchronous knowledge broker' between the missing stakeholders and the policymakers at BEIS. Although the DA sticks to the scripted role, he still has some personal bias that cannot be erased. Therefore, it is impossible to distinguish completely to what extent the DA also represents himself. However, with this approach it is expected that the DA gets an additional and different knowledge about the missing stakeholders than the workshop participants have about them and thus be able to (at least partially) represent them indirectly.

4.5. SWOT analysis

Due to the originality of the approach, a preliminary assessment of its strengths and weaknesses is required. In order to do so, a SWOT analysis of the setting is undertaken (Osita, Onyebuchi, & Nzekwe, 2014). SWOT is an acronym for strengths, weaknesses, opportunities and threats and it is a framework for evaluating these factors in projects and organizations. It allows to identify external and internal factors that are unfavourable and favourable to achieve the objectives of the adapted setting. Therefore the elements analyzed are:

- *Strengths* (internal and favourable) stand for the attributes of the approach that give benefits over the others
- *Weaknesses* (internal and unfavourable) refer to the features (e.g. distractions, competition) of the approach that place it in a disadvantage compared to others

- *Opportunities* (external and favourable) external aspects that the approach could exploit to its advantage
- *Threats* (external and unfavourable) elements in the environment that could harm the approach and impede to achieve its goals.

Therefore, performing a SWOT analysis is crucial because it can help to explicit the key factors that can support or undermine the new DA approach. However, SWOT method has its own weaknesses that it is necessary to highlight. The principal one is that it does not provide a prioritization so, for instance, weak opportunities may seem to counterbalance strong threats. In the next paragraphs, the four elements will be discussed in detail for the new DA, while Fig 4-3 at the end of section summarizes al the main points of the analysis.

4.5.1. Strengths

Several strengths have been identified. In general, confidentiality and time constraints posed by BEIS are respected: no external person is needed and no modifications to the participants schedule are needed. All the effort to prepare the setting is on the facilitators. Benefits compare to the 'Stakeholder role play' suggested by Bryson (2004) are that, in this new setting, the DA can prepare himself on the missing stakeholders before the workshop and explore the issues and concerns (e.g. reading literature, interviews) while a participant might not have the knowledge to bring their interests or mental model. In other words, the new DA somehow guarantees a 'minimum' standard over the missing stakeholders' representation that there is not with other approaches while the benefits over the traditional Devil's Advocate proposed by Vennix (1996) are multiple. First, it is not just a script for part of a workshop but, as said, it is something continuously present. In all the modelling phases of the workshop the DA shares information that a missing stakeholder might have and so have an impact on the group and on the model. Second, participants that are locked-in in their mental models and assumptions might not even see them when playing the Vennix (1996) script while an external input from a DA could highlight those ones.

4.5.2. Weaknesses

The new DA setting has four major weaknesses. First, it requires to the facilitator to play the DA to have enough knowledge to represent the missing stakeholders otherwise it may raise unrealistic issues during the workshop, ending up to lower the quality of the model and also the relationship with the group of participants. This risk is not there in any of the similar approaches mentioned earlier since the facilitators do not get involved in the group dynamics at all. Related to that, another weakness is the time required to prepare the scripts for the setting. In order to collect the information to 'feed' the DA with a lot of preparation is due: reading of scientific literature, exploration of grey literature, interviews with the stakeholder and

subject experts, etc. Compared to the other approaches where the preparation time is almost null, the one required by this new setting in considerably higher. Thirdly, the facilitation team loses 'capacity' since at least one of them plays the DA during the whole workshop. This increases the workload for the remaining facilitators. Lastly, this new approach is encompassed of uncertainty. Since it is an original setting, there are no previous experiences on using it, therefore, although careful analysis ca ben conducted in advance for assessing the entire situation, no one can anticipate all the factors that will interplay a role during the session.

4.5.3. Opportunities

An external benefit that might arise from the new DA setting is that it may help to structure better the process. The idea is that having an expert in modelling/facilitation as a participant can help the facilitators to structure the work of the group. For example, DA may show other group members how to suggest variables and express concepts in form of causal relations and thus end up leading by example the other participants on how to behave and interact during a workshop.

4.5.4. Threats

Numerous possible threats have been established. First, the acceptance of the participants of this original setting is unknown and unpredictable. What may harm more the group dynamics is the reaction of participants to the facilitator playing the DA loss of neutrality. Specifically, the fact of being challenged by a 'new' participant that comes from outside the group and that was before perceived as neutral can generate adverse reactions in some participants. Moreover, as already mentioned in the weaknesses part, the credibility of the DA depends on the participants perceived quality of the issues and comments raised. In addition, the DA could struggle to step in the discussion. This because there could already be some group dynamics formed and getting in for an outsider may be challenging. Alternatively, the DA could steer the process. Due to his deeper experience in PSDM and SD than other participants, he could more or less voluntarily impose the point of view he represents. There is also the risk that during the session the DA behaves like a facilitator. For someone trained and experienced in PSDM conduction it may be difficult to avoid to take back his 'natural' role for which he has been taught. For instance, the actual facilitators may be struggling and the DA cannot control himself from leaving his role of participant and help them behaving like a facilitator. On top of that, the facilitation team is reduced of at least member. As said in the weaknesses this makes life harder for the remaining facilitators and the fatigue can lower the quality of their performance, especially in long workshops. Lastly, if it is performed in one session out of a series of workshops, the setting could create confusion on DA's contribution. For instance, some of DA's suggested structures might be integrated in the model in the session in which the DA is performed and then proposed to be left out in a latter workshop. The facilitator may be trapped in a situation in which he covers two roles: the former DA and the actual facilitator.

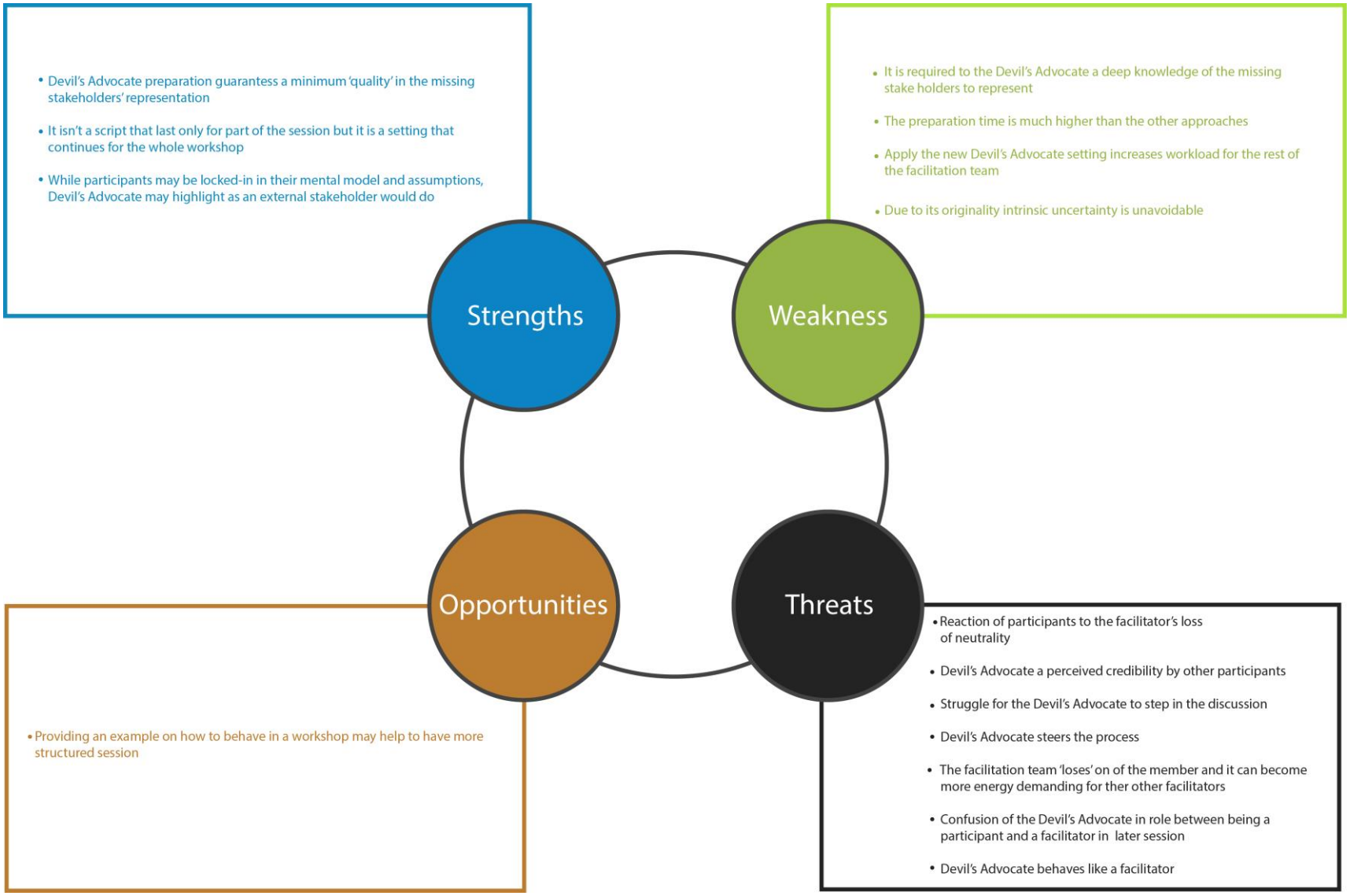


Figure 4-3: New Devil's Advocate SWOT analysis

Source: conceived by the author

4.5.5. Potential risks and mitigation

The elevate number of potential threats creates a high degree of risk. Therefore, this makes necessary to prepare mitigation strategies. These are reported in Table 4-2 below. Some of the mitigations are already integrated in the approach while others have been specifically elaborated to diminish the related risks. These mitigation strategy are expected to decrease the degree of potential risk that the new DA setting can face when applied in real cases.

Table 4-2: New Devil's Advocate risks and mitigations

Expected risk	*Mitigation strategy*
Reaction of participants to the facilitator's loss of neutrality	Transparency from the beginning of the role of the DA
DA perceived credibility by other participants	All the issues the DA wants to raise are previously studied and documented (backed by sources) in the provided script
DA steers the process	The other facilitators make sure the DA is not going to become a talking head or lead the group process
Struggle for the DA to step in the discussion	DA should be self-confident and consider himself as much as possible as a participant
The facilitation team 'loses' one of the member and it can become more energy demanding for the other facilitators	Shorter workshop, more breaks (if needed), different structure than the usual one in which the participants are more active (e.g. table top modelling)
Confusion of the DA in his role between being a participant and a facilitator. The facilitator will act as a DA only during a workshop some structures suggested by him might be integrated in the model in that session and then proposed to be left out in a later session	Once the role game of the DA is over, the DA assumes back the role of facilitator and therefore he is neutral with respect of the content. He may just ask the participants to explain why and let them to decide.
DA behaves like a facilitator	It might be that in addition to play his role the DA absentmindedly acts a facilitator (e.g. after speaking they give instructions, as "*it is your turn to speak*", that are usually given by the facilitator). In this case, the actual facilitator should politely interrupt him, get the control back of the workshop and remember him his role of DA.

Source: compiled and conceived by the author

4.5.6. New Devil's Advocate setting post-execution analysis

Since what has been described is an original setting, a careful and scrupulous analysis needs to be done after it has been employed. This is crucial in order to understand the performance of the new DA approach. First, since it is planned to record the workshops, the sessions in which the new DA is used can be transcribed and then analyzed. This because studying a session transcription allows to have some 'hard' data to build a preliminary assessment upon. To interpret this data the transcription is coded adapting the guidelines of Hyunjung and Andersen (2012) to the case. Specifically what is coded are all the interventions made by a DA during the session. For intervention it is meant what is communicated by a participant when they take the floor to talk during a group discussion. All the other interventions made by the other workshop's participants are analyzed too, because their understating is instrumental to the coding of the DA's interventions. However, they are not coded since there is no necessity to do that to analyze the DA contribution. The coding process is finalized to evaluate how the DAs intervened during the session and how they contributed to the map. To assess this last, an established 'linking the map to the data source' approach is use during the coding process (Hyunjung & Andersen, 2012). To complete this operation the transcript is cross-compared with the map resulting from the workshop, thus the structural changes made or impacted by the DA can be identified and tracked back in the DA's interventions. Below in Table 4-3 the description of the coding scheme to adopt is reported. Obviously, a deep assessment of the new setting needs to take into account the feedback of all the people in the session: participants, DAs and facilitators. This is important because feelings, emotions, perceptions and other personal and relevant opinion related to the new DA approach probably do not emerge during a workshop discussion and in this case, the best way to collect it is to openly ask them for their opinion about the method used. Then, these can be complemented with short memos (following the guidelines in Miles, Huberman, & Saldana, 2013) written by the actual workshop facilitators right after the workshop containing their personal reflection on how the session unfolded. They can be valuable because they could provide additional information than the simple oral feedbacks. In addition, once the setting is performed, in order to have a complete overview, its outcomes can be compared with the expected risks previously identified, to see whether they emerged or not and, in case these problematic situations appeared in the workshop, whether the suggested mitigation strategies worked .

Table 4-3: Second workshop coding scheme

Type of code	*Description*	*Why*	*How*
Repetitions	Interventions that are repetitions of a previous one or a continuations after an interruption	Counting them allows to not accounting twice the same interventions	(\\repetitions)
Variables or connections unaccepted	Interventions directly suggesting variables or connections and that are refused by the group	This code shows how the unsuccessful rate of the DA suggestions was.	(*'name of variable or connections unaccepted'*)
Variable or connections accepted	Interventions directly suggesting variables or connections and that are accepted by the group	This code shows how the successful rate of the DA suggestions was. Moreover, the code helps to keep track of the structural changes directly ascribable to the DA actions and links maps to the data source	(*'name of variable or connection accepted'*)
Contributions to structural changes	Interventions that contributed to a discussion that leaded to structural change (e.g. suggestion of an idea that was translated in a structure, suggestion of a name for a variable for a topic under discussion, etc.)	It keeps track of all the structures in which the DAs were directly involved in the creation or modification	(contribution to a structural change)
Discussion started by a DA	Interventions of the DAs that stimulated discussion in the group on new issue of from a new perspective. These interventions are mostly questions or informational support	To purpose of this code is to see how much were the DAs able to open new discussions	(discussion started by a DA)
Generic interventions	All the interventions that are clearly categorizable in the other categories (e.g. clarifications, information, etc.)	It is necessary to no leave out of the coding scheme any DAs' intervention and keep track of all of them	(generic intervention)
Facilitation interventions	All interventions that are closer to what a facilitators does than to how a participant behaves during a workshop	This code allows to account for the times the DAs leave their role of participants and get back to be workshop facilitators	(facilitation intervention)

Source: conceived by the author

5. Results and discussion

The research results will be presented in the following way. Initially, the process (how the method was applied in practice) and its outcomes are described. The purpose of that is to show the reader how the process unfolded and what outcomes were produced over time. After that, a detailed analysis of the results obtained is conducted. First, the application of the new DA setting is assessed and discussed and then, the results and insights from the SFD model are displayed.

5.1. Process and outcomes

As said, the research was conducted with the PSDM approach described before and it engaged only policymakers from BEIS, in the context of a joint project between BEIS and UCL. The time span available to perform the study was extremely short, since it was from the late February until the end of April. Four system dynamicists constituted the research team: an experienced SD and PSDM lecturer and practitioner from UCL, a PhD student from UCL with e solid expertise on homeowners renovations' decision-making but no previous knowledge on PSDM, a fellow EMSD colleague and the author of this thesis. It needs to be specified that the PhD student only helped during the workshops and did not contribute any further to the realization of the project. The process consisted of preliminary interviews in February, two workshops interspersed by an interview with the gatekeeper, five interviews with experts in BEIS to refine and quantify the model and a final follow-up meeting with participants and open to all the policymakers interested in the outcomes.
Fig 5-1 shows how the process unfolded.

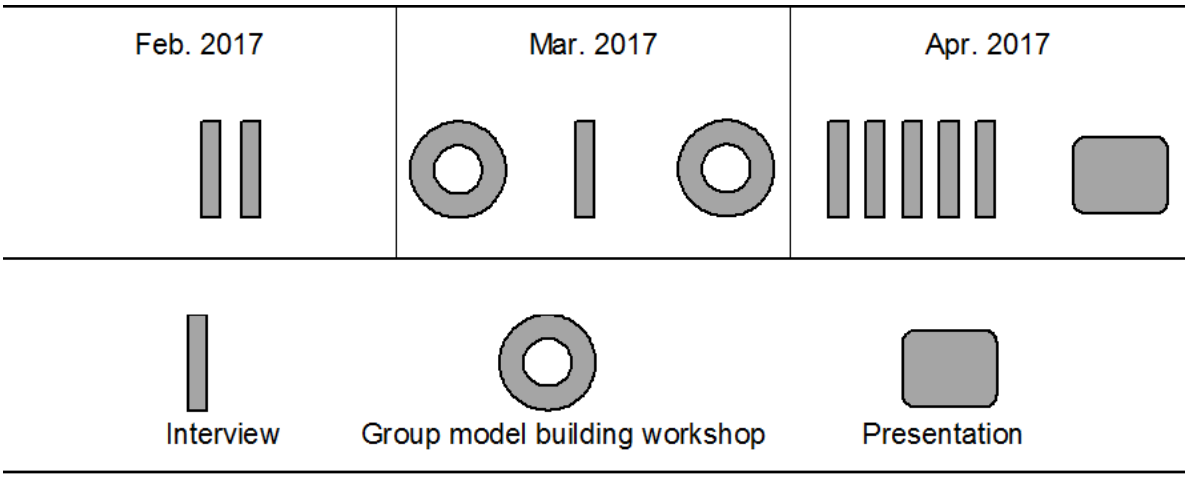


Figure 5-1: Participatory System Dynamics Modelling process employed

Source: Cappuccio et al., 2017, p. 6

5.1.1. Preliminary interviews

In February, preliminary interviews took place between the research team and the gatekeepers. In this case, the first contact with the gatekeepers was crucial under many aspects. It served the purpose of familiarizing

the organization with the methodology. Moreover, exactly in this stage of the process, the research team was informed of the high time pressure and of the confidentiality issues with the information involved and that, due to these conditions, it would not have been possible to have other participants to the project than policymakers in BEIS. This meeting also helped to structure the process and to set clear deadlines. In this particular case, there was room only for two workshop sessions in March and for a final follow-up meeting in April in which the researchers would have shared the results of their work. However, gatekeepers provided their availability to arrange interviews with their experts. The result of this interview was an agreed document in which a detailed plan of action was black on white. It was very important in order to have complete clarity on how the process would have looked like, on what would have been the outcomes and to manage the gatekeeper expectations.

5.1.2. First workshop

The first workshop took place in the beginning of March. It was a full day workshop (6 hours) and attending to it there were six participants and the entire research team (four facilitators). First, there was an introductory moment in which all the participants and facilitators had time to introduce themselves. Thereafter, a facilitator presented to the group previous applications of SD to similar topics, highlighting what the outcomes lookalike, what is the methodology potential and what it does stands for (e.g. prediction and forecasting). Second, the script '*Hopes and Fears*'[7] was used in order to let all the participants to express what they hoped to achieve what their concerns were for the session and the project. It was extremely helpful, since it let the researchers know that a couple of important participants had to leave earlier than the official ending time of the workshop and that consequently they would have liked to get into the mapping process as soon as possible. Knowing this allowed the facilitator to get in touch with the 'group life' (Phillips & Phillips, 1993) and adapt the session to the participants' needs. This was possible because the session was structured on 'chunks' based on scripts making it flexible to be readjusted to the group need. Consequently, facilitators agreed to skip what was not strictly necessary and to move as quickly as possible to the mapping phase. Then the SD language, symbols and main concepts (stock, flow, variable, polarity, feedback and behaviour over time) were introduced to the participants, using the well-known metaphor of the bathtub (Sterman, 2002; Sweeney & Sterman, 2000). After that the introductory part was over and the participants became more actively involved. In order to define and clarify the problem the script '*Graphs over time*'[8] was utilized. Participants were asked to draw graphs over time in blank sheets of paper of what they perceived to be problems in the system. Unfortunately, the task seemed to be not explained clearly enough and most

[7] https://en.wikibooks.org/wiki/Scriptapedia/Hopes_and_Fears
[8] https://en.wikibooks.org/wiki/Scriptapedia/Graphs_over_Time

of the participants started to list with words what they think the problems were instead than depicting behaviours over time (Fig 5-2).

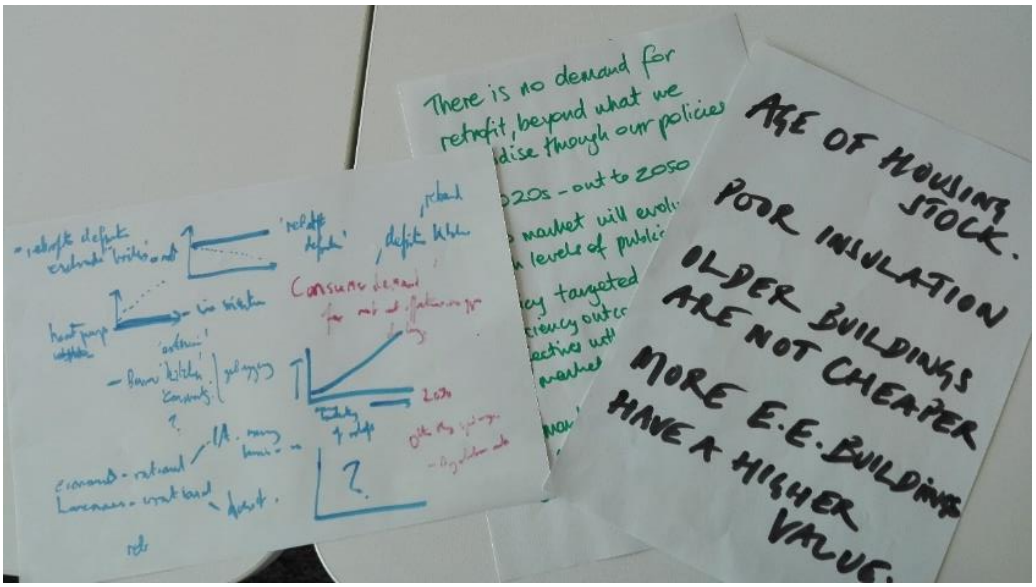


Figure 5-2: Problematic behaviours brainstormed during the first workshop

Source: taken by the author

Nonetheless, all the input were clustered on the board and used as starting point for the mapping process that lasted until the end of the workshop. Facilitators then began to ask for causes and consequences, as traditional group model building prescribes (Vennix, 1996). The discussion was very dense of content and the participants appeared to be very excited and active in sharing their ideas. Although group members' high involvement is a definitely positive sign, the session resulted to be a little bit chaotic. Participants were so eager to share their ideas that they resulted to be 'hasty' in formulating them in form of variables and relations creating some confusion. The entire workshop got recorded.

5.1.3. First workshop outputs

Nevertheless, the feedbacks from the participants were very positive at the end of the session. They liked the process, they found useful to have a map serving as a group memory during their discussions and appreciated the fact that they could already identify some important loops. Also among the research team during a debrief post-session there was an overall feeling of satisfaction with the outcomes. However, the facilitators agreed that in some moments the session was chaotic and the discussion among the participants was not very structured. As said, the mapping process started from the scratch and the result at the end of the day is shown in Fig 5-3 below.

Figure 5-3: First workshop map

Source: taken by the author

Behind the scenes, this map was translated in Vensim software (Annex A). Then it was revisited and refined by the researchers with the help of the recording in order to clean it up, namely avoiding duplication of the same concepts or disaggregating variables (Fig 5-4). On this revised CLD, the main loops were identified, highlighted and analyzed (Annex B). These outcomes from the first workshop were sent to the participants in form of workbook after the session, as Vennix (1996) recommend. In addition to show them the outcomes of their efforts and to be transparent on the work done by the research team between the sessions, it served as validation step: the participants were asked to refer back if any inconsistency was found or to bring their concerns directly to the next workshop.

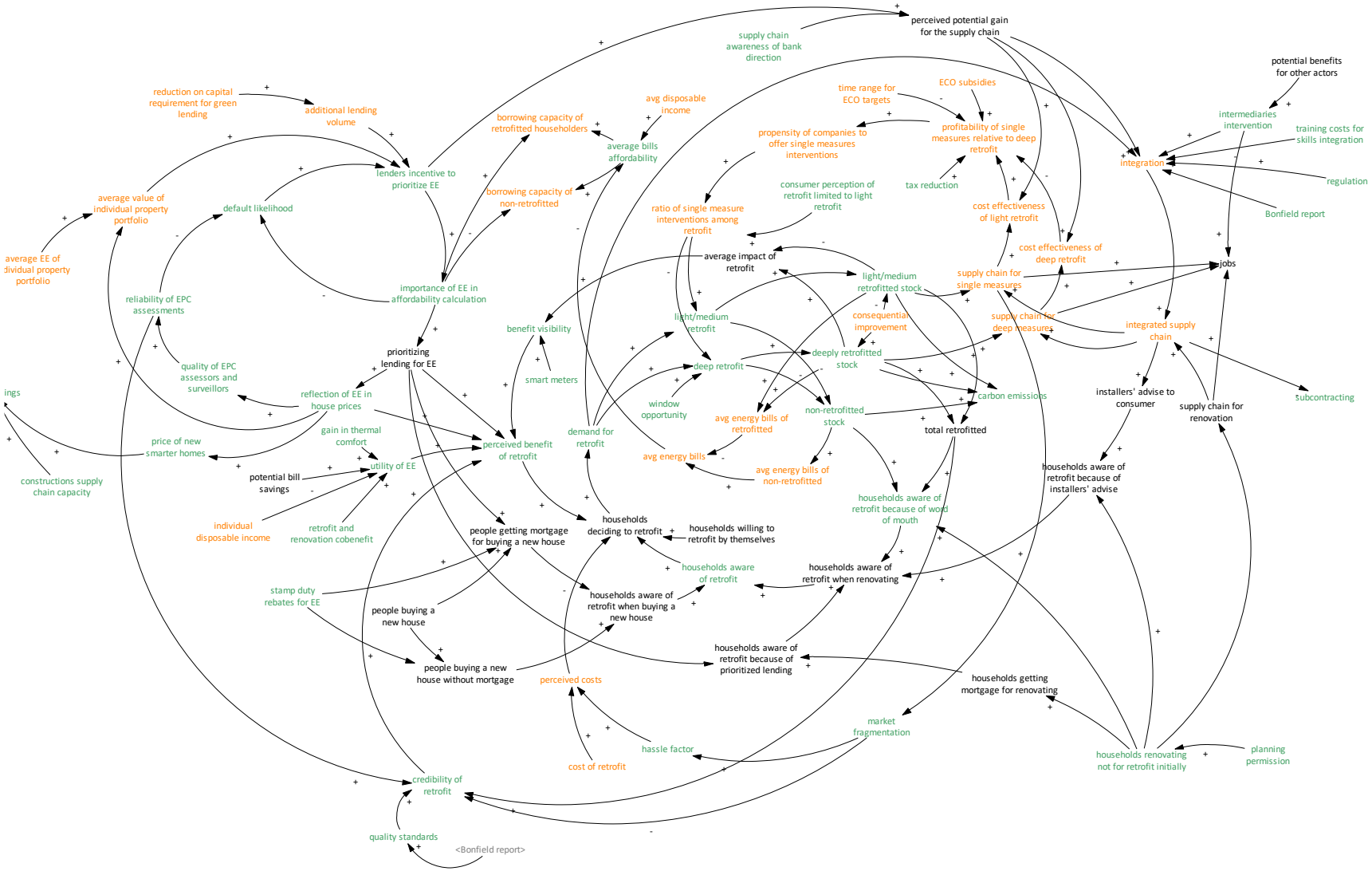


Figure 5-4: First workshop refined map. In green the variables explicitly mentioned in the workshop; in orange the ones coming from the disaggregation of variables mentioned in the workshop and in black the variables added by the research team

Source: conceived by the author

5.1.4. Second workshop

In preparation of the next session a short meeting with the gatekeeper was hold. It served to set up the workshop and to inform the organization about the willingness of the researchers to try a new approach to overcome the homogeneity issue among participants. The second session was completely devoted to revise, expand and improve the work done so far. The research team prepared a 'hybrid model' to be used as a starting point for the group work (Annex C). This map was an adjustment of the refined map resulting from the previous workshop (Fig 5-4). Here the key stocks and flows were identified, variables arranged in sectors (homeowner decision-making, supply chain, lenders, physical stock and renovations) and loops slightly simplified. Since this model combines the CLD features of the previous map and some characteristics of SFD, it was renamed 'hybrid'. This decision was made because the previous map was judged too 'row' to be used as a starting point in a new session (risking to generate confusion) and therefore an adapted version was believed to better facilitate discussion and increase the speed of the work.

The workshop lasted four hours and there were five participants and four facilitators. One of the participants did not attend the first session. In this workshop the Devils Advocate setting was performed. At the beginning, the slide below was used to provide the key information about it to the participants (Fig 5-6).

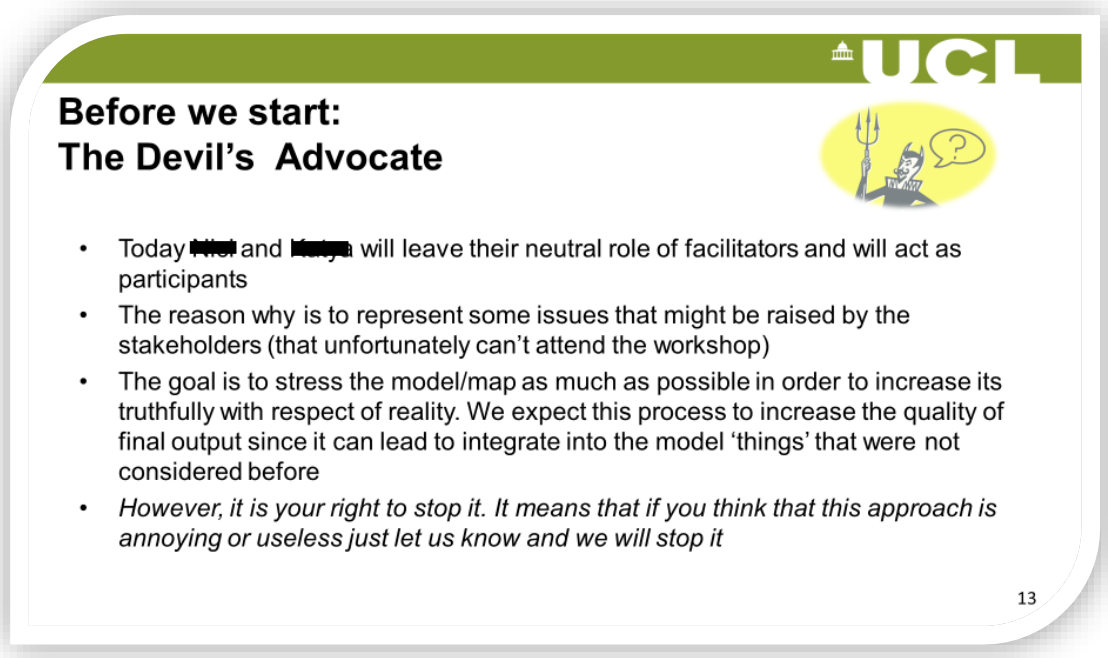


Figure 5-5: New Devil's Advocate introductory slide

Source: conceived by the author

Two facilitators played the Devil's Advocate (DA) role while two facilitated, and this setting remain for the whole session. It was decided that the experienced SD practitioner and the PhD student performed the DAs

because in possession of a wider expertise on the subject under discussion. In this case, the missing stakeholders that needed to be represented in the session were identified based on the input of the first workshop and on a preliminary review of the literature. Three main points of view were recognized as potentially lacking: lenders, supply chain stakeholders and homeowners. However, one of the participants had a background of working in a financial institution and therefore he was judged enough to represent the mental model of lenders. Therefore, in order to collect information on the interests and issues of the remaining two missing stakeholders, three interviews with experts (two on the supply chain and one on homeowner decision processes) were conducted and a literature review was performed. Then all the inputs received were collected in a 'script' (following the guidelines described in paragraph 4.4) that was provided to the two DAs a few days before the session. Here there were described all the information about the behaviour to adopt during the workshop and the issue likely to be raised by the missing stakeholders that the DAs should have tried to bring into the session. The script used for this workshop can be found in the Annex D. The workshop was composed of two major parts. First, the hybrid map was revised. Second, the participants were provided with posties on which to write variables they considered important and missing and stick them on the model, where they believed it was appropriate. Then, the group discussed added variable by added variable and, once agreement was achieved, it was connected to the structure. It is important to note that the two DAs were actual participants and took part to all the group tasks and were treat as the others by the facilitators for the entire session. Lastly, also this session was recorded.

5.1.5. Second workshop outputs

Participants provided positive comments on the session and expressed appreciation for the new DA setting. The research team was satisfied with the session and its outcomes. Then the resulting map was translated in Vensim. In figure 5-5 the starting structure of the hybrid map is reported in black and all the addition made during the workshop are highlighted in red. On the initial structure there was only a revision (it was erased since the effect was judge as negligible) of a causal link and it is portrayed in Fig 5-5 with a dotted red arrow. This represents the fact that the aforesaid link was not realistic. Lastly, the recording of the workshop has been transcribed (Annex E) and one of the two facilitators wrote a memo on his perceptions, ideas and feelings about the session (Annex G).

5.1.6. Interviews

Based on the new map it was built a SFD model. During the construction process, five additional interviews with experts from BEIS were arranged in order to clarify uncertain concepts, to collect data for the quantification phase and to validate part of the model structure.

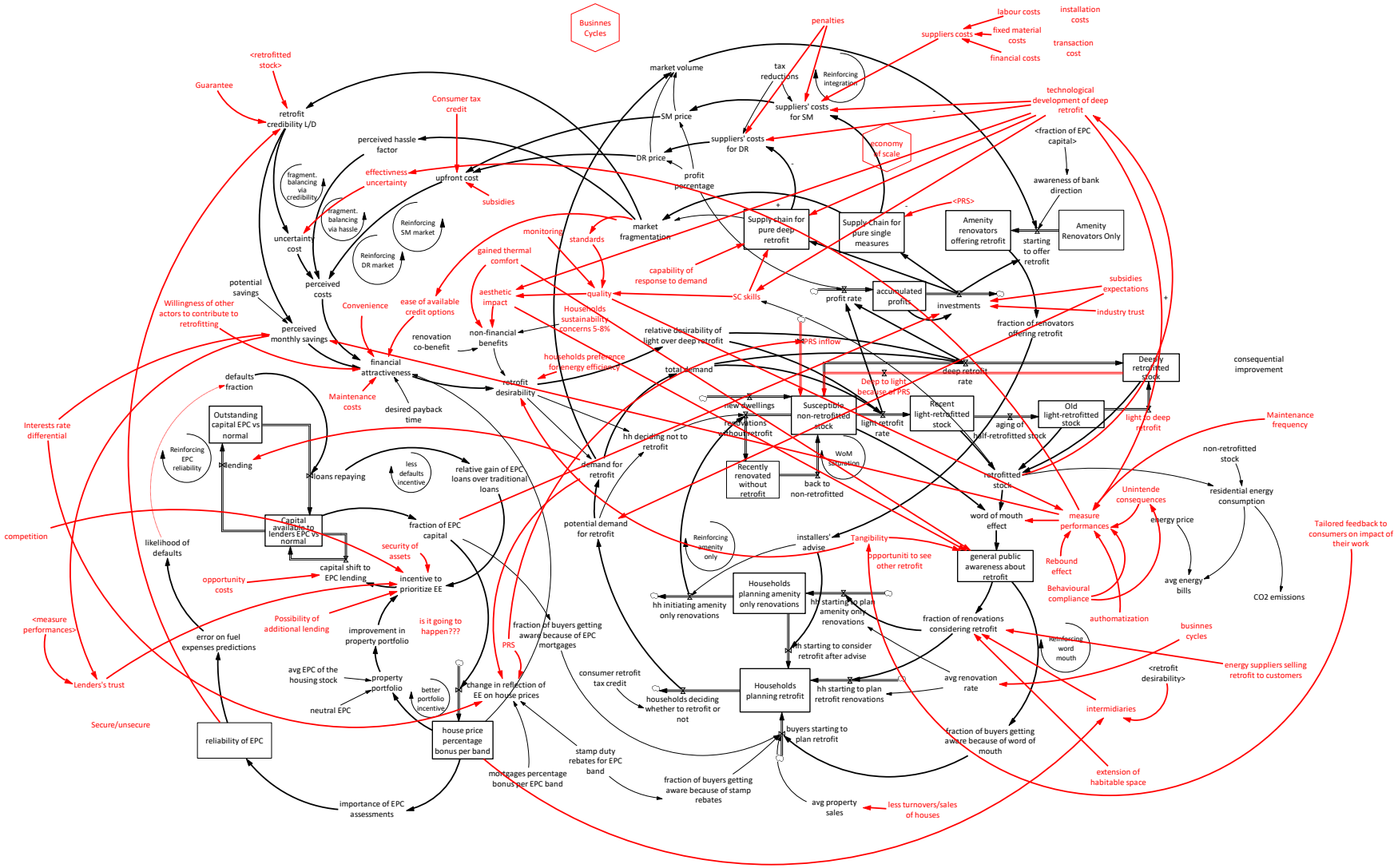


Figure 5-6: Second workshop map. In black structure of the hybrid map at the beginning of the workshop and in red the addition made during the session

Source: conceived by the author

5.1.7. Follow-up

By the end of April, the SFD has been concluded and presented in a follow-up meeting with workshop participants and other BEIS experts that were interested in the outcomes of the project (twelve people in total). Fig 5-6 below shows the model structure. The SFD is focused on the UK homeowners retrofit uptake rate and on the portion of housing stock that they own. The model is composed of more than 3000 symbols and takes into account five different energy efficiency measures that were considered as sensitive by BEIS: condensing boiler, double-glazing, loft, solid and cavity wall insulation. It simulates the uptake of these measures between 2000 and 2050. Due to the complexity of the map the participants were provided with a simplified CLD of the model in which all the most important loops have been reported (Fig 5-8). Several run and insights arising from the model structure were presented to the participants. With the support of the simplified CLD they were even able to track back by themselves the structural at the origin of some behaviours. Also in this case the participants feedback were very positive and constructive. In addition, they stated their willingness to continue further the research on the subject with the use of PSDM methodology in collaboration with UCL. Finally, few days after the follow-up, a report with the full explanation of the results was sent to BEIS.

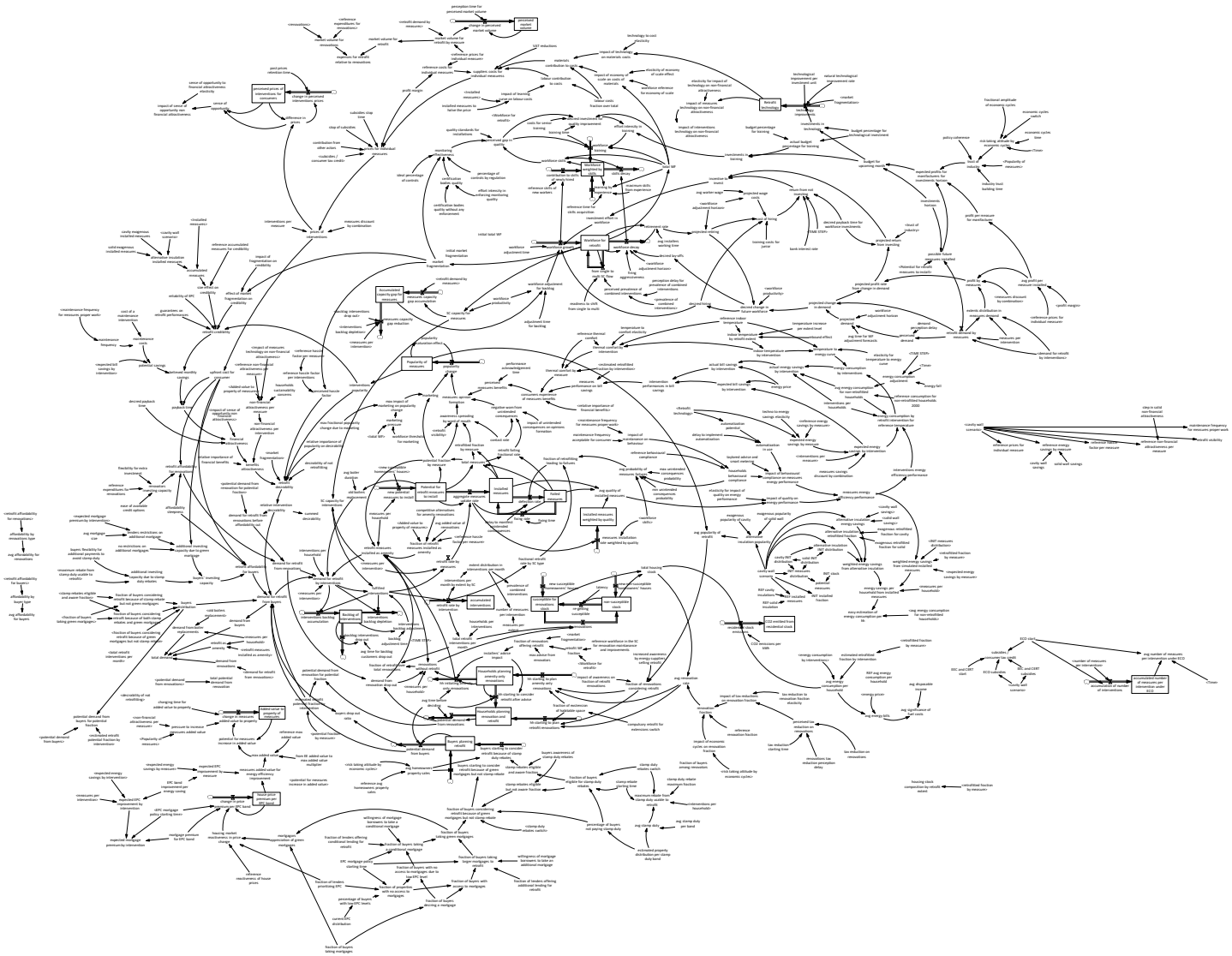


Figure 5-7: UK homeowner retrofit uptake Stock and Flow model

Source: conceived by the author

5.2. New Devil's Advocate setting analysis

In the following section the performance of the new DA setting used during the second workshop is assessed and discussed.

5.2.1. Coding analysis: how did the 'new' Devil's Advocate influence the model?

The second workshop recoding was transcribed and then codified following the instructions displayed in detail in section '4.5.6' (Annex E). All the interventions made by both the DAs during the mapping phase of the workshop (duration 3h30min approximately) have been coded. Two important aspects need to be mentioned. First, the audio recordings of the session were in some parts inaudible and therefore difficult to understand. This has slightly vitiate the quality of the row data. Second, the coding process has been carried out in a 'conservative mode'. This means that when there was low degree of confidence on which code attribute to the intervention, this last was classified as generic intervention. This choice was taken in order to decrease as much as possible the chances of overestimating the impact of the DAs.

The goals of this coding analysis were to assess how the DAs intervened during the session and how they contributed to the map. In Table 5-1 are reported the overall results of the coding, namely the sum of interventions done in the workshop and the number of directly attributable variables and connections addictions done by the DAs and the other participants. A variable or connection is directly attributed to the DAs when they clearly suggest or mention it, in all the other cases the item is attributed to the other participants.

Table 5-1: Second workshop Devil's Advocates and participants cumulative interventions, variables and connections

Items accountable to	*Interventions*	*Variables*	*Connections*
DAs	111	14	26
Other participants	452	40	49
TOTAL	563[9]	54	75

Source: compiled and conceived by the author

From this information it is possible to appreciate the quantitative impacts of the DAs: they made the 19.7% of the total interventions during the workshop and they directly contributed respectively for 26% and 34.7% of new variables and causal links. Table 5-2 outlines how the specifics of each DA interventions have been categorized through the coding (DA1 and DA2 refers to the two different facilitators playing the role,

[9] The interventions made by the facilitators have been left out from the calculation

respectively the experience practitioner and the PhD student). In addition, cross-comparing the coding transcription and the resulting map from the second workshop (Fig 5-6 in the previous chapter), it has been possible to link back all the DAs contribution to the map. Thus, all the variables or connections directly and explicitly suggested by the DAs and therefore directly attributable to them have been highlighted in Fig 5-8 below. This is a way to show graphically the impact of the news setting on the model development.

Table 5-2: Second workshop coding results for both Devils Advocates

Type of intervention	*DA1*	*DA2*	*Total DAs*
repetitions	6	0	6
variable or connections unaccepted	0	0	0
variable or connection accepted	15	1	16
contribution to a structural change	13	0	13
discussion started by a DA	8	0	8
generic intervention	56	3	59
facilitation intervention	9	0	9
TOTAL	107	4	111

Source: compiled and conceived by the author

All these data provide interesting information. First of all, the DAs the impact on the session was quite significant. As shown in Table 5-1 the actively participated in the discussion and contributed remarkably in defining the system structure. Moreover, looking at the coding results (Table 5-2), it is possible to appreciate that the DAs did not just directly 'suggest variables' (code 'variable or connection accepted') into the session, but they provided support to other structure structural changes (code 'contribution to a structural change'), started discussions (code 'discussion started by a DA') , etc. In this respect, surprisingly, the group did not refuse any of the structures directly hinted by the DAs. Therefore, it is reasonable to state that the DAs had a broader impact on the session that just proposing prepared issues and structures. However, looking in detail it is possible to see that the vast majority of the contributions only comes from one facilitator, the experienced one. The same DA in few occasions abandoned her DA role to intervene as facilitator (8.4% of her interventions have been coded as 'facilitation intervention'). The frequency of these facilitation interventions is higher in the second part of the session. Nevertheless, the percentage of these contributions is relatively low. In addition, a comparison has been done between the resulting map (Fig 5-6) and the inputs provided to the DAs in the scripts. To recall, these inputs were possible issues that some of the missing

stakeholder could have raised in the session. There were 45 inputs provided to the DAs before the session and it was possible to identify at least partially 20 of them in the map (Annex F). Also from this perspective the performance was satisfactory: raising all the 45 issues or items was realistically almost impossible and 20 is a good result. However, it is very difficult to extrapolate and isolate the contribution of the DAs from the others. This because a PSDM workshop is a group process and all the participants influence each other. For instance, what has been categorized as a generic intervention of a DA maybe can have prompt a reflection in a participant that later, influenced by that intervention, proposed a structural change. Consequently, an intervention that led to a structural change would have been classified as a generic one, and so on. Therefore, the researcher's judgemental component in this analysis was very strong. Obviously, the reliability of these data is relative, however they still offer interesting information. Although there may be disagreements in some of the coding that has been done, the overall results are clear and they are a valuable first assessment of the performance.

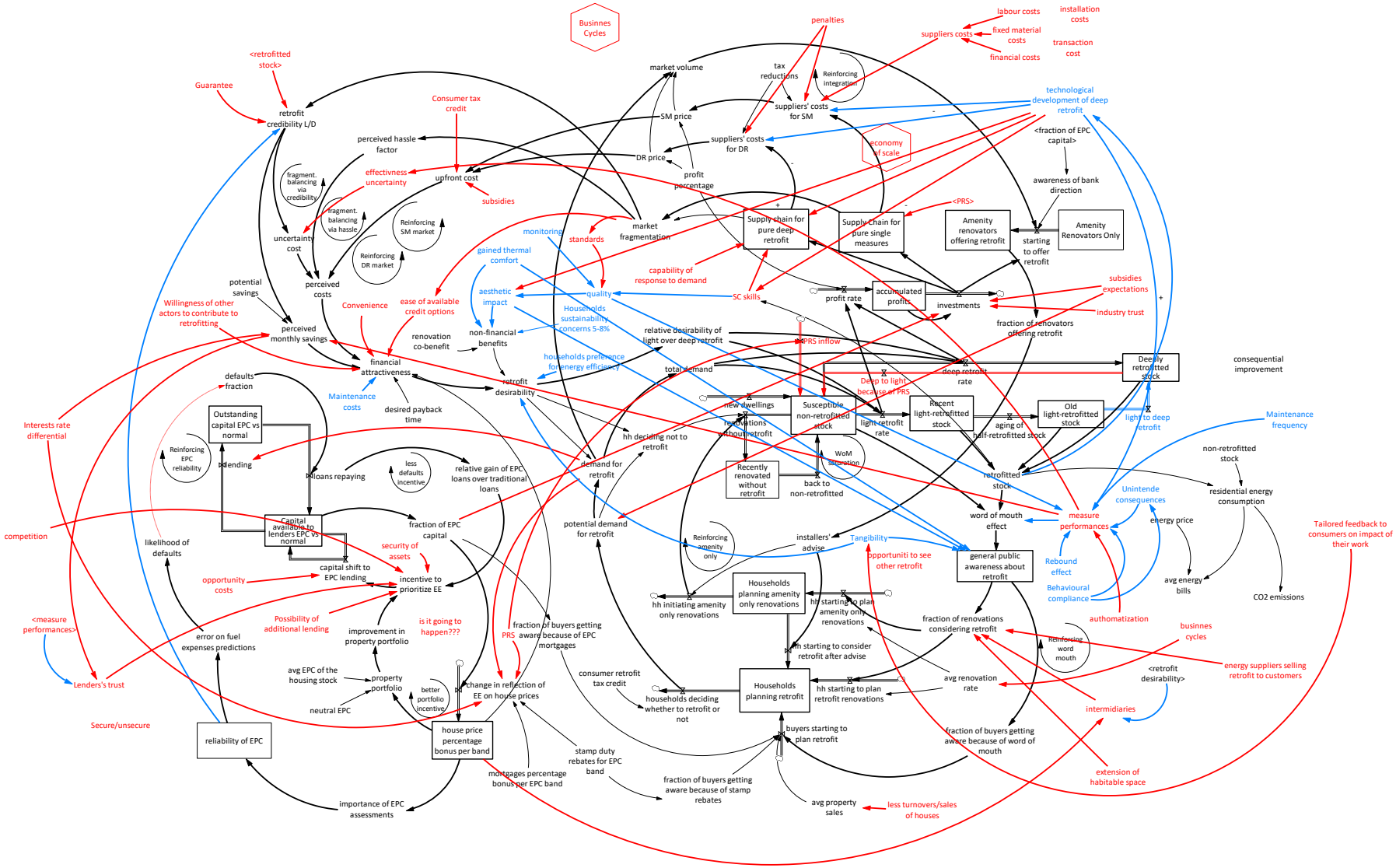


Figure 5-8: New Devil's Advocates impact. In black structure of at the beginning of the workshop, in red the addition made during the session and in blue the structure directly suggest by the Devil's Advocates

Source: conceived by the author

5.2.2. Participants' feedbacks

After the explanation of the new setting, all the participants welcomed positively the idea of having someone trying to act as some of the missing stakeholder. They motivated this favourable acceptance stating that it is good to have a challenge to their usual way of thinking.

When in the end the participants were asked about their experience with the DAs, they replied (Annex E):

"*As he said* [referring to one of the participant that in the beginning of the session expressed his positive opinion]*, it's good to have challenge and more input. I think it works well*."

In the same line another participant added:

"*For avoiding group thinking I think it's really important… Because we will all ultimately work together and work on* [inaudible] *it's good to have a challenge*."

Then the participants were asked how they felt during the process:

> "*I thought it was quite useful* [referring to the new DA], *just a different thought process*"
>
> "*Yeah, working in a different way*"

Lastly, when the researchers explicated them their initial worries on the effectiveness of the new setting and on their reactions to the inputs of someone external to the group, a participant said:

> "*You got trust* [to do this]"

In general, there were not negative comments about the new DA setting and the workshop attendants had a positive reaction to it. The participants liked the idea of having new perspectives that questioned their behaviour and helped to avoid group thinking. What is very interesting is the reason why participants said they were willing to be challenged with this original setting. They said that their reactions were positive because the research team gained trust before. This factor seems to be something important to not underestimate.

5.2.3. Facilitators' feedbacks

In the subsequent days after the session, interviews were performed with the two facilitators that executed the DA role during the workshop. Both reported they had good feelings during the session. They thought it went well and when they were asked whether they would consider using this new setting again if they found themselves in a similar 'cooker-pressure' situation, they responded affirmatively. Another aspect that was highlighted by both facilitators is the 'experience' required to perform the role. It means that according to them, more experience on the DA role can make the difference. This translates in the idea that if they have to play it again it would be much easier for them. However, they also reported some issues they faced. The

unexperienced facilitator found several times difficult to step in the conversation because she was not feeling completely comfortable to jump in the group discussion and because she was trying to formulate her intervention in the most consistent way with SD and this slowed her down. On the contrary, the other facilitator did not have this problem. As described above, the experienced PSDM practitioner mixed her DA role with the one of facilitator few times. When asked why she thought it happened she said in that precise moment she was not aware she was mixing up her DA role with the facilitation one and that she realized that few time after it happened, probably due to lack of experience abovementioned. However, both the behaviours were far from what stakeholders do. Certainly, they usually do not limit themselves if they do not elaborate their thoughts in the most consistent way with SD and they normally do not interfere with the facilitation process. Fortunately the DAs were two in the session so the experience facilitator were able to compensate for the lack of confidence of the other one and luckily the DA that could not resist to act as a normal facilitator, concentrated it at the end of the session when already most of the work was done. In this respect, it must be noted that it seemed that other participants did not notice that and gave importance to the fact. Concluding, the background and personality of the facilitators playing the DA appear to have a strong impact on the way the DA role is carried out. The more self-confident and PSDM experienced facilitator was more able to perform the role although she felt in the trap to use her expertise for helping the two actual facilitators during that workshop in a moment of difficulty. However, this idea needs to be taken with a grain of salt: these are the results of only the first case in which the new DA setting was applied, therefore it is too early to generalize. Lastly, the two actual facilitators debriefed the second workshop right after its conclusion and one of them wrote a short memo on the session following the guidelines of Miles, Huberman and Saldana, (2013) (Annex G). From these sources, overall, the new setting for the session was judged as positive. It did not create any conflict among the participants and the group dynamics were fluid, namely there was not any interruption of friction due to the DAs interventions. The DA did not appear to steer in any way the process with their rooted knowledge in SD. The other participants seemed to accept very well the idea of having two new 'experts' in the room. Moreover, the whole process seemed to be much more structured than the first session in which participants were more discussing among themselves with the use of the map than formulating variables. The reasons identified for this outcome were two. First, the two facilitators were more experienced with the group dynamics and more capable to manage and conduct the session in the right way. Second, the DAs provided to the other participants an example on how to suggest variables and links in a proper manner, ending up leading them by example. Unfortunately, also both the facilitators noted that few times the experience SD practitioner mixed her role of playing a stakeholder with the one of being a facilitator. However, it was perceived that it happened most in the end of the session, in a moment in which both the actual facilitators were struggling in attempt of depict in the map a concept arose by a participant and she helped in sorting out the problem. Complicity and teamwork among the whole research team were

appreciated and believed important to the good results of the workshop. Lastly, both of facilitators were satisfied with the 'quality' of the map resulting from the workshop.

5.2.4. Assessment with respect of the predicted risks

In Table 4-2 the possible risks the setting could have faced were reported. For each expected risk a mitigation strategy was defined. It is worth to assess if these accidents appeared in the session, whether the mitigation strategies were successful or not and if other elements played a role in that situation. Table 5-3 below, reports the results of this analysis. This assessment was done based on the participants' and facilitators feedbacks, workshop transcription and outcome map analysis. It is important for two main reasons. First, it provides an idea on the effectiveness of the mitigation strategy and second, it shows where efforts are needed for further improvements. Several ideas discussed in this paragraph will be recalled in the discussion section.

Table 5-3: New Devil's Advocate expected risks and mitigation strategies assessment

Expected risks	*Mitigation strategy*	*Outcomes*
Reaction of participants to the facilitator's loss of neutrality	Transparency from the beginning of the role of the DA	The risk did not lead to unfavourable situations and the mitigation strategy is thought to have contributed to that; the trust participants had in the research team helped
DA perceived credibility by other participants	All the issues the DA wants to raise are previously studied and documented (backed by sources) in the provided script	The risk did not lead to unfavourable situations in the workshop
DA steers the process	The other facilitators make sure the DA is not going to become a talking head or lead the group process	The risk did not lead to unfavourable situations in the workshop
Struggle for the DA to step in the discussion	DA should be self-confident and consider himself as much as possible as a participant	One out of two DAs faced this issue, the mitigation strategy did not work well enough
The facilitation team 'loses' one of the member and it can become more energy demanding for the other facilitators	Shorter workshop, more breaks (if needed), different structure than the usual one in which the participants are more active (e.g. table top modelling)	The actual facilitators at the end of the session were relatively tired and this may have contributed to the issues that pushed the experienced practitioner playing the DA to help them in the last part of the workshop
Confusion of the DA in his role between being a participant and a facilitator. The facilitator will act as a DA only during a workshop some structures suggested by him might be integrated in the model in that session and then proposed to be left out in a later session	Once the role game of the DA is over, the DA assumes back the role of facilitator and therefore he is neutral with respect of the content; he may just ask the participants to explain why and let them to decide.	The DA was performed in the last participatory session and therefore this risk could not be 'experienced'
DA behaves like a facilitator	If, in addition to play his role, the DA absentmindedly acts a facilitator (e.g. after speaking they give instructions, as "*it is your turn to speak*", that are usually given by the facilitator), the actual facilitator should politely interrupt him, get the control back and remember him his role of DA.	The mitigation strategy did not work perfectly since one DA acted as a facilitator in some moments

Source: compiled and conceived by the author

5.2.5. A comparison with Gerrits & Vaandrager (2017)

Comparing the results of the new DA setting with the approach used by Gerrits and Vaandrager (2017) described the method chapter is interesting. Both the research teams tried new techniques to overcome homogeneity in the participants group. The projects' settings and structures were almost the same: preliminary contacts with gatekeepers, two workshops and a follow-up for sharing the results. In addition, the environments in which the studies took place were very similar: while this research collaborated with policymakers in a British Department, Gerrits and Vaandrager did the same with policymakers in a Dutch municipality. On top of that, both the participants were under huge time pressure. Although there were so many similarities, the results of the two projects are the opposite. The 'adventure' of Gerrits and Vaandrager had a negative outcome and the collaboration between researchers and organization ended. Contrarily, this study was successful and set the ground for future fruitful cooperations between the two partners. In the light of the new experience gained on pressure-cooker PSMD by the use of the new DA setting, it is interesting to relook at the attempt of Gerrits and Vaandrager: how did it come that the two approaches leaded to such contrasting outcomes?

The insufficient results obtained by Gerrits and Vaandrager can clearly be ascribed to the poor script design. The most critical part of their technique can be identified in the request made to the participants to perform interviews with people outside the organization between the two workshops and create maps out of these interviews. The task was carried out by very few participants and besides that the quality of these ones was extremely low and not usable to start the discussion in the next session. But the real point still not been discussed is how two expert practitioners, such as Gerrits and Vaandrager, failed to actuate a script that on paper in the preparation stage seemed to work (their participants expressed the willingness to gain some system thinking skills and letting them practicing through mapping interviews seemed a good idea). The response in this question could be that they missed to take into account and assess the '*group life*' (Phillips & Phillips, 1993). Groups are not just a sum of people, there are entities *per se* with their own emotional life, constrains, attitudes and influences. From this perspective, they made two mistakes: one from a practical and one from a pragmatic point of view. From the practical side it was not optimal to ask to a group that is already under time pressure to spend some extra time, in addition to the one allocated for the workshops, to perform interviews and mapping. If participants are already experiencing lack of time, asking them time-consuming activities can be harmful. Most probably, they will not do the task, if they perform the assignment the results are likely to be poor and even if they carry the task in a satisfactory way they won't be very happy for all the stress they have been exposed to. All these clearly are negative outcomes for a PSDM project. Second, from a pragmatic perspective they underestimated the initial skepticism that there was in the group towards the facilitators and the methodology. To perform the type of activity Gerrits and Vaandrager designed a lot of 'support' and 'trust' are required. Participants need to be open to, supportive to and curious

about the tasks they are asked to do during a project. To reach that group emotional stage it takes time. A PSDM project, although compressed, is a common journey that participants and facilitators undertake together through which a relationship is constructed (Campbell, 2001). It is similar to every human relationship: to trust, respect and align the point of view with someone takes time, you do not rely too much in someone you perceived as a stranger. With groups, it is the same. Skepticism, lack of support and trust towards the methodology is common at the beginning of every project. However, after a solid relationship is built between the different actors in the room, performing tasks, even if original, is much easier. To get to that point it takes time and it requires facilitators ability to understand the group life. Actually understanding the group life is one of the main tasks of facilitator: "*to understand the group the facilitator observes verbal and non-verbal behaviour, attends to relationships between participants and maintains awareness of his or her own feelings*" (Phillips & Phillips, 1993). Gerrits and Vaandrager did not understand the group and its lack of confidence and involvement in PSDM, and this translated in them asking the participants to perform extra work for a project that they were not confident with. It is not very surprising it did not work. Therefore understanding the group life seems to be crucial in a PSDM. It is not compelling only for the activities that facilitators do with the group during the sessions but also for the preparation of the workshops. This is true because it helps to tailor the session structure to the group's real needs, and it appears to be even more crucial when developing new approaches, scripts, techniques and settings for PSDM.

The facilitators' group life lack of understanding can be a possible partial explanation for such different outcomes. However, there could be more. So far, it has been assumed that the contexts in which the project took place were almost equal. Although many characteristics were equal (dealing with policymakers under time pressure in a homogenous context), there is still an important feature that was different: the cultural environment. Gerrits and Vaandrager did not described in detail this aspect in their article. However, it is possible to imagine how working with policymakers from a Dutch municipality and from a British department is different. The participants from BEIS were very eager to improve their understanding, to acquire new knowledge and to be challenged. This translated in them to be open to all the inputs and challenges facilitators posed to them. This provided a fertile ground for trying a new approach. Instead, Gerrits and Vaandrager may have faced a different cultural context that undermined their attempt.

5.2.6. New Devil's Advocate setting limitations

The new DA setting has inevitably multiple limitations or still unanswered questions that may impede its applications. First of all, as all PSDM practices it is heavily context dependent (Gerrits & Vaandrager, 2017). Exact replication of the contexts only works in lab settings: closed and decontextualized environments. This because it is almost impossible to replicate for complex social situations such as PSDM (Gerrits & Vaandrager, 2017). Therefore, it is really difficult to state whether the new DA setting worked well because of its intrinsic good structure or because of it was tried in very favourable environment. Moreover, the selection of the

inputs provided to the DAs in the script before the session (see Annex D) was not thoroughly systematic. From this angle, there were two main weaknesses. Firstly, the stakeholders that needed to be represented somehow in the workshops were selected among the one mentioned during the first workshop by participants. Although this decision offers a certain solidity (these stakeholders have been chosen based on the knowledge of experts), it is impossible to state that the whole range of stakeholder have been at least considered. It is still possible that during the first workshop the participants did not mention some important players. The second weakness regards the way information about stakeholders have been collected and categorized. As said, interviews with experts and stakeholders and a scientific and grey literature analysis have been performed. However, it is impossible to determine whether and when all the issues that are important for stakeholder have been included. Moreover, the way this information are categorized in the script is still completely up to the facilitators preparing the role. Another limitation regards the freedom left to the facilitator playing the DA. As we saw in the extremely different performance of the DA1 and DA2, personal factors, such as background and personality, can affect the way the role is played. Although backed and sounded guidelines on stakeholders interests and suggestions on how to share these ideas with the group are provided in the script, ultimately how to intervene and the content of the intervention is completely left to the 'will' of the DA. Therefore, the choice of who plays the role is a very sensitive issue, because a DA interpreting the role in the wrong way can have no impact in the model (e.g. too shy to intervene during group discussion or to raise any issue) or even a negative one (e.g. if DA intervention harm the group dynamics or if the content of the interventions is wrong and unreal). At the moment, the selection is recommended on the background, self-confidence, interpersonal skills and capacity of adaptation of the facilitator, but analysis of the skills needed to be a good DA could improve this process. Lastly, the originality of the approach is one of the strengths but also a weakness. To assess correctly and understand better how this setting works, more analysis are needed. Now these are not there yet, therefore many ideas are still at a preliminary stage.

5.2.7. Bringing together the results on the New Devil's Advocate setting

From all the perspectives of analysis the DA shows overall positive results. It had a remarkable impact on the workshop map and it did not have any detected side effect on the participants, rather they accepted the idea of 'being challenged' for the outcome sake very favourably. The loss of neutrality of someone that was previously a facilitator was not perceived as a problem. Moreover, it seems it served the purpose of being a 'knowledge brokerage' between the workshop participants and the stakeholders that could not attend the session. The feeling among the research team was that the issue of homogeneity was partially overcome.

However, in this facilitated setting the importance of the 'human' component in the facilitation team is even higher than the usual. First, the personality of the DA affects how the two facilitators played the role: the more experienced one (assumed to be self-confident in a PSDM workshop) performed dramatically better

than the inexperienced one (that stated to feel somehow 'shy' with respect of the group). In this respect, in our experiment having two DAs made possible that one compensated for the lack of the other. Second, the importance of teamwork among facilitators has not been stressed properly yet. Teamwork was necessary during the preparation phase (working together in developing the DA setting), in the selection of the roles (how the different roles were assigned), in the workshop conduction (need of 'complicity' and 'harmony' in the facilitation team) and in the unusual interactions during the session (facilitators playing the DAs had new relationships with their facilitator colleagues compared to the usual ones). However, this topic is not new in PSDM literature. Richardson and Andersen (1995) already highlighted the importance of teamwork in facilitated SD. Nevertheless, sometimes practitioners forget this aspect but this new setting proved even more the prominence of teamwork in PSDM. Another factor that emerged as crucial is the facilitators ability to understand the 'group life' they are working with (Phillips & Phillips, 1993a). This skill was necessary to develop this new approach and suited it to the participants needs. It could be one of the reasons why the attempt of Gerrits and Vaandrager (2017) failed, while the one used in this study succeeded. More in general, understanding the 'group life' (mood, necessities, feelings, etc.) seems to be important for every PSDM but a minimum requirement to whom want to perform original settings, scripts or unorthodox variations from the traditional approach. However, excluding the cultural context as an important aspect could be misleading: it was not possible to determine whether the new DA setting worked well just because of its good design or because the environment in which it was 'played' was favourable. A side outcome that arose from the employment of the setting was that the workshop discussion among the participants became more structured than it was in the previous session. It seems that the DAs showed to the other participants how to properly formulate variables and express their concepts in order to include them in the map. This could be one of the future applications of the approach: guiding 'undisciplined' PSDM groups to adopt more productive ways to discuss and to relate to the task they are working on.

Nevertheless, there is one last aspect that needs to be highlighted and discussed. The DAs have a broad freedom during the session and most of their decision are left to their judgment. Although they may have tent to follow very carefully the script they were provided it is reasonable to assume that to a certain degree, even unwillingly, they might have expressed also personal opinions (it is impossible not to give a personal contribution playing this role, for instance the way the issues are raised already contains some personal influences). In this respect, it is difficult to clearly state and separate how much of the DAs contribution was depending on the DAs personal opinion and on the inputs belonging to the missing stakeholders written in the script. Therefore, it would be more precise to affirm that the DAs in the new setting work first as an asynchronous knowledge broker between the participants and the missing stakeholders, but also, to some extent, as a way for facilitators to express their opinion on the content under discussion in the workshop.

5.3. Model based policies' analysis

A picture of the final model has been reported in Fig 5- 7 before. As said the model is composed of more than 3000 symbols and takes into account five different energy efficiency measures that were considered as sensitive by BEIS: condensing boiler, double-glazing, loft, solid and cavity wall insulation. It simulates the uptake of these measures between 2000 and 2050 and, at present, the model produces relevant outputs. In this section, the main model dynamics, the insights gained on the homeowner retrofit uptake and on the policies under analysis are discussed.

5.3.1. Model validation

Before looking at the insights gained through the model, it is important to discuss how much the model can be trusted. In other words, to what extent it can be considered as a reliable representation of reality. In SD, models do not aim to claim to be true because all models are to some extent 'wrong' (Sterman, 2002) since they are "*limited, simplified representation of the real word* [and] *they differ from reality in ways large and small, infinite in number*" (Sterman, 2000, p. 846). Therefore "*no models are valid or verifiable in the sense of establishing their truth*" (Sterman, 2000, p. 890) but the question modelers need to answer is "*never whether a model is true but whether it is useful*" (Sterman, 2000, p. 890). In this perspective model validity is strictly related to the model purpose (Barlas & Carpenter, 1990). Consequently validation is a formal/objective and semi-formal/subjective activity that aims to build confidence on the usefulness of the model with respect of its purpose (Barlas, 1996). As Barlas (1996) recognizes, although model validation is typically and technically defined to be conduct after model construction, in practice it has a "distributed and prolonged" (Barlas, 1996, p. 184) nature and it exists in every phase of the methodology. This was the approach adopted for the validation of the model built in this research. The structural validity (Barlas, 1996) has been evaluated through extreme condition tests (Barlas, 1996; Sterman, 2000), unit consistency (Barlas, 1996; Sterman, 2000), constants and parameters assessment through use of expert opinion and literature (Sterman, 2000); 'walkthroughs' (Barlas, 1996) and reviews of the structure with experts (Barlas, 1996) while model behaviour validity has been assessed mainly in two different way. First, stress tests in which parameters were set to extreme values to check the reasonability of the behavioural outputs, have been performed. Second, the model replicates quite well six different reference modes. It reproduces the uptake of the five considered measures (Fig 5- 10 and Fig 5-12) and the decrease over time in the average households energy consumption (Fig 5-11). These figures are discussed in detail in the next sections. However, the fact that the model replicate the behaviour of several variables in different sectors of the model can be considered as a good sign of the reliability of the outputs.

Moreover, the stock and flow model has been drawn upon knowledge of subject-experts in BEIS and this fact may increase even further the model's reliability. In addition, the five interviews performed with experts in

BEIS during the last part of the project supported the validation process and help to increase the confidence in the model even further. On top of that, the fact the model has been built in joint collaboration with subject-experts provides a preliminary assessment of the model boundaries adequacy (Sterman, 2000). Following Sterman (2000) and Sterman & Rahmandad, (2012), model documentation is provided in Annex H.

5.3.2. Main dynamics

The model structure can help to understand what the main dynamics involved in the UK homeowner retrofit uptake rate are. However, looking at the model in its entirety may prevent the reader to capture what the pivotal loops and interactions are. This is mostly due to the model large size and its consequent difficult analysis. Therefore, the main dynamics have been portrayed in simplified a CLD visible in Fig 5-9 (side note, this CLD was the one provided to the follow-up participants).

Seven crucial loops have been identified. The loop named R1 represents the fact that the more retrofit measures are installed, the more they become popular because of a raise in retrofit awareness. It can be considered a word of mouth effect. However, it is necessary to specify that, although similar, the concepts of awareness and popularity are different. *Awareness of retrofit* refers the degree to which homeowners know the existence of a retrofit measure. Instead, *measures popularity* is a step beyond awareness. Popularity merges the concepts of awareness with the one of positive or negative opinion because homeowners aware of retrofit may have a good or bad consideration about it. In case there is awareness and a good opinion about a measure, it is possible to say that it is popular. Consequently, the increase in measures popularity pushes more households that are already undertaking other renovations in their property to consider topping up these interventions with retrofit measures leading to a raise in the retrofit demand and uptake rate. *Visibility* is different for every measure and this determines different 'speeds' of this loop per each retrofit type. For example, double-glazing and boilers have a great visibility since their position in the edifice make them easily noticeable and, moreover, they are one the first things people look at in a property. On the contrary, cavity wall and solid wall insulation have a low visibility due to physical (they are embedded and hidden in the walls) and behavioural (people tend to overlook at them when examining a property) reasons. *Renovation rate* represents the number of generic renovations that are done over time in the UK. *Measure affordability* relates to the costs of a measure. The higher the upfront cost of installing a measure is, the lower the demand for that measure is because, obviously, less people can afford to pay for it. The costs range of the five measures considered is quite high. To give an idea, a solid wall insulation can cost on average around 12000£, cavity wall and loft insulation approximately 500£ while condensing boilers and double-glazing costs on average around 4000£ (although the cost of double-glazing depends most on the number of windows to install).

Balancing loop B1 represents the potential retrofit measures to install. This means that it not possible to install more energy efficiency measures than the potential available in the UK housing stock and that, therefore, there is a natural limit to the retrofit uptake. Another limiting factor to the uptake rate is the *supply chain size.* The supply chain needs to sustain the demand for retrofit. Namely, the supply chain must be developed enough in order to meet the demand, otherwise, the demand remain unsatisfied. However, it must be noted that there is a positive connection between *retrofit measures demand* and *supply chain size*: when the demand for retrofit increases, the supply chain tends to increase, namely more companies become available to do retrofit installments, because they see new opportunities for profits.

Reinforcing loop R2 portrays a mechanism through which a retrofit measure becomes perceived among the population as something that adds value to the property, not just as a way to decrease the house energy consumption. This depends on the measure popularity, and it influences the number of *renovators doing retrofit as amenity renovation* and consequently it raises the demand for retrofit, closing the feedback loop. The key idea here is that when a measure gets popular, households begin to consider more that retrofit type when they evaluate a property. This raise in the importance given by the households translates in an increase in the perceived benefits added to the home by that specific retrofit measure, making it worth installing besides energy efficiency consideration. Therefore, it is not just an efficiency improvement to top up on an amenity renovation anymore, but it becomes an amenity renovation itself (called retrofit as amenity), that adds value to the house.

Similarly, in R3, *measures popularity* has been recognize also for having a positive effect on the *non-financial attractiveness* of the retrofit measures. The non-financial attractiveness of a measure is a variable that takes into account the intrinsic 'appeal' a retrofit intervention has. It incorporates the *measure aesthetics value*, the thermal comfort, etc. It is not only composed by 'positive factors'. In this case, they are integrated in the *measure hassle factor* and it represents the hassles involved in the installation phases (e.g. disruption, time and effort needed, paperwork, etc.). This factor has a negative impact on the non-financial attractiveness and it decreases its value. The *non-financial attractiveness* is then combined with the *financial attractiveness (*namely, how much the ratio between *perceived savings by measure* and *measure upfront costs* is appealing) to define the *measure desirability.* This directly and positively influences the demand for that measure: the more desirable it is, because of non-financial and financial considerations, the more homeowners will go for it. In this respect, *retrofit affordability* plays a key role. *Retrofit affordability* refers to the extent households can afford to pay for a specific measure, for instance a very expensive instalment has low affordability while relatively cheap ones have high affordability. It works as a funnel to retrofit desirability, since even if a measure is judged as desired by homeowners, they will not go for it if they can not afford to pay for. As said, the loop is closed because it has been found that the *measure popularity* positively affects the *non-financial attractiveness*. This is because the more popular a measure is, the more its non-financial features are

perceived and acknowledged by homeowners. This mechanism is very similar to the one in R2, the only difference is that it affects different households' decision point.

The *measure aesthetics value* is a dependant variable. It is influenced by the *supply chain investments in technology* because technological progresses have been found to be also focused to increase the aesthetics of retrofit measures. Since the investments depends overall on the *supply chain size,* the positive feedback loop R4 is closed. A dotted arrow has been drawn between *supply chain investments in technology* and *measure upfront costs*. This because technological improvements can decrease the cost of a measure, however this effect, although identified by workshop participants, seems to have almost no impact on the system so far.

Reinforcing loop R5 reflects the fact that a bigger supply chain can invest more in training and therefore have skilled workers that make good quality installations. This is important because poor quality installations deliver lower savings on the energy bill than what the ones promised 'on paper'. On the contrary, high quality job ends to positively impact the homeowners' perceived savings and so the financial attractiveness, closing a positive loop.

The *quality of installations* has a positive effect also on measure popularity. An installation of a retrofit measure that is not properly done, can generate unintended consequences or be aesthetically not similar to what homeowners expected. Therefore, the opinion of the households becomes adverse and the popularity is negatively affected by that. Contrarily, a well done job tends to increase the *measure popularity*. This is the underlying logic behind reinforcing loop R6.

Lastly, red arrows represent where the two financial polices assessed, stamp duty rebate and green mortgage premium for energy efficiency, are going to affect the system: they are supposed to economically support buyers, thus increase the measures' affordability, and to stimulate the market in evaluating more energy efficiency.

This is an aggregated depiction of the main dynamics in a very large model. This representation is useful because it helps to understand what the interrelations involved in the homeowner retrofit uptake system are. However, many loops have been left out for the sake of simplicity. This is the reason why in this simplified CLD the vast majority of the loops is reinforcing. Many balancing loops are present in the complete version of the model and have the function of limiting the uptake rate to the actual potential.

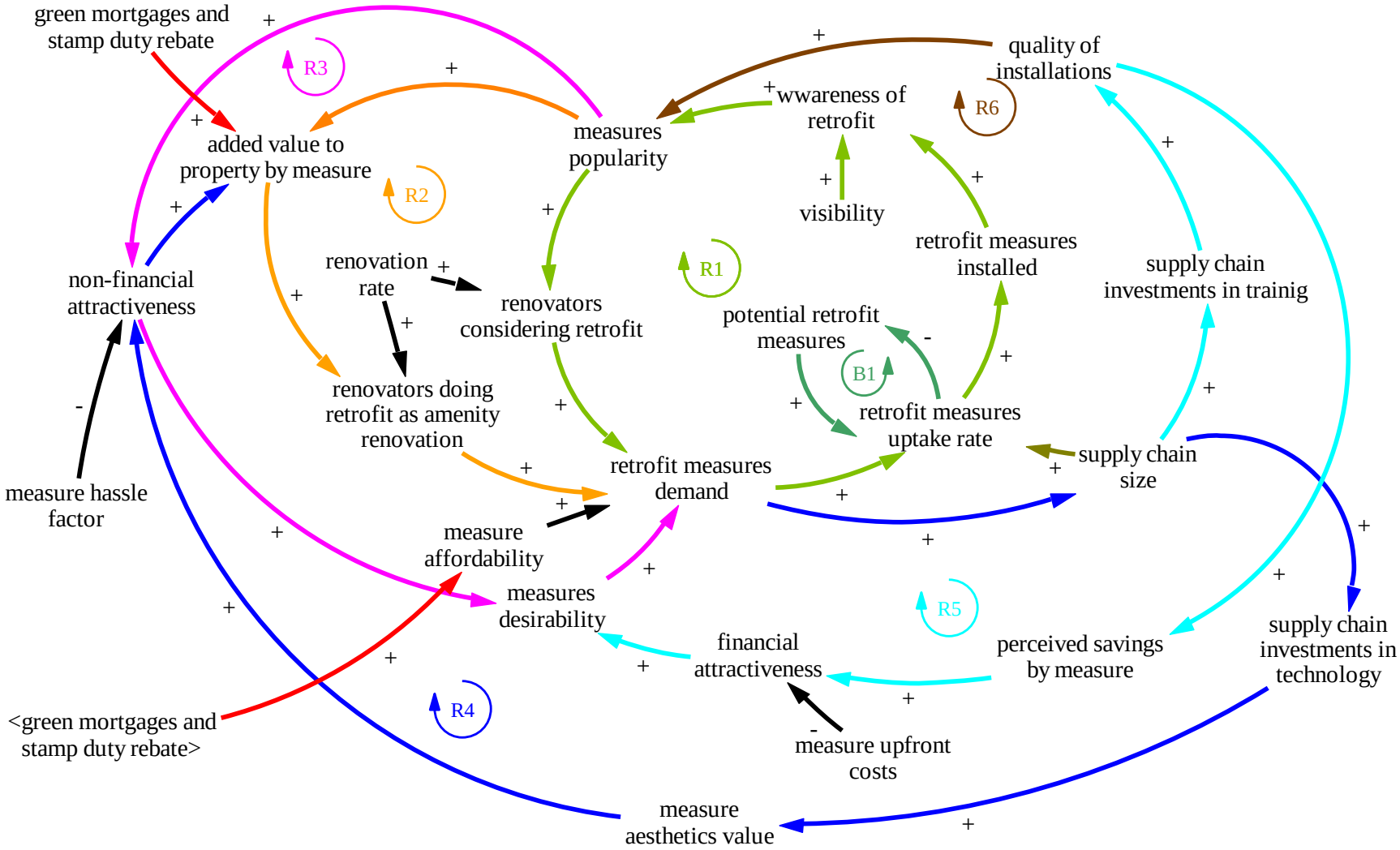


Figure 5-9: UK homeowners' retrofit uptake simplified Causal Loop Diagram. In light green R1, dark green B1, orange R2, violet R3 blue R4, light blue R5, brown R6, black parameters and red policies

Source: conceived by the author

5.3.3. Base run and future trends

Firstly, in Fig 5-10 the baseline simulations report the total measures installed for double-glazing, condensing boiler, loft and cavity wall insulation between 2000 and 2050. These runs assume current polices (see ECO subsidies) to remain in place. The model captures the homeowner decision process in which retrofit measures' affordability and desirability are dependent on the upfront cost, with the subsidies depicted as discounts on these costs. That is the way EEC, CERT and ECO subsidies are portrayed in the model. The Green Deal policy has been left out because of the low impact on the system. Moreover, the model structure simulates also the compulsory regulation from 2005 regarding boilers replacement with new efficient ones (condensing boilers). The growth trends relate to the accumulations of the measures installed. As show in the previous paragraph, there are numerous reinforcing loops driving the system to grow. Nevertheless, this growth 'naturally' slows down as the market approaches its saturation (balancing loop B1). For the initial period of the simulation it is possible to compare the model runs (thin black line) with the historical data (thick red line) in order to assess the model reliability. The historical data has been taken from Palmer and Cooper (2013).

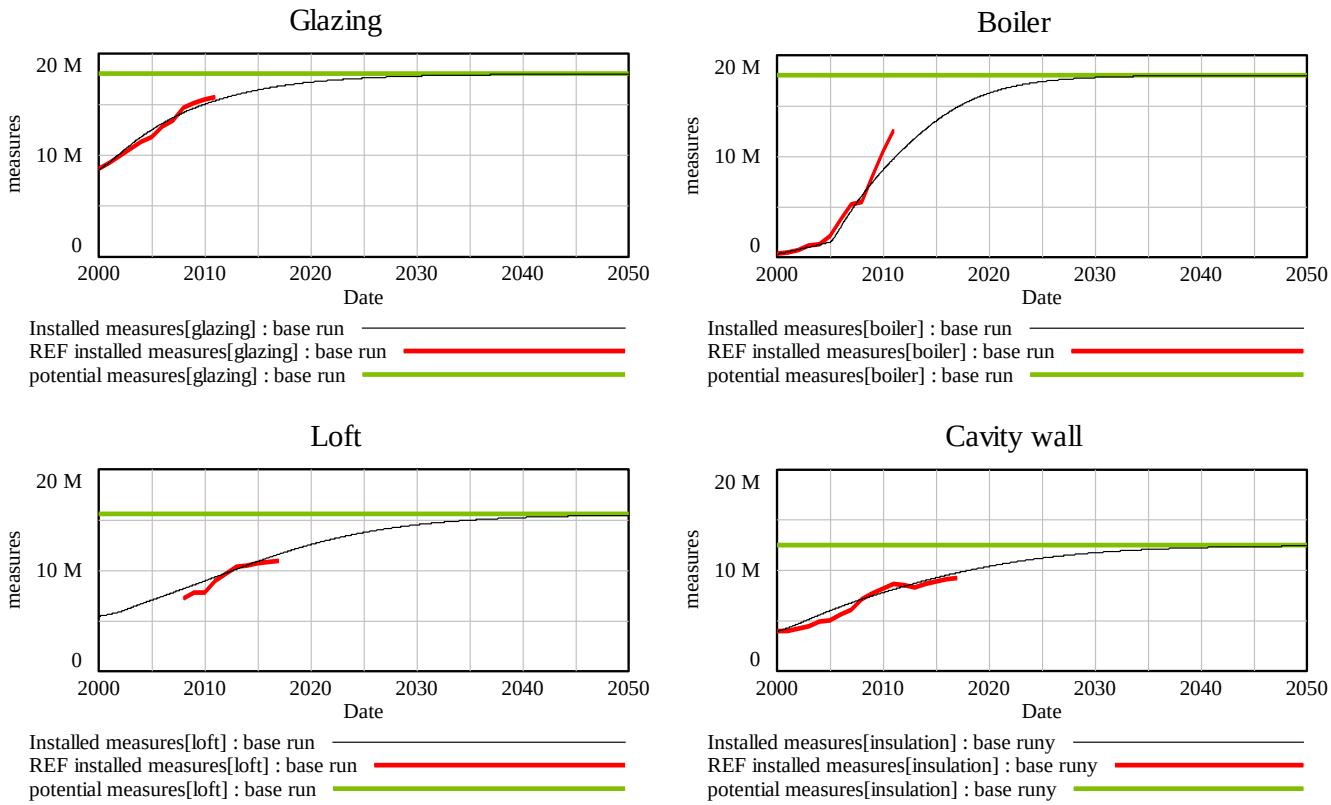


Figure 5-10: Stock and Flow model baseline run. Clockwise starting from top-left: double-glazing, loft, boiler and cavity wall. The graphs show the cumulative number of measures installed for each category in the baseline scenario. The light green line indicates the (target) potential measures to be installed, the red line represents historical reference data and the thin black line shows the simulation output

Source: conceived by the author

As figure 5-10 shows, the model runs match relatively well the reference data, thus increasing the confidence in model validity. Double-glazing curve is boosting even without the support of any policy effort and, from the model, it seems it will reach the maximum potential diffusion in the UK way before 2050. Condensing boiler uptake was heavily affected by the compulsory regulation approved in 2005. The impact is clearly visible on the slope of the curve that suddenly increases in that year. This situation seems to ensure that efficient boilers will get to their potential in time for helping the UK to meet its pledges. With respect of loft and cavity wall insulation, their curves appear to have a lower inclination than the other two. Nonetheless, they still seem adequate to reach the target in a reasonable amount of time.

It is worth looking at the monthly average energy consumption per households (Fig 5-11). Also in this case the model is able to produce outputs (thin black line) that match acceptably the historical data (thick red line), although the model captures only the general trend and not the reference model oscillations. Despite the decrease in energy consumption is depending not only on retrofit uptake but also on a multiplicity of reasons (e.g. increase in energy price, better appliances, etc.), it provides extra confidence in the model validity and quality. However, after 2015 the decrease in energy consumption is completely dependent on the retrofit uptake since the other factors do not vary anymore. Looking at the future trend, it is visible that energy consumption still decreases but with a lower steepness.

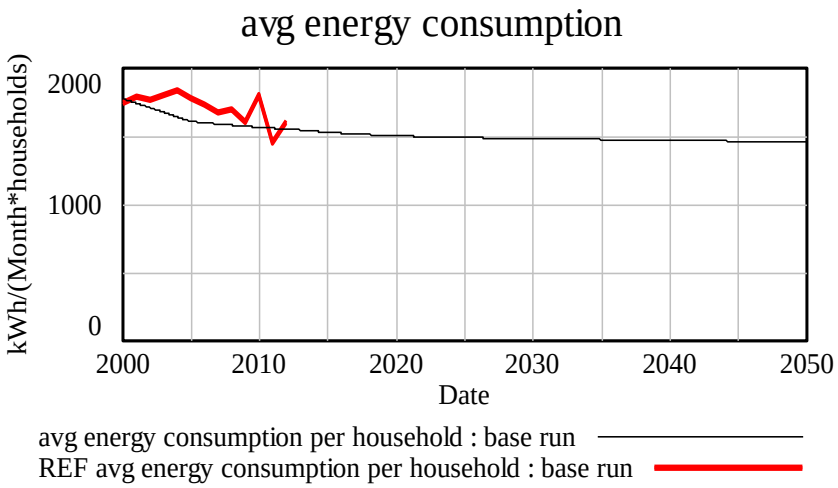


Figure 5-11: Baseline run average households energy consumption.

Source: conceived by the author

What is missing in the discussion is the retrofit uptake of solid wall insulation. Also in this situation the base runs depict adequately the reference mode (Fig 5-12). However, the trend clearly appears to be problematic and way below the potential (target), especially if compared with the others' measures. The reasons for this situation have been identified in the high upfront costs compared to the energy savings it delivers (long payback time), in the massive disruption involved during the installation (elevate hassle factor) and in the

low non-financial attractiveness (the measure is not perceived as something that may improve the aesthetics of the house).

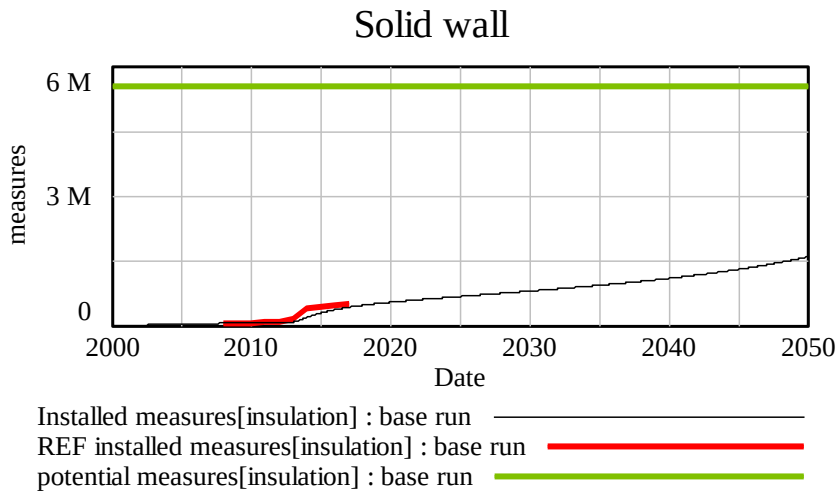


Figure 5-12: Solid wall cumulative uptake in the baseline scenario. The light green line indicates the (target) potential measures to be installed, the red line represents historical reference data and the thin black line shows the simulation output

Source: conceived by the author

Hereinafter the analysis will focus on the solid wall insulation uptake rate since the other four measures (double-glazing, condensing boilers, cavity and loft insulation) seem to be already in good track.

5.3.4. Impact of subsidies

Before looking at the impact of new policies, it is important to assess the effects of the previous ones. From the model it quite definitely emerges that subsidies mechanisms had a significant impact on the homeowners retrofit uptake. This can be seen in the Fig 5-13. It reports the base simulation in which subsidies are in place (thin black line), a scenario in which current policies are interrupted in 2017 (purple line) and a run in which it is portrayed what would have been likely to happen if these policies had never been implemented (orange line). From the graph, it is clearly visible that the slopes of the three curves are completely different, and this means that subsidies dramatically changed the number of solid wall measures installed. Nevertheless, their effect does not appear to be strong enough to assure the uptake rate of solid wall insulation sufficiently increases to reach the targets by 2050.

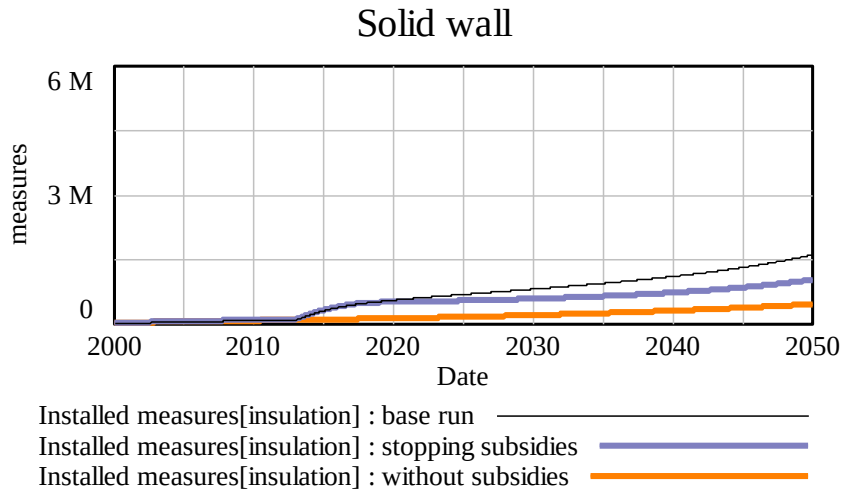


Figure 5-13: Solid wall cumulative uptake for subsidies different scenarios: base run with subsidies (thin black), scenario in which subsidies are stopped (purple) and have never been implemented (orange)

Source: conceived by the author

5.3.5. Mortgage policy and stamp duty policy impacts

Fig 5-14 reports model runs with the introduction of the green mortgage, policy while Fig 5-15 shows simulations with the addition of a stamp duty rebate. As mentioned above the focus is only on solid wall since the other measures are much closer to the targets and already affordable by the vast majority of homeowners. It appears clear that both the policies do not seem to have a remarkable impact. It needs to be specified that the reason why the two graphs look very similar is because both the policies depend on the initial potential demand for retrofit from house buyers, which is identical for both of them.

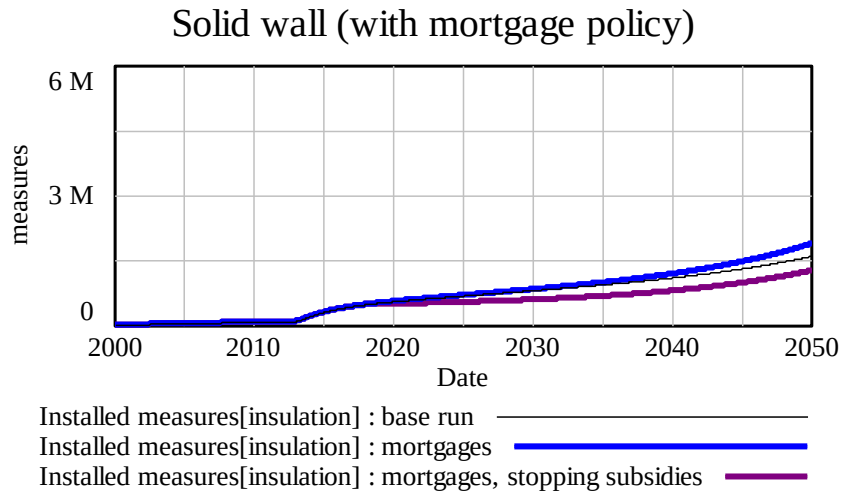


Figure 5-14: Solid wall cumulative uptake for different policy scenarios: base run (thin black), mortgages policy with current subsidies (blue) and mortgages policy without subsidies (violet).

Source: conceived by the author

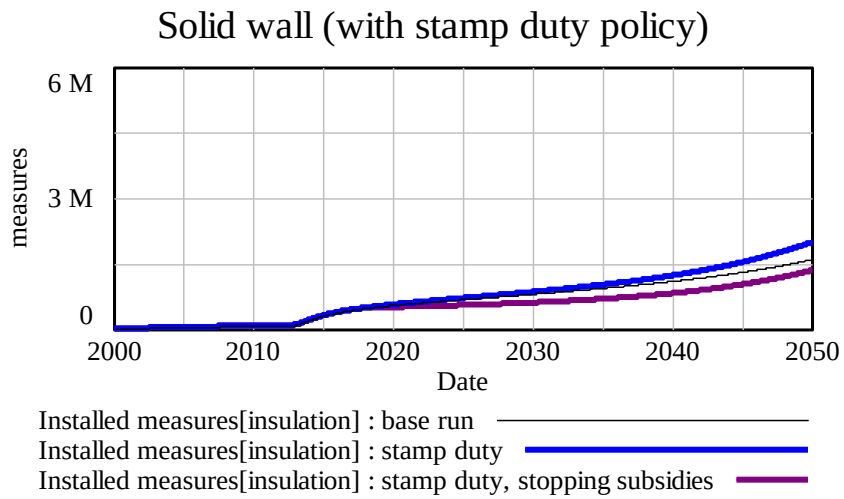


Figure 5-15: Solid wall cumulative uptake for different policy combination scenarios: base run (thin black), stamp duty rebates with current subsidies (blue) and stamp duty rebates without subsidies (violet).

Source: conceived by the author

The motive for the scarce effect of the policies to a conspicuous degree relates to the small size of the demand from households who are buying a house (red line in Fig 5-16) compared to the demand from those who start to plan renovations (blue line in Fig 5-16). Renovations are almost ten times more recurrent than property purchases. The reader should not be fooled by the overall demand decrease. It happens because this graph combines all five measures, including those that are reaching their potential. So the more a measure closes the gap, the less instalments are done due to the saturation effect.

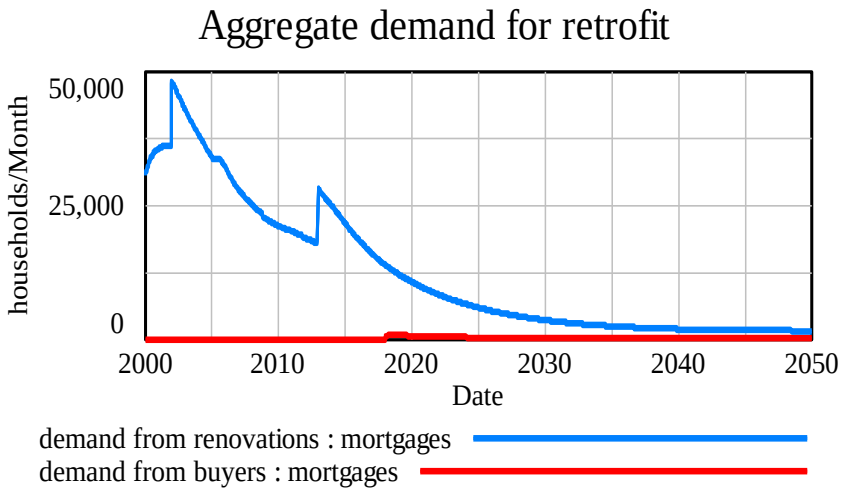


Figure 5-16: Number of households installing retrofit measures every month. The blue line describes those households who retrofit during their renovations, the red line those who retrofit when buying a new house

Source: conceived by the author

The reasons why the policies have a tiny impact on the system do not only reside in the small demand of households buying a house. On top of that, for buyers getting to the point of retrofitting their new property

takes many steps, each of which constitutes a cut in the initial potential flow. Fig 5-17 compares the 'cutting phases' of homeowners starting a renovation and ending up retrofitting their property (above) with house buyers that finish to eventually improving their new dwelling (below).

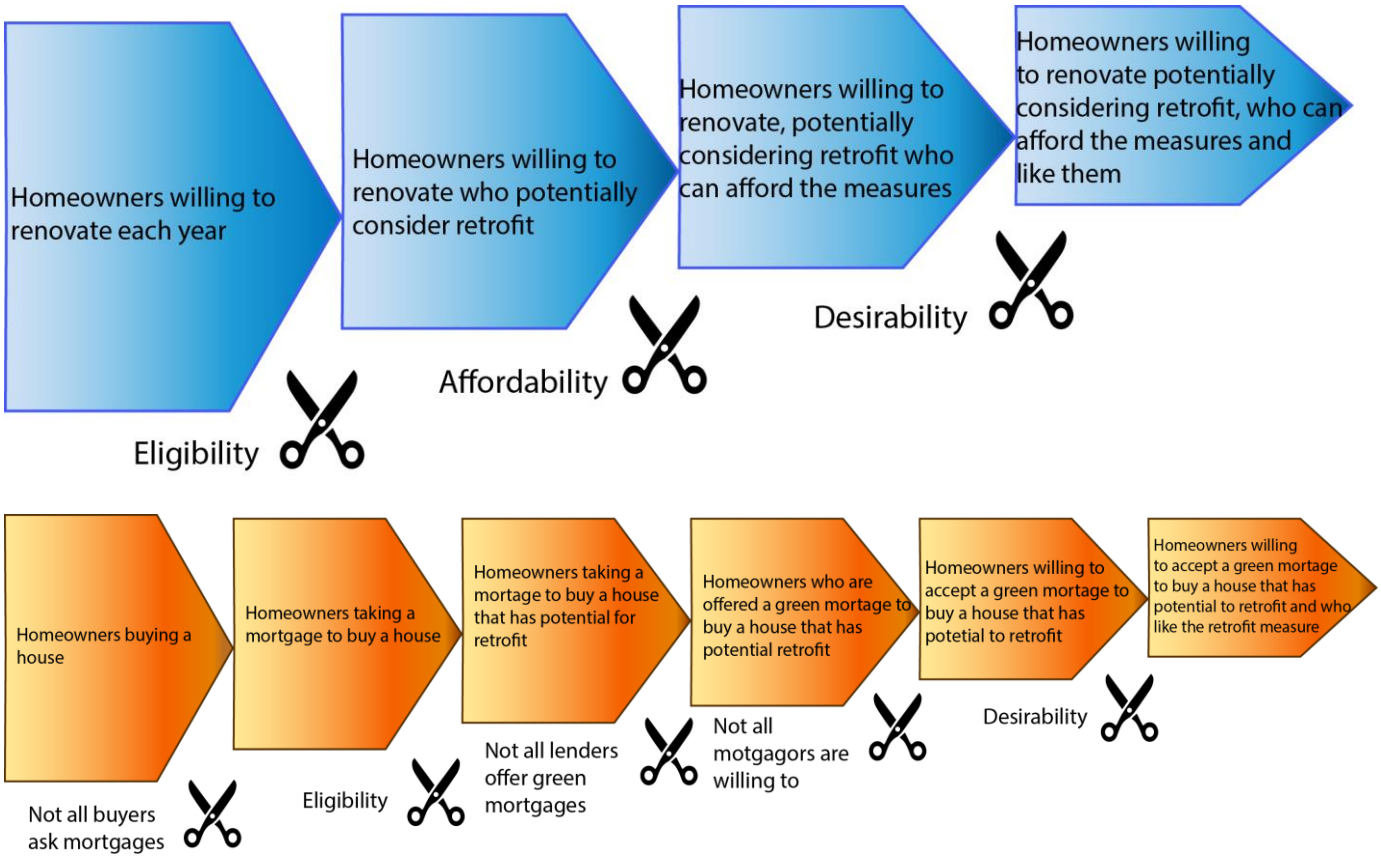


Figure 5-17: Renovators (above) and buyer (below) cutting phases

Source: conceived by the author

Even if it is assumed an optimistic scenario for the mortgage policy in which both lenders' and mortgage takers' are willing to engage with green mortgages, there are still other conditions that need to be overcome before retrofit: eligibility (it relates to the saturation effect, namely not all of them are buying houses where the measure has still to be installed) and desirability.

5.3.6. The importance of the amenity renovations mechanism

The analysis of the model has highlighted an important aspect related to the homeowners retrofit uptake. The demand for retrofit deriving from renovations has two origins. The first refers to homeowners starting a renovation for generic reasons (such as amelioration of kitchen and bathroom) but ending up also considering retrofit measures (due to word of mouth effect). Instead, the second source, called 'retrofit as amenity', refers to households who consider retrofit measures from the very beginning due to their desirability. The principal difference in these two types of demand lies in the budget homeowners allocate to retrofit. In the first case, retrofit is a top-up, and because of this the budget is restricted, while in the

'retrofit as amenity' situation, the uptake depends on the desirability without a similar constraint on the investment. In practice in the first process, households are willing to consider to spend an extra, estimated in the 10% of the expenditure for the generic renovation they are undertaking (Energy Saving Trust, 2011), while in the second case, since the purpose of renovation is the retrofit itself, the homeowners do not have particular constraints because all the investment they make is for that measure. A vivid example of this retrofit as amenity mechanism is the double-glazing uptake in which only the first type of demand would not explain the uptake trends (Fig 5-18).

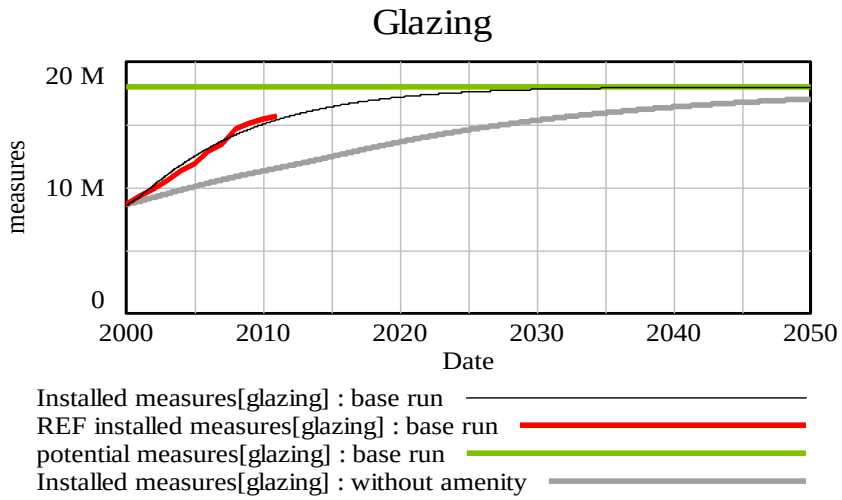


Figure 5-18: Double-glazing cumulative uptake. Potential (green), historical data (red), base run (thin black) and glazing uptake without amenity effects (grey).

Source: conceived by the author

Looking in detail at the retrofit as amenity mechanism can help to understand better how it works. Fig 5-19 below offers a summary of this specific underlying structure. *Added value to property by measures* positively influences the total retrofit demand, because the higher it is the more homeowners are prone to retrofit as amenity. This variable refers to the homeowners' willingness to retrofit if a specific measure is perceived to add value to their house. This value slowly changes over time depending on the measure's popularity (how much the measure is known and the positive opinion associated with it) and the non-financial attractiveness (like aesthetic value, safety and thermal comfort, but not bill savings). Moreover, the *added value to property by measures* can be affected also by how much retrofit is considered as a financial added value to the house. Namely, whether the energy efficiency of a property provides some financial advantages or not. At the moment in the system, this link is null because there is not any financial advantage from this point of view. However, triggering this relation is one of the possible outcomes of the two policies under exploration. Accessing to bigger mortgages due to the house efficiency level, getting extra credit to retrofit a new property, paying a lower stamp duty for retrofitted dwellings or for a purchased houses that get retrofitted, are all actions that are supposed to increase the measure's financial added value.

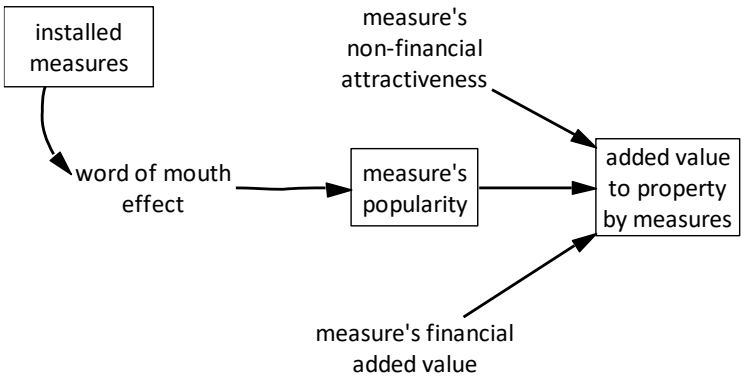


Figure 5-19: Summary of the causal connections influencing the variable 'added value to property of measures'. Variables in boxes represent accumulations that change only with delay

Source: conceived by the author

5.3.7. Insights on financial policies: the importance of market assimilation time

In this respect, what appears to be a very sensitive factor related to the *measure financial added value* is the time the market needs to 'assimilate' the new opportunities deriving from the two policies. In other words, the time needed until the market values improvements in energy efficiency, namely the time required to households to appreciate the financial benefits brought by energy efficiency, strongly influences the impact of the two policies. Fig 5-20 shows how the cumulative number of solid walls insulations grows with increments in the markets reactiveness (lower time to perceive the financial benefit added by energy efficiency) to the mortgage policy.

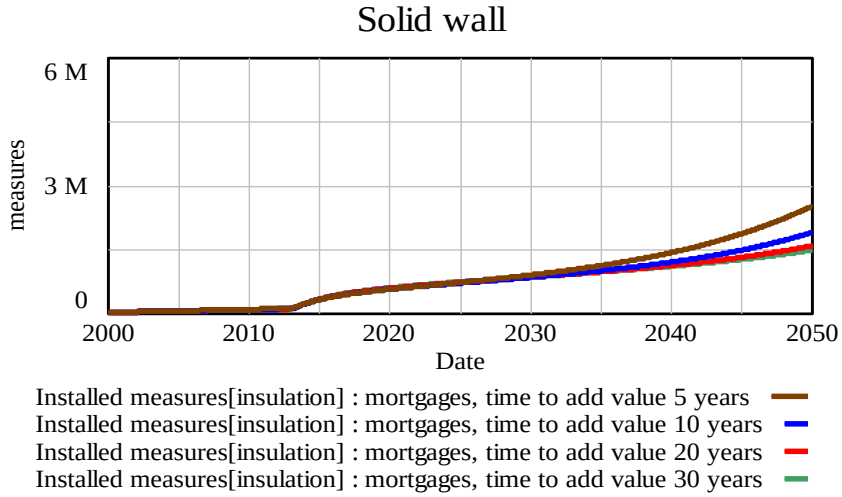


Figure 5-20: Solid wall uptake with mortgage policy for delay durations for changing the added value to a property: 5 years (brown), 10 years (blue, equivalent to mortgages run), 20 years (red), 30 years (green).

Source: conceived by the author

Unfortunately, despite the importance in the exact duration of this delay in the UK households' perception, its realistic estimations still necessitate to be done since neither scientific or grey literature provide any satisfactory description.

5.3.8. Financial affordability: only one of the barriers

Since increasing the financial affordability has been the main goal of most of the UK policies, with the model it has been explored what would the changes in the solid wall uptake be for different homeowners' budget values for retrofit. Surprisingly, the effects of increasing the budget without any further actions (e.g. policies, improvement in non-financial attractiveness, etc.) are very small. This is shown in Fig 5-21. Here the base run (thin black) in which households are willing to add the 10% on their generic renovation expenditure for installing a retrofit measure is reported and then the cases in which they are willing to top up two (thick blue), three (thick red) and four (thick green) times more are tested. This happens because affordability is only one of the criteria that homeowners take into account when they need to decide whether retrofit or not. Therefore, a measure that becomes affordable does not get 'automatically' installed if it is not also desirable.

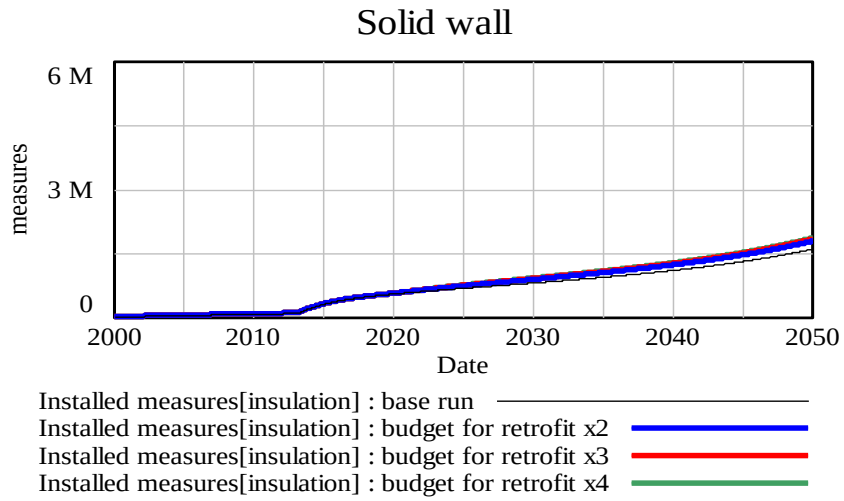


Figure 5-21: Solid wall uptake for different values of budget for retrofit: base run with a max. 10% retrofit expenditure compared to renovation expenditure (black), retrofit budget x2 (blue), x3 (red), x4 (green).

Source: conceived by the author

5.3.9. Importance of 'popularity' and 'non-financial attractiveness"

On the contrary, *non-financial attractiveness* has a remarkable impact on the solid wall uptake rate, even stronger than the two tested policies. This is clearly visible in Fig 5-22.

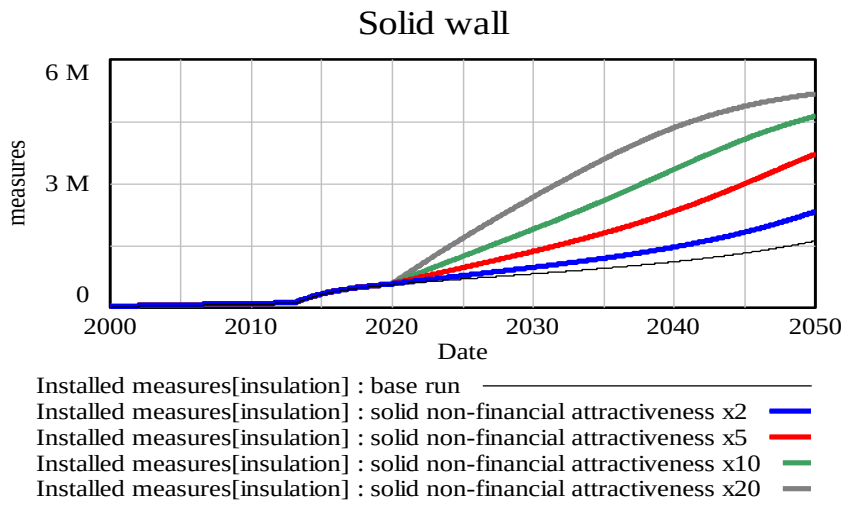


Figure 5-22: Solid wall uptake for different values of non-financial attractiveness of solid wall: base run (thin black), and different scenarios for 2 times, 5 times, 10 times and 20 times (like double-glazing) higher attractiveness of solid wall insulation.

Source: conceived by the author

After the model analysis, *non-financial attractiveness* appears to be a crucial leverage point especially if compared with changes in the affordability through variations in homeowners' budget, previously explored. Thus, an action that reinforces and improves the aesthetic value, perceived safety and thermal comfort of solid wall (although this idea applies to any measure) seems to be crucial, or even necessary, to reach the desired targets. This because it triggers the reinforcing mechanism that shifts this measure into an amenity renovation that a households desires for those aspects independent from just energy efficiency. In this respect, it may be worthwhile to recall that the *hassle factor* acts as a limiting factor for the non-financial attractiveness, like solid wall insulation installation that requires high disruption.

So far, the main lesson is that households do not install a non-desirable measure, even if they have an increased expenditure capacity. The motivation is that recognizing the retrofit measures as something attractive because of its thermal comfort, aesthetics, or because it adds value to the property is pivotal for homeowners when it comes to retrofit. These characteristics can make a retrofit measure not just 'something' to add to an already decided amenity renovations, but an amenity renovation itself which households directly strive for. In addition, also popularity seems to have a compelling role in increasing the retrofit uptake of solid wall insulation (this accounts for all the measures). Popularity is important because it triggers the reinforcing mechanism of demand through three different ways: it increases the awareness of energy efficiency among homeowners planning renovations making them consider retrofit, it improves measures desirability and it raises their added value to a property. This effect is explored in Fig 5-23. Step changes in popularity of solid wall in 2020 of 10 (thick blue line), 20 (thick red line), 40 (thick green line) and 60 (thick grey line) percentage points of the base run popularity (thin black line) are tested and reported on

the right. On the left the corresponding solid wall insulation cumulative uptake are portrayed. Looking at both graphs makes clear the strong correspondence between the two elements: for example, even a small increase of 10 percentage points can be amplified and accumulated over time, bringing the system to reach a number of solid wall insulations at the end of 2050 twice as the base run. These reinforcing loops are some of the key drivers for retrofit demand and anything that supports these mechanisms, like for example marketing, would increase the uptake rate.

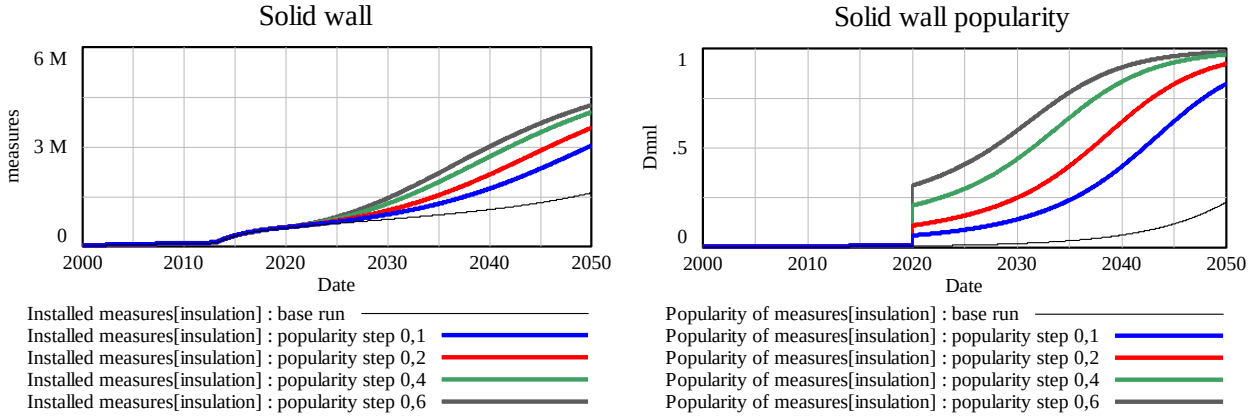


Figure 5-23: Popularity effect on cumulative solid wall uptake. On the left: Solid wall uptake for different step changes of popularity 2020: base run when popularity grows naturally (thin black), step increase in popularity at time 2020 of 10% (blue), 20% (red), 40% (green) and 60% (grey).
On the right: Effects on popularity: base run when popularity grows naturally (thin black), step increase in popularity at time 2020 of 10 percentage points (pp) (blue), 20 pp (red), 4 pp% (green) and 60 pp (grey).

Source: conceived by the author

5.3.10. Model assumptions and limitations

The model produced and used for this analysis has several limitations, as all the models have, since they are mere simplifications of reality. In this paragraph, all the limitations identified and acknowledge by the author are discussed. The confidence in the model is considered solid enough to judge as reliable the model outputs. However, further testing and validation are recommended mainly for three reasons. First on one hand, the fact the model is drawn upon knowledge of subject-experts can provide strong model reliability, on the other hand, this could be seen as a downside since it limits the structure to the joint expertise available. Although we included the new DA setting in the second session, the lack of 'real' stakeholders in the workshops may still have lead the participants to overlook important structure of the system. Second, the large size of the model increases the necessity of validation. Although several tests have been carried out so far, they still may have neglected some inconsistencies. Related to this aspect, modellers faced a general lack of reliable data for quantification on the supply chain sector of the model and on some specific qualitative connections. When it was not possible to ground in scientific literature, governmental reports or other written reliable sources, the quantification was based on best guesses done by experts in BEIS and researchers themselves. Third, building confidence in the model usefulness is a progressive and never-ending process that can be

conducted continuously over time (Barlas, 1996) since nobody can ever tell to be 100% confident on a model. This limitations need to be accounted especially in cases of further researches drawn upon this study.

In addition, assumptions needed to be done to capture such a complex system in a model. First, in the base case all the people who retrofit are part of the people who renovate. Moreover, any window of opportunity (a period of the households' life in which it is more likely they undertake home renovations) has not been modelled, and then all the homeowners are assumed to be have the same probability to do a renovation. In the model homeowners can only choose among four different measures (wall insulation, loft insulation, double-glazing and condensing boilers) when they make decision on retrofit (cavity wall and solid wall are both included, but are considered mutually exclusive in the model, since they can not be installed in the same house). These have been chosen because they are the main measures monitored by governmental bodies, but in reality the spectrum of possibilities is wider. During the model building process, it has been chosen not to take into account new measures potential, and new dwellings as well. This assumption is realistic since the replacement rate of the UK housing stock is extremely low (Shrubsole et al., 2014). Therefore, the housing stock results to be static and not dynamic. Also technical possibilities that would have increased the potential for measure instalment, such as triple glazing, have been excluded, since exploring it was outside the scope of the study. Some assumptions were taken also in the mortgage policy structure. First, the mortgage lenders reactions to the new policy are not modelled. Thus some possible unintended consequence of this policy arising in this sector is still unknown. This decision was made because of the lack of knowledge on this part of the system. Moreover, households refinancing their mortgages to do retrofit are not taken into account (assumed to be zero). This means that homeowners that have issues in repaying their mortgage are not offered the green mortgages focus of the policy. Lastly, rebound effects (Ürge-Vorsatz, Harvey, et al., 2007) have not been explored.

5.3.11.Policy Implications

There are several relevant policy lessons that can be drawn upon this analysis. Regulatory measures have been very effective in the UK. This is clearly visible from the case of condensing boiler: the regulation that made mandatory install only this new type of efficient boilers completely changed the uptake trends. Now, these trends seem comfortable enough to help the UK to meet its pledges on time. This result is not unexpected: as outlined in the literature review, energy efficiency mandatory regulations, such as building codes and appliance standards, have been already identified as successful policy instruments (Lucon et al,. 2014). Similar is the case of energy efficiency obligation scheme (CERT, EEC, ECO) that proved to be effective in the sustainment of the uptake of several measure. From this perspective they can be consider, to some extent, to be successful since the trends of some specific measures, such as loft and cavity wall insulation, are in a good track to meet the targets on time. These outcomes are not new, since good results of these types of policies have been already appreciated (Bertoldi, 2012 cited in Lucon et al, 2014, p. 720). However,

this instrument also highlighted a side effect well described in the literature (Eyre et al., 2009 cited in Lucon et al, 2014, p. 720): this mechanism of subsidies works well to incentivize cheap and mass market measures, such as loft and cavity wall insulation, rather than massive, expensive and more effective in terms of energy saving, like solid wall insulation. Therefore, the concerns among policymakers on the capability of this type of schemes not being the best for achieving long-term high saving targets, appear to be founded (Eyre et al., 2009 cited in Lucon et al, 2014, p. 720).

For what concerns market based financial policies, thorough the model analysis, it has been possible to gain also many insights. First of all, financial tools aiming to support the diffusion of green mortgages or to provide tax rebates seem to have direct low impact on the whole system because they target a very tiny portion of households (basically only who is buying a house). This acts a major limitation on the direct effects on the retrofit uptake. However, it can be interesting to look at the spill-over effects they can have, namely at the feedback loop that these policies aim to stimulate. As discussed above, these interventions seem to be somehow able to trigger the *financial added value by measure* mechanism. However, the impact of this mechanism on the solid wall uptake rate is strongly dependent on the time households need to appreciate and react to these new financial benefits. Specific knowledge on this is still lacking, as highlighted before, but it seems worth investing efforts to understand better the exact values of this information delay (e.g. market analysis, surveys, etc.) in order to support future policymaking actions in the best way possible. However if we look at other countries experiences, it is possible to see how this effect is actually in place in this type of financial policies. In the literature review, it was briefly outlined the German loan mechanism via the KfW (Kreditanstalt für Wiederaufbau), the German development bank, through which many building retrofit refurbishments were supported (Rosenow et al., 2013). This is the story of a successful intervention, however looking at Fig 5-24, in which the amount of loans and grants delivered are shown, it is possible to appreciate the fact that it took time (from 2001 to 2006) to the policy to work at one's best (appreciable in the size increase). When designing financial policies, policymakers should keep in mind that the broad impact of their intervention may be delayed in time and that the magnitude of the results is strongly dependent on this delay. Consequentially, in case they opt for these tools, they need to be willing (have enough political capital to invest) to wait the results and not scrap everything if the desired outcomes do not appear quickly.

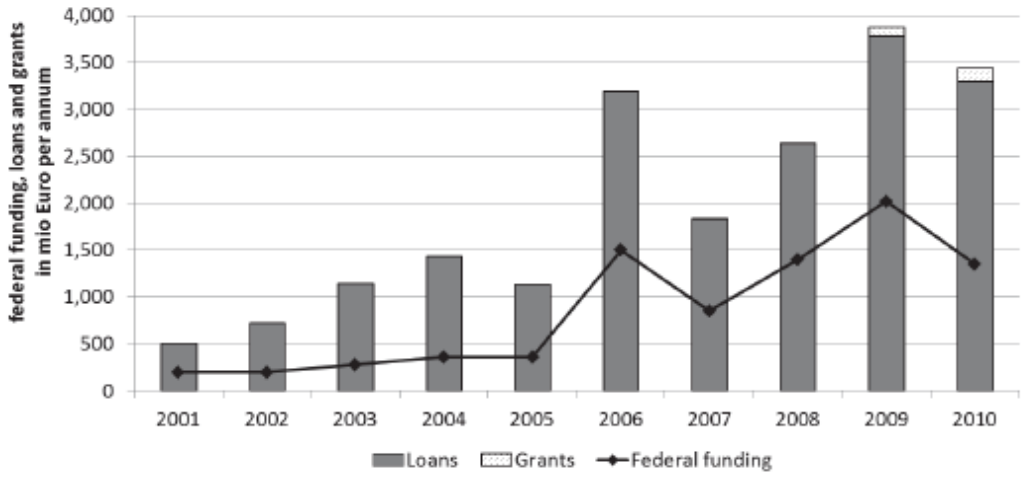


Figure 5-24: German Federal funding of the financial scheme supporting retrofit and loans and grants issued

Source: Rosenow et al., 2013, p. 86

In addition, since these are market-based interventions, the policymakers have to 'play following the rules of the game'. It means that these tools and measures need to be appealing to the customers. First, this is especially the case of green mortgages to support energy efficiency uptake. To prompt households to go for them it is necessary that they have a very competitive interest rate or other desired features. For instance, looking at the example of two successful financial items, the German scheme mentioned above offers very low interests compared to other financial products (Rosenow et al., 2013) or in Japan, financial institutions sell products that provide a discount greater than 1% on mortgages and loans for constructing or buying a house, depending on the grade of efficiency (Murakami et al., 2004 cited in Lucon et al, 2014, p.720). Second, what is definitely a minimum requirement for any market-based to be successful is the fact that the 'thing' this financial tools want to support must be desired by homeowners. Otherwise, policymakers will end up again, as they did with the Green Deal scheme, 'selling the loan instead the car' (Rosenow & Eyre, 2016). Therefore, if policymakers want to continue the path of developing financial based policies, much effort needs to be done in order to make more appealing the retrofit, in the UK case solid wall in specific (e.g. technological developments to decrease costs and disruption entailed by installation). Lastly, policymakers should start to focus more on the awareness and popularity of retrofit among households. Out of the analysis, it has appeared to have a major impact on the system. Most of the important loops in the system pass through this concepts and, as shown, variations in their value dramatically change the behaviour of the system. Consequently, any attempt to support an increase in awareness and popularity can not but benefit the uptake of retrofit measure. Policymakers have already some policy tools to act on this part of the system (e.g. advertising, awareness campaigns, etc. in Lucon et al, 2014) and many other could be developed tailored on the context they will be applied to.

6. Conclusions and Further Research

6.1. Main lessons

This dissertation primarily aimed to improve the understanding of the dynamics involved in the homeowners retrofit uptake, considering the UK as a case study. Especially, the objective was to increase the knowledge on the loops, barriers, drivers and interactions between different actors and their decision-making processes related to the homeowner energy efficiency demand. To answer this question a PSDM approach was thought to be best suited for the challenge, and therefore applied. It was used in a context of a joint project between UCL and BEIS, and through a series of workshops and interviews with policymakers from BEIS a SFD model was developed and validated. Hence, using SD modelling, this research mapped interlinkages and explored dynamics between homeowners' decision-making about retrofit and other actors in the system (the retrofit supply chain and mortgage lenders). Model simulations uncovered that four out of the five retrofit measure analyzed are probable to reach their potential before 2050, thus being on track for helping the UK to meet its long-term carbon savings pledges. These measures are double-glazing, energy efficient boilers (condensing), loft and cavity wall insulation. Instead, solid wall insulation showed problematic installation trends that would not make this measure to reach the desired level on time. Therefore, it appeared clear that solid wall insulation requires incentives and policy support that go beyond currently implemented policies. Although the large model size, it was possible to distil out seven main loops that were deeply described and discussed in section '5.3.2'. Many lesson have been drawn out the model analysis, however, a very important insight consisted in the fact that a retrofit measure's uptake seems to be remarkably affected by its '*popularity*' and 'non-*financial attractiveness*' (aesthetics, thermal comfort and low hassle factor). These characteristics generate reinforcing virtuous loops that raise the perceived retrofit measure's added value to the property by homeowners, such that this specific measure starts to be installed also for amenity purposes rather than only for energy efficiency. Technological improvements can potentially be a key driver to trigger this non-financial attractiveness since they can increase the aesthetics and thermal comfort of a retrofit measure and decrease the hassle factor involved in the installation procedure. However, it takes time for a measure to become popular by word of mouth without any binding regulation or extraordinary external events and, unfortunately, this effect cannot be overcome by any financial policy. The historical uptake of double-glazing seemed to be a clear example of this mechanism.

Speaking about financial policies, the second research question of this dissertation aimed to assess the impact on the uptake rate of financial policies, such as a *green mortgage policy* or a *stamp duty rebate*, and to explore what would be their effectiveness from a dynamic perspective (namely would they be able to trigger virtuous or enable vicious feedback loops?). The analysis of the model showed that the two policies direct impact on the homeowners retrofit uptake would be limited. The main reason for that is because that

the additional potential demand coming from house buyers and targeted by the policies is very small (approximatively one tenth) compared to the usual demand from renovators. However, the indirect effects these policies triggered seem to be more important and substantial. These indirect consequences relate to the fact that policies' impact becomes more 'tangible' if they are able to enhance a change in a measure's perceived added value to the property. These effects could be primed by an increase in the financial benefits associated to that measure (in this case, extra credit issued by lenders or lower taxation) that would contribute to the general measure's added value to the property. Then, this, combined with the intrinsic features of the measure ('measure non-financial attractiveness') and catalysed by its popularity, can make the measure sufficiently attractive to become an amenity renovation itself, and not just an energy efficiency top up on another renovation done for amenity purposes as it usually is. However, it takes time for markets to assimilate changes on stamp duty or green mortgage lending caused by policy interventions. These delays consist in how much time homeowners need to perceive a measure, in this specific case solid wall insulation, as an added value to their property since it guarantees bigger mortgages or a reduced stamp duty. These delays might impede the UK to reach its pledges because the policies' effectiveness is very sensible to how quickly and strongly households perceive such added energetic, financial, aesthetic and comfort value. Future efforts might aim to explore and develop policy instruments to strengthen and fasten these processes. In addition to all of that, from the analysis another important aspect arose. Increasing homeowners' affordability for energy efficiency is a *conditio sine qua non* for the uptake rate of measures such as solid wall insulation. However, it is definitely not enough; the measure also needs to be perceived as desirable by homeowners. Previous policies in the UK were mainly only focused on the financial aspects of the system. Green mortgage and stamp duty policies may also have some spillover effects by stimulating desirability, influencing measure's added value through financial benefits, but they seem to be insufficient to reach the installed solid wall insulation targets in 2050, even in the optimistic case of an extremely reactive market, without any intervention towards making solid wall insulation more desirable to households. Therefore, it appears clear that there are no 'silver bullets' for reaching deep and at scale retrofit. This condition was already highlighted by Papachristos (2015) in his study on the Dutch context and it can be extended to the UK. To British policymakers, this research suggests that to make any financial policy adequately effective, it is required to integrate it with other policy tools directed to increase, support and stimulate factors like measure's popularity, non-financial attractiveness and perceived retrofit added value to the property. Some of these tools already exist (Lucon et al, 2014) and some of them still need to be developed. However, a mix of policy instruments tailored to the UK context seems to be the solution (standards, informational campaigns, smart technology, behavioural incentives, national innovation policies, etc.). Moreover, in case policymakers want to pursue the path of financial policies, it is necessary to reduce the time markets and homeowners need to perceive their effects. Only in this way, these type of policies would trigger virtuous

reinforcing loops that will favour the uptake rate of energy efficiency measures, such as solid wall insulation, in a reasonable amount of time.

The research context made the research team face a very challenging situation. Due to time pressure and confidentiality on the issues dealt with, only policymakers from BEIS attended the workshop. Having heterogeneity and plurality of points of view and stakes among group participants is one of the most important conditions for PSDM (Vennix, 1996). Although this is not such an uncommon problem (Gerrits & Vaandrager, 2017), an approach to overtake this issue was still not available in the literature. In response an adaptation of the traditional Devil's Advocate was develop for this purpose. This approach tried to 'artificially' recreate in the workshop room the mental model of the missing stakeholders through a facilitator acting as them (the DA). Therefore, this thesis aimed to explore the effectiveness of the adapted and new DA setting as a tool to overcome homogeneity in a PSDM group of participants in a case in which relevant stakeholders cannot be involved in the participatory process. Overall, the results were positive. The two facilitators that played the DAs were able to raise some issue that would have been likely to be raised by the missing stakeholders and, as it was shown, their actions had a great impact in the map structure. Moreover, other participants appreciated the new setting: they liked being challenged by new and fresh ideas and they did not feel problematic the fact that facilitators, that before were neutral, became involved in debates on the content. A positive side effect of this approach was that the group discussion became more structured than it was in the previous session. This was identified to be due to the enhanced facilitators' experience with the group but also to the DAs that lead by example the other participants on how to conduct a fruitful discussion in a PSDM session. However, this setting required a lot of preparation time, especially if compared with other scripts and techniques. Moreover, the study highlighted that playing the DA may be challenging for a facilitator: it could be difficult to step in the group discussion or it could be hard to completely avoid behaving as a facilitator and act just as a stakeholder would do. Ultimately, when using this new approach, a lot of freedom is left to the DA judgment. However, the applications of the new DA setting performed in this study was the first, and at the moment it is very difficult to separate the good results obtained from the cultural context in which the approach was used. Nevertheless, the author is confident to state that the setting was effective with respect of the purpose. It helped in carrying out a successful PSDM project in a 'pressure cooker conditions', namely a PSDM project 'compressed' because of external constraints (in this case time and confidentiality, but it could be also, for example, budgetary) in which homogeneity conditions might have undermined the quality of the outcomes (Gerrits & Vaandrager, 2017). From a broader perspective, this original setting for PSDM showed to what extent the methodology can be flexible (the scripted part mixed, omitted, extended, etc.) and thus compressed, should the situation require. It demonstrated that PSDM works well also in less than ideal situations whereby there is confidentiality and time pressure and in which there is little room to execute the method as prototypically described (Vennix, 1996). These might be valuable

lessons for practitioners that will face in the future similar circumstances. Last but not least, this study proved again that PSDM is "still more art than science" (Andersen, Richardson, & Vennix, 1997, p. 187). To prepare and perform original setting and scripts, it seems required to researchers some types of skills that appear to be not teachable. In these cases, a particular inner sensitiveness to understand the group life (Phillips & Phillips, 1993) and judge all the factors (e.g. trust) and details involved is necessary. Unfortunately, these abilities cannot be fully taught to someone, but they are something that people develop by themselves during their life.

6.2. Further research and developments

The work described and contained in this dissertation can be seen as a starting point for further research in two main directions: one with respect of the model and one concerning methodological developments for the new DA setting.

Six major paths of future work on the model or related issue have been identified. First, refinements in order to increase the robustness of the quantification process seem to be a crucial next step to perform. As said, some values and relationships are not well rooted in the literature, therefore, specific and targeted research appears to be the most suited way to increase the confidence in them. Second, structural improvements could increase further the reliability of sensitive SFD structures. These structural progresses may consist in supplementary validation (see: Barlas, 1996; Sterman 2000), and a revision and assessment of the assumptions taken and limitations involved. This is mostly due to model's large size and this process would remarkably contribute to enhance researchers and audience confidence on the outcomes. Third, additional participatory group sessions to revise, build and validate relationship could be done. These would increase further the built structure's reliability and they might enlarge the level of details in the model. In this respect, these sessions might include a wider range of stakeholders in the workshops in order to extend the shared understanding created also to these individuals and to integrate in the model their point of view, thus decreasing the probability of overlooking important causal structures. Fourth, the model could be expanded and used as starting point to analyze new parts of the system. Potential lies in the possibility to explore dynamics of mortgage lenders and retrofit supply chain more in detail. This might lead to widen the scope of the model. Fifth, it could be considered to make the model go through a 'gamification' process in order to create a user-friendly interface and thus support learning and policy evaluations. Sixth, from a much broader perspective, future researches could aim to assess the long-term impacts of the PSDM project on governmental organisations like BEIS, as called by Cappuccio et al. (2017). For example, questionnaires evaluating could be submitted to workshop participants to assess whether the approach had a long-term impact on consensus, commitment, insights and communication about the subject or not.

Further work with respect of the new DA setting appears to be necessary to consolidate the approach not as a promising practice but as an established one. More applications of the setting need to be performed and evaluated to understand whether the good outcomes obtained in this case study are depending on the approach or on contextual factors (e.g. organization culture could have been the real reason for the positive results). Therefore, an increased number of applications of the setting would provide more data to assess the effectiveness of the approach and to see if it works well also in other contextual situations. Moreover, future research on the method should be directed toward an improvement of the approach's rigorousness, especially for what concerns the preparation of the script. In this sense, the selection of the missing stakeholders might be improved. Here, it was based on the literature and on the inputs received by the workshop participants during the first session. Integrating this procedure with other techniques, for example the ones suggested by Bryson (2004), could increase the reliability of the selection. In addition, the choice of the sources used to construct the possible issues that would have been likely to be raised by the missing stakeholder and the way they are embedded in the DA script, can be improved. In the sense that it could be done in a more systematic way. However, techniques to do so have not been found yet, so that there might be a new path of research. This would increase the confidence of facilitators in the issues the DAs raise in the sessions. Moreover, the setting was tried in only one workshop of PSMD project; future research could try to apply it in a series of sessions, to see whether it still works well or its performance decreases as the workshops go on. Lastly, the way the approach was assessed in this study is just a preliminary attempt to evaluate such an original setting. This evaluation process is still open for revisions, suggestions and improvements in order to make it comprehend more all the aspects influenced by the new DA setting. Summarizing, future studies on the new DA approach should go towards increasing its rigorousness and to increase the number of contexts in which it is applied.

References

Alberini, A., Banfi, S., & Ramseier, C. (2013). Energy Efficiency Investments in the Home: Swiss Homeowners and Expectations about Future Energy Prices. *The Energy Journal*, *34*(1), 49–86.

Allwood, J. M., Cullen, J. M., & Milford, R. L. (2010). Options for Achieving a 50% Cut in Industrial Carbon Emissions by 2050, *2050*.

Andersen, D. F., & Richardson, G. P. (1997). Scripts for group model building. *System Dynamics Review*, *13*(2), 107–129.

Andersen, D. F., Richardson, G. P., & Vennix, J. A. M. (1997). Group model building : adding more science to the craft. *System Dynamics Review*, *13*(2), 187–201.

Andersen, D., & Richardson, G. (1997). Scripts for group model building. *System Dynamics Review*, *13*(2), 107–129.

Armenia, S., Falsini, D., & Oliveri, G. (2009). Energy Management in Residential Buildings: A System Dynamics Approach. In *The 27th International Conference of the System Dynamics Society*,. Albuquerque, New Mexico, USA.

Backlund, S., Thollander, P., Palm, J., & Ottosson, M. (2012). Extending the energy efficiency gap. *Energy Policy*, *51*, 392–396.

Barlas, Y. (1996). Formal aspects of model validity and validation in system dynamics. *System Dynamics Review*, *12*(3), 183–210.

Barlas, Y., & Carpenter, S. (1990). Philosophml roofs of model validation: two paradigms. *System Dynamics Review*, *6*(2), 148–166.

BEIS. (2017a). *Household Energy Efficiency National Statistics, Headline Release*. London, UK.

BEIS. (2017b). *Household energy efficiency national statistics 2016*. London, UK.

Bertoldi P. (2012). Energy Efficiency Policies and white certificates: analysis of experiences in the European Union. JRC European Commission.

Bishoff, V. (2013, October 16). Only 12 homes sign up to Government's Green Deal energy efficiency scheme. *Daily Mail*.

Blok, K., Geng, L., Harvey, D., Lang, S., Levermore, G., Mehlwana, a M., … Dave, R. (2007). Residential and commercial buildings. *Climate Change 2007: Working Group III: Mitigation of Climate Change*, *Chapter 6*, 387–446.

Blumberga, A., Zogla, G., Davidsen, P., & Moxes, E. (2011). Residential Energy Efficiency Policy in

Latvia : A System Dynamics Approach. In *System Dynamic Conference* (pp. 1–23). Washington, DC.

Bonfield, P. (2016). *Each Home Counts*. London, UK.

Booth, A. T., & Choudhary, R. (2013). Decision making under uncertainty in the retrofit analysis of the UK housing stock: Implications for the Green Deal. *Energy and Buildings*, *64*, 292–308.

Brandemuehl, M., & Braun, J. (1999). The Impact of Demand-Controlled and Economizer Ventilation Strategies on Energy Use in Buildings. In *American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc.* (pp. 1–11). Atlanta, USA.

Brignall, M. (2015, February 21). Seven excuses that will cost you a fortune in energy bills until you switch. *The Guardian*.

Brounen, D., Kok, N., & Quigley, J. M. (2013). Energy literacy, awareness, and conservation behavior of residential households. *Energy Economics*, *38*, 42–50.

Bryson, J. M. (2004). What to do when Stakeholders matter - Stakeholder Identification and Analysis Techniques. *Public Management Review*, *6*(1), 21–53.

Campbell, D. (2001). The long and winding (and frequently bumpy) road to successful client engagement: One team's journey. *System Dynamics Review*, *17*(3), 195–215.

Cappuccio, V., Cunico, G., & Zimmermann, N. (2017). Shaping policy development in a UK Government department. In *HopefullNESS*. Tampere, Finland.

Committee for Climate Change (2015). *Reducing emissions and preparing for climate change:2015 Progress Report to Parliament*.

Clifford, T., & Prasad, J. (2016). *Bridging the Gap - Role of energy efficiency*.

Collins, M., & Dempsey, S. (2017). *Residential Energy Efficiency Retrofits: Potential Unintended Consequences*.

Correljé, A., & van der Linde, C. (2006). Energy supply security and geopolitics: A European perspective. *Energy Policy*, *34*(5), 532–543.

DCLG. (2013). *English housing survey 2011 to 2012*. London, UK.

DCLG. (2016). *Dwelling Stock Estimates : 2015, England*. *Housing Statistical Release*. London, UK.

De Bono, E. (1999). *Six thinking hats*. Back Bay Books.

de Gooyert, V., Rouwette, E., van Kranenburg, H., Freeman, E., & van Breen, H. (2016). Sustainability transition dynamics: Towards overcoming policy resistance. *Technological Forecasting and Social Change*, *111*, 135–145.

DECC. (2015). *Cutting the cost of keeping warm - A poverty strategy for England*. London, UK.

DECC. (2016a). *Annual Fuel Poverty Statistics Report 2016*. London, UK.

DECC. (2016b). *National Energy Efficiency Data-Framework (NEED)*. London, UK.

Dowson, M., Poole, A., Harrison, D., & Susman, G. (2012). Domestic UK retrofit challenge: Barriers, incentives and current performance leading into the Green Deal. *Energy Policy*, *50*, 294–305.

Eker, S., & Zimmermann, N. (2016). Understanding the Mechanisms behind Fragmentation in the Housing Construction and Retrofit. In *34th International Conference of the System Dynamics Society 2016: Proceedings* (pp. 1–13). Delft, The Netherlands.

Elias, A. A. (2008). Energy efficiency in New Zealand's residential sector: A systemic analysis. *Energy Policy*, *36*(9), 3278–3285.

Emmert, S., Van De Lindt, M., & Luiten, H. (2010). Bar Energy. Barriers to Changes in Energy Behaviour among End Consumers and Households. *Final Report. Amsterdam: The Netherlands Organisation for Applied Scientific Research-TNO*

Energy Saving Trust. (2011). *Trigger points: a convenient truth*. London, UK.

Erbach, G. (2015). *Understanding energy efficiency*.

Eskinasi, M., Rouwette, E., & Vennix, J. (2011). Houdini: A System Dynamics Model for Housing Market Reforms. In *2011 System Dynamics Conference* (pp. 1–19). Washington, DC.

European Commission. (2014). 2030 Energy strategy, *European Parliamentary Research Service*.

Eyre N., M. Pavan, and L. Bodineau. (2009). Energy Company Obligations to Save Energy in Italy, the UK and France: What have we learnt? European Council for an Energy Efficient Economy, La Colle sur Loup, France, pp. 429 – 439.

Faberi, S., Mebane, W., & Presutto, M. (2001). High Efficiency Household Appliances and Low Income Families in Italy. In *Energy Efficiency in Household Appliances and Lighting* (pp. 529–540). Berlin, Heidelberg: Springer Berlin Heidelberg.

Forrester, J. W. (1961). *Industrial Dynamics*. Massachusetts Institute of Technology Press.

Forrester, J. W. (1969). *Urban Dynamics*. Cambridge, Massachussets: MIT Press.

Frederiks, E. R., Stenner, K., & Hobman, E. V. (2015). Household energy use: Applying behavioural economics to understand consumer decision-making and behaviour. *Renewable and Sustainable Energy Reviews*, *41*, 1385–1394.

Fuerst, F., McAllister, P., Nanda, A., & Wyatt, P. (2013). *Final Project Report: An investigation of the effect*

of EPC ratings on house prices.

Geller, H., Harrington, P., Rosenfeld, A. H., Tanishima, S., & Unander, F. (2006). Polices for increasing energy efficiency: Thirty years of experience in OECD countries. *Energy Policy*, *34*(5), 556–573.

Gerrits, L., & Vaandrager, D. (2017). Group Model Building in a Pressure Cooker : A Field Experiment with Public Policy. *Systems Research and Behavioral Science*. http://doi.org/10.1002/sres.2446

Gosden, E. (2016, April 14). Failed Green Deal scheme cost £17,000 for every household that signed up. *The Telegraph*.

Government, U. (2017). *House building ; new build dwellings , England : December Quarter 2016 Quarterly Figures* (Vol. 620).

Grimshaw, H. (URBED). (2016). *Retrofit factfile*.

Guertler, P., Robson, D., & Royston, S. (2013). Somewhere between a "Comedy of errors" and "As you like it"? A brief history of Britain's "Green Deal" so far. In *ECEEE Summer Study Proceedings* (pp. 153–164).

Hamada, Y., Nakamura, M., Ochifuji, K., Yokoyama, S., & Nagano, K. (2003). Development of a database of low energy homes around the world and analyses of their trends. *Renewable Energy*, *28*(2), 321–328.

Hamilton, I. G., Shipworth, D., Summerfield, A. J., Steadman, P., Oreszczyn, T., & Lowe, R. (2014). Uptake of energy efficiency interventions in English dwellings. *Building Research & Information*, *42*(3), 255–275.

Hannes, H. (2012). Baltic Cyber Shield: Research from a Red Team versus Blue Team Exercise. *Pentest Magazine*, *9*, 80–86.

Harvey, L. D. D. (2013). Recent Advances in Sustainable Buildings: Review of the Energy and Cost Performance of the State-of-the-Art Best Practices from Around the World. *Annual Review of Environment and Resources*, *38*(1), 281–309.

Hastings, S. R. (2004). Breaking the "heating barrier": Learning from the first houses without conventional heating. *Energy and Buildings*, *36*(4), 373–380.

Heffner, G., & Campbell, N. (2011). *Evaluating the co-benefits of low-income energy-efficiency programmes*. *International Energy Agency*.

Hills, J. (2012). *Final report of the Hills Independent Fuel Poverty review: getting the measure of fuel poverty*. London, UK.

Hong-Minh, S., & Strohhecker, J. (2002). A system dynamics model for the UK private house building

supply chain. In *The 20th International Conference of The System Dynamics Society* (pp. 1–65). Palermo.

Hopwood, B., Mellor, M., & O'Brien, G. (2005). Sustainable Development: Mapping Different Approaches. *Sustainabel Development*, *13*, 38–52.

House of Commons Energy and Climate Change Committee. (2016). Home energy efficiency and demand reduction. Fourth Report of Session 2015–16. HC 552. London, House of Commons

Hyunjung, K., & Andersen, D. F. (2012). Building confidence in causal maps generated from purposive text data: mapping transcripts of the Federal Reserve. *Dyn. Rev*, *28*(4), 311–328.

IPCC. (2014). IPCC Fifth Assessment Synthesis Report-Climate Change 2014 Synthesis Report. *IPCC Fifth Assessment Synthesis Report-Climate Change 2014 Synthesis Report*, 167.

Jollands, N., Waide, P., Ellis, M., Onoda, T., Laustsen, J., Tanaka, K., … Meier, A. (2010). The 25 IEA energy efficiency policy recommendations to the G8 Gleneagles Plan of Action. *Energy Policy*, *38*(11), 6409–6418.

Jones, R. (2013, January 26). A Green Deal but not a great deal. *The Guardian*.

Kelly, M. J. (2009). Retrofitting the existing UK building stock. *Building Research & Information*, *37*(March 2015), 196–200.

Kruyt, B., van Vuuren, D. P., de Vries, H. J. M., & Groenenberg, H. (2009). Indicators for energy security. *Energy Policy*, *37*(6), 2166–2181.

Lane, K., & Energy Efficient Strategies Pty Ltd. (2015). *Achievements of applicance energy efficiency standards and labelling programs: a global assessment* (Vol. 4E).

Linares, P., & Labandeira, X. (2010). Energy efficiency: Economics and policy. *Journal of Economic Surveys*, *24*(3), 573–592.

Lovins, A. B. (1976). Energy Strategy: The Road Not Taken? *Foreign Affairs*, *55*(1), 65–96.

Lucon, O., Ürge-Vorsatz, D., Zain Ahmed, A., Akbari, H., Bertoldi, P., Cabeza, L. F., … Vilariño, M. V. (2014). *Buildings*. *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 671.

Macmillan, A., Davies, M., Shrubsole, C., Luxford, N., May, N., Chiu, L. F., … Chalabi, Z. (2016). Integrated decision-making about housing, energy and wellbeing: a qualitative system dynamics model. *Environmental Health : A Global Access Science Source*, *15 Suppl 1*(1), 37.

Mallaburn, P. S., & Eyre, N. (2014). Lessons from energy efficiency policy and programmesin the UK from

1973 to 2013. *Energy Efficiency*, *7*(1), 23–41.

Malpass, P. (2014). Histories of Social Housing: A Comparative Approach. In *Social Housing in Europe* (pp. 255–274). Wiley Blackwell.

Meadows, D. H. (1980). The Unavoidable A Priori. *Elements of the System Dynamics Method*, 23–57.

Meadows, D. L., Meadows, D. H., & Randers, J. (1972). *The Limits to Growth* (First). New York: Universe Books.

Miles, M. B., Huberman, A. M., & Saldana, J. (2013). *Qualitative Data Analysis: A Methods Sourcebook*. SAGE Publications.

Mirkovic, J., Reiher, P., Papadopoulos, C., Hussain, A., Shepard, M., Berg, M., & Jung, R. (2008). Testing a collaborative DDoS defense in a red team/blue team exercise. *IEEE Transactions on Computers*, *57*(8),

Morse, A. (National A. O. (2016). *Green Deal and Energy Company Obligation Annual Update 2015*. London, UK.

Müller, M. O., & Ulli-Beer, S. (2010). Policy Analysis for the Transformation of Switzerland's Stock of Buildings. A Small Model Approach. In *Proceedings of the 28th System Dynamics Conference, 2010* (Vol. 41). Seoul, Korea.

Murakami S., K. Iwamra, Y. Sakamoto, T. Yashiro, K. Bogaki, M. Sato, T. Ikaga, and J. Endo. (2004). CASBEE; comprehensive assessment system for building environmental efficiency (Environmental Engineering). Journal of Architecture and Building Science, 199 – 204.

United Nations. (1948). The Universal Declaration of Human Rights.

Nelsen, A. (2014, September 9). Europe's dependency on Russian gas may be cut amid energy efficiency focus. *The Guardian*. London, UK.

Osita, I., Onyebuchi, I., & Nzekwe, J. (2014). Organization's stability and productivity: the role of SWOT analysis an acronym for strength, weakness, opportunities and threat. *International Journal of Innovative and Applied Research*, 2 (9) , 23-32.

Palmer, J. (DECC), & Cooper, I. (DECC). (2013). *United Kingdom housing energy fact file*. *Department of Energy & Climate Change*.

Papachristos, G. (2015). Household electricity consumption and CO2 emissions in the Netherlands: A model-based analysis. *Energy and Buildings*, *86*, 403–414.

Parliament of the United Kingdom. Climate Change Act 2008, HM Government 1–103 (2008).

Phillips, L. D., & Phillips, M. C. (1993). Faciliated Work Groups: Theory and Practice. *The Journal of the Operational Research Society*, *44*(6), 533–549.

Phillips, Y. (2012). Landlords versus tenants: Information asymmetry and mismatched preferences for home energy efficiency. *Energy Policy*, *45*, 112–121.

Poudineh, R., & Jamasb, T. (2014). Distributed generation, storage, demand response and energy efficiency as alternatives to grid capacity enhancement. *Energy Policy*, *67*, 222–231.

Pruyt, E., & Yücel, G. (2011). Energy Transition in The Dutch Dwelling Stock. In *The 29th International Conference of the System Dynamics Society* (pp. 1–22).

Richardson, G. P., & Andersen, D. F. (1995). Teamwork in Group Model Building. *System Dynamics Review*, *11*(2), 113–137.

Roberts, S. (2008). Altering existing buildings in the UK. *Energy Policy*, *36*(12), 4482–4486.

Rosenow, J. (2012). Energy savings obligations in the UK-A history of change. *Energy Policy*, *49*, 373–382.

Rosenow, J., & Eyre, N. (2016). A post mortem of the Green Deal: Austerity, energy efficiency, and failure in British energy policy. *Energy Research and Social Science*, *21*, 141–144.

Rosenow, J., Eyre, N., Bürger, V., & Rohde, C. (2013). Overcoming the Upfront Investment Barrier - Comparing the German CO 2 Building Rehabilitation Programme and the British Green Deal. *Energy & Environment*, *24*(1–2), 83–104.

Rouwette, E. A. J. A., Vennix, J. A. M., & Mullekom, T. van. (2002). Group model building effectiveness: a review of assessment studies. *System Dynamics Review*, *18*(1), 5–45.

Ryan, L., & Campbell, N. (2012). *Spreading the net: the multiple benefits of energy efficiency improvements*. *International Energy Agency*.

Sanstad, A. H., & Howarth, R. B. (1994). Consumer Rationality and Energy Efficiency. In *ACEEE Summer Study on Energy Efficiency in Buildings Abstract* (pp. 1–14).

Santangelo, A., & Tondelli, S. (2017). Occupant behaviour and building renovation of the social housing stock: Current and future challenges. *Energy and Buildings*, *145*, 276–283.

Schein, E. H. (1990). A General Philosophy of Helping: Process Consultation. *Sloan Management Review*, *31*(3), 57.

Scott, R. J., Cavana, R. Y., & Cameron, D. (2016). Recent evidence on the effectiveness of group model building. *European Journal of Operational Research*, *249*(3), 908–918.

Serghides, D. K., Dimitriou, S., & Katafygiotou, M. C. (2016). Towards European targets by monitoring the energy profile of the Cyprus housing stock. *Energy and Buildings*, *132*, 130–140.

Shrubsole, C., Macmillan, a., Davies, M., & May, N. (2014). 100 Unintended consequences of policies to improve the energy efficiency of the UK housing stock. *Indoor and Built Environment*, *23*(3), 340–352.

Skelton, B., Fernandez, D., & Fitzgibbons, A. (2009). Energy saving trust green finance uptake. Final debrief. *Quadrangle & Energy Savings Trust (EST).* London, UK

Soo, C. K. (2015). *Working Paper Quantifying Animal Spirits : News Media and Sentiment in the Housing Market* (No. 1200). *Working Paper*.

Office for National Statistics (UK). (2016). UK Perspectives 2016: Housing and home ownership in the UK. London, UK.

Stave, K. (2010). Participatory system dynamics modeling for sustainable environmental management: Observations from four cases. *Sustainability*, *2*(9), 2762–2784.

Sterman, J. D. (2000). *Business Dynamics: Systems Thinking and Modeling for a Complex World*. Boston: Irwin/McGraw-Hill.

Sterman, J. D. (2002). All models are wrong: Reflections on becoming a systems scientist. *System Dynamics Review*, *18*(4), 501–531.

Sterman, J. D., & Rahmandad, H. (2012). Reporting guidelines for simulation-based research in social sciences. *System Dynamics Review*, *28*(4), 396–411.

Sweeney, L. B., & Sterman, J. D. (2000). Bathtub dynamics: Initial results of a systems thinking inventory. *System Dynamics Review*, *16*(4), 249–286.

Syal, R. (2016, April 14). Green deal scheme did not deliver energy savings, audit finds. *The Guardian*.

Team, B. I. (2011). *Behaviour Change and Energy Use*.

Tuominen, P., Klobut, K., Tolman, A., Adjei, A., & De Best-Waldhober, M. (2012). Energy savings potential in buildings and overcoming market barriers in member states of the European Union. *Energy and Buildings*, *51*, 48–55. 5

Houzz UK. (2016). *Houzz & Home – UK August 2016*.

Ürge-Vorsatz, D., Danny Harvey, L. D., Mirasgedis, S., & Levine, M. D. (2007). Mitigating CO 2 emissions from energy use in the world's buildings. *Building Research & Information*, *35*(4), 379–398.

Ürge-Vorsatz, D., Eyre, N., Graham, P., Harvey, D., Hertwich, E., Jiang, Y., … Novikova, A. (2012). Energy End-Use: Buildings. In T. B. Johansson, N. Nakicenovic, A. Patwardhan, & L. Gomez-Echeverri (Eds.), *Global Energy Assessment - Toward a Sustainable Future* (pp. 649–760). Cambridge: Cambridge University Press.

Ürge-Vorsatz, D., Koeppel, S., & Mirasgedis, S. (2007). Appraisal of policy instruments for reducing buildings' CO2 emissions. *Building Research & Information*, *35*(4), 458–477.

Vaughan, A. (2015, July 23). Government kills off flagship green deal for home insulation. *The Guardian*.

Vennix, J. A. M. (1990). *Mental models and computer models*. *Radboud Repository*. Radboud University Nijmegen.

Vennix, J. A. M. (1996). *Group model building: facilitating team learning using system dynamics*. J. Wiley.

Vennix, J. A. M., Andersen, D. F., Richardson, G. P., & Rohrbaugh, J. (1992). Model-building for group decision support : Issues and alternatives in knowledge elicitation, *59*, 28–41.

Videira, N., Antunes, P., Santos, R., & Gamito, S. (2003). Participatory Modelling in Environmental Decision-Making: The Ria Formosa Natural Park Case Study. *Journal of Environmental Assessment Policy and Management*, *5*(3), 421–447.

Videira, N., Lopes, R., Antunes, P., Santos, R., & Casanova, J. L. (2012). Mapping Maritime Sustainability Issues with Stakeholder Groups. *Systems Research and Behavioral Science*, *29*(6), 596–619.

Waters, L. (DECC). (2016). *Energy Consumption in the UK November 2016 update*. London.

Weiss, J., Dunkelberg, E., & Vogelpohl, T. (2012). Improving policy instruments to better tap into homeowner refurbishment potential: Lessons learned from a case study in Germany. *Energy Policy*, *44*, 406–415.

Wilson, C., Chryssochoidis, G., & Crane, L. (2013). The conditions of normal domestic life help explain homeowners ' decisions to renovate. *ECEEE Summer Study Proceedings 2013*, (Decc), 2333–2347.

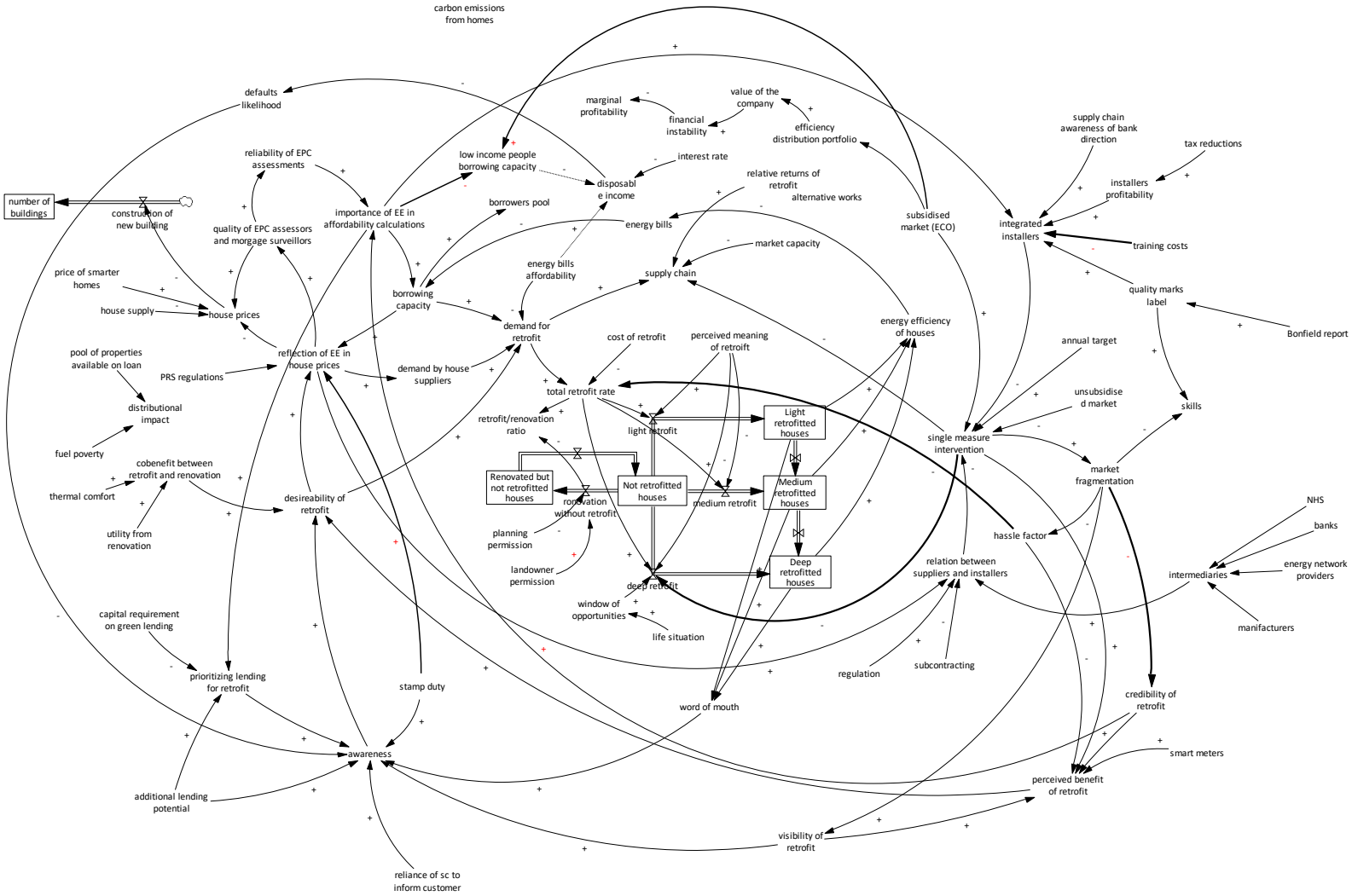
Wilson, C., Crane, L., & Chryssochoidis, G. (2015). Why do homeowners renovate energy efficiently? Contrasting perspectives and implications for policy. *Energy Research and Social Science*, *7*, 12–22.

World Health Organization. (2011). *Health co-benefits of climate change mitigation – Housing sector*.

Xing, Y., Lannon, S., & Malcolm, E. (2014). Exploring the use of systems dynamics in sustainable urban retrofit planning. In *Sustainable Urban Development to 2050: Complex Transitions in the Built Environment of Cities* (pp. 49–70). Routledge.

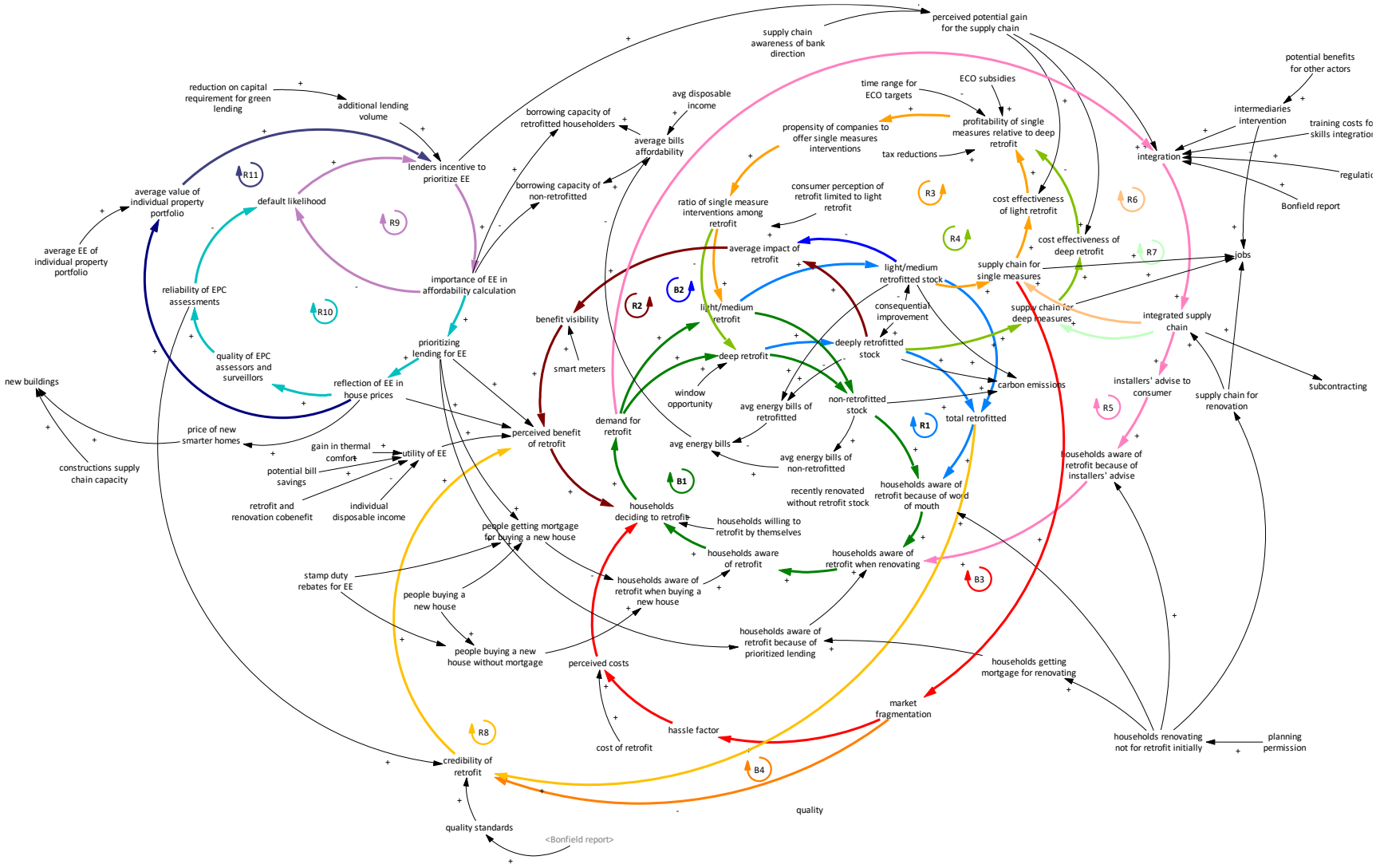
Yang, M. (2012). Background and Literature Review on Energy Efficiency Gaps. In *Closing the Gap: GEF Experiences in Global Energy Efficiency* (pp. 9–27). Springer Science and Business Media.

Annex A: First workshop map software translation



Source: conceived by the author

Annex B: First workshop refined map loops identification



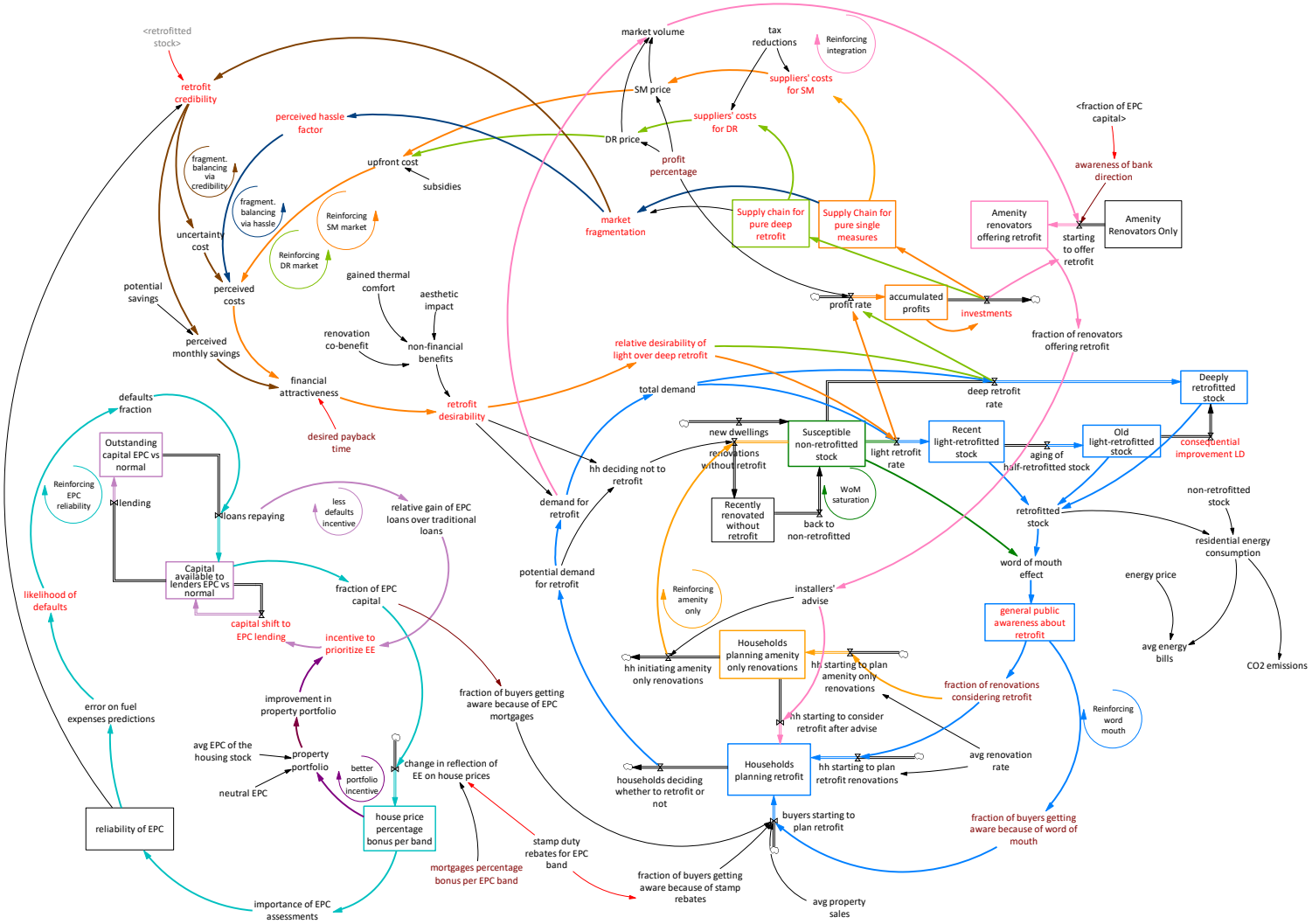
Source: conceived by the author

Table: Loop name and explanation

LOOP NUMBER	*Meaning*
B1	Saturation loop
R1	Word of mouth effect
R2	High visibility loop
B2	Low visibility loop
R3	Single measure supply chain (SC) growth
R4	Deep measure SC growth
R5	Integrated SC growth
R6	Integrated single measure SC growth
R7	Integrated deep measures SC growth
R8	Credibility reinforcing loop
B3	Counteracting effect of fragmentation by increased hassle factor
B4	Counteracting effect of fragmentation by loss of credibility
R9	Incentive to prioritize energy efficiency lending due to reduced default likelihood
R10	Incentive to prioritize energy efficiency lending due to increased reliability of Energy Performance Certificate (EPC)
R11	Incentive to prioritize energy efficiency for lenders with a good energy efficiency portfolio

Source: compiled and conceived by the author

Annex C: Second workshop Hybrid Map



Source: conceived by the author

Annex D: The New Devil's Advocate Script

DEVIL's ADVOCATE FACILITATION ROLE

The facilitators **introduce** him and his role (mainly his loss of neutrality) in the beginning of the workshop.

[Facilitator] "*As you saw last time, facilitators don't interfere with the content under discussion among the participants. What they can do is to ask question that challenge the participants. Today DA1 and DA2 will leave their neutral facilitation role and act as one of the participants for most of the session. The reason why we made this choice is that we want to bring some issue into 'the workshop room' that might be raised by the stakeholders (that unfortunately can't attend the workshop). The idea is to stress the model/map as much as possible in order to increase its truthfully with respect of reality. We expect this process to increase the quality of final output since it can lead to integrate into the model 'things' that were not considered before*". "*However, it is your right to stop it. It means that if you think that this approach is annoying or useless just let us know and say that you do not want that facilitator to be there*".

What does the Devil's Advocate (DA) do? He acts as one of the participant, but a "special one". **Guidelines**:

- He sits among the participants and not among the facilitators.
- He suggests links and variable as any participant. Therefore, he participate to the nominal group techniques and the modelling phase (suggesting variables, links, arising questions, etc.).
- He does not interfere in the group activity that requires reaching a consensus among participants. He has 'less power'. This because reaching consensus is an internal group process through which the commitment on the model is built and so nobody of the facilitation team should interfere with it. In practice, after every discussion in the modelling phase, in which also the DA can take part, the facilitator usually ask to the participants if they all agree on the suggested item. In this moment the DA should not interact (if something appears to be extremely wrong he can ask clarifications but he cannot put a veto or start a conflict)
- The goal of the DA is to add more perspective to the group and then improve the model quality. Remember that with this adjustment we are exploring to what extent a facilitator can leave his role and intervene on the content and what contribution can give to the model. To do so, the DA can share his reasoning as a normal participant and the data source these ideas come from. He should try to set himself in an inquiry mode when suggesting variable, etc. For example:
    - NO: "*this is wrong, the literature says this, this and this.*" obviously their reaction can quite negative towards the workshop setting
    - YES: "*I see. But, have you ever consider this option described in this source?*" or "*I read some articles. This might be placed here and connected to this. Is it useful? Why don't you think so?" or "Let's consider other possible options – what questions could we come up that pose issues to the option we have been discussing?".* In this case, the DA just challenge their ideas and do not impose anything. The burden of thinking about the stimulus from the DA is shifted to the participants since they need to think about in order to answer to the question. Moreover, questions are less "harmful" in a discussion than statements.
- Ultimately the role of the DA is just posing ideas (backed by sources), explaining the reasoning why these ideas could be relevant and then support the participants to accept them or not. They are the one who take a decision. The DA should never forget this while conducting his role.
- All the issue that DA will arise are studied and analyzed before with the facilitation team in order to check and assess their robustness and relevance. All the issues needs to have a stakeholder they could be referred to, the source backing that claim (literature, interview with experts, …), a sentence as

guideline for the DA on how to present the issue to the other participants and a list of possible variables related to. (see the table below).

However, there is not much information (almost nothing) on this type of approach. It is a quite new setting in GMB what we are doing, and there could be some aspects we are not taking into account and then something not expected can arise in the workshop.

ISSUE TO RAISE	*STAKEHOLDER BEARIER OF THAT ISSUE*	*HOW TO FRAME IT*	*POSSIBLE VARIABLE RELATED TO*	*SOURCE*
Existing dwellings are likely to represent 70–80% of the 2050 stock. 30% are going to be new houses. In 2016 140,660 houses have been completed. (Legislation "Building Regulations and associated technical guidance", regulation called "Zero carbon emissions" that have been stopped)	Constructors/ other policymakers (Department for communities and local Government)	"At the moment new houses are not relevant in the model. It is a stock outside the core structure. But I think that if we adopt a long term view they can be important and therefore valuable to be taken into account". "Are there any legislative requirements for energy efficiency and GHG emissions from new buildings? ('in which stock is the rate going in?')	"New building rate", "demolition rate",	(Shrubsole et al., 2014), (UK Government, 2017)
Top renovation payments methods: 1) Savings/personal finances 85% 2) Cash from home mortgage refinance 14% 3) Credit card – to be paid off over time 14% 4) Gift/inheritance 11% 5) Personal loan from friends/family 4%	Renovation expert	From what I know only 14% of the people that are renovating chose to pay with cash from home mortgage refinance. Is this data realistic according to you? "Do you agree that knowing the magnitude of people paying in this way is important?	"Percentage of people using mortgages refinance for paying renovations"	(Houzz report, 2016)
People in UK are very reluctant in undertaking loans and mortgages	Industry stakeholders/ Households	Households in UK are not very willing to take a loan or refinance their mortgage to pay for their renovations. This can have an impact on the policy.	"Reluctance towards mortgages and loans"→ "Percentage of people using mortgage refinance to pay for renovations"	Esfand Burman, research associate, UCL Institute of Environmental Design and Engineering with long experience in the construction sector

Households distrust Households seems reluctant to accept financial offers coming from other actors	Households	*"Generally, those who chose not to pursue support despite being contacted described being 'put off' by the method of contact. Cold-calls and leaflets were viewed with suspicion by some participants, and associated with experiences of 'scams' or nuisance sales contact. There was also widespread cynicism about the offer of financial support, and a sense that there would be drawbacks – 'there's always a catch'."*	"Households trust in financial offers"	DECC Supplier Obligation Consumer Research: Summary Report
It is not so easy for a household to move from a renovation plan to a plan that include also retrofit. Many times the people pay for their renovations with their savings; therefore, it is not so easy to add the extra costs of a retrofit measure to the plan.	Householders	Many times people wait to save enough to pay for the whole renovation before to undertake it. In this perspective it could be challenging for them to add some extra costs for retrofitting to their initial plan. (quote from Yekatherina *"sometimes it is more difficult to take the decision to retrofit when you are already renovating"*)	"cost of the retrofit compared to the cost of the renovation"	Yekatherina Bobrova, PhD candidate at UCL Institute of Environmental Design and Engineering
Rebound Effect: "The assumption of reduced energy demand as a result of better insulated buildings will be affected by, for example, comfort take-back thereby potentially undermining policy objectives. Increase in disposable income and on the other hand, increased consumption of 'goods', while possibly providing economic benefits, could increase carbon emissions in other sectors such as agriculture or manufacturing, undermining GHG reduction targets".	Householders/ Energy providers	"Now we are assuming that once the people retrofit their house they will keep their internal temperature stable. Are we sure about that? I mean I can imagine households raising their house internal temperature since heating their home becomes cheaper. Is this a minor issue or does it need to be somehow expressed in the model?"	"Average internal temperature"	(Shrubsole et al., 2014)

People habits drive the energy consumption. Living in a house that has been retrofitted requires different practice to the householders. The way householders behave dramatically effect the energy use they make (and therefore consume). Households needs to be taught on how to 'use' the new measure.	Householders	For having an impact on the energy consumption it not just necessary to change the stock of houses but also the householders need to change their behaviour accordingly. Living in a retrofitted house might recognize different habits than what the householders were used to. Households might need to be taught on how to do it.	"Energy use" depends on the "EE level of the house" and on the "Compliance of householders behaviour with the new retrofit measure"	Yekatherina Bobrova, PhD candidate at UCL Institute of Environmental Design and Engineering ; Clive Shrubsole, senior research associate, UCL Institute of Environmental Design and Engineering with long experience in the construction sector
Unintended consequences of retrofit on householders. If not properly carried out the retrofit can create unintended negative consequences on the householders' life.	Householders	Currently in the model, all the retrofit measures just create benefits for the householders. This may not actually be the case in reality. Many times retrofitted houses generate unintended consequences that decrease life quality or create severe issues on the building in which they live (increase in internal humidity, dust mites, allergies, fabric damage etc.). *(From Katya personal experience: "I live in a house that has been retrofitted but that is uncomfortably warm! It is because when the retrofit has been done there was not a resize of the*	"Probability of unintended consequences"	Yekatherina Bobrova, PhD candidate at UCL Institute of Environmental Design and Engineering, (Shrubsole et al., 2014)

		heating system or a reconstruction of the ventilation strategy)		
Negative word of mouth. If householders experience negative unintended consequences, they might start to talk around in a negative way about retrofit. This might generate a negative word of mouth that disincentive other householders to retrofit. Moreover, most of the time negative rumours spread quicker than positive ones.	Householders	Once a householder experience negative unintended consequences, they will start to talk negatively about it. Moreover, negative rumours tend to spread quicker than positive ones	"Probability of unintended consequences"→ "negative word of mouth"; "speed of negative word of mouth"	Yekatherina Bobrova, PhD candidate at UCL Institute of Environmental Design and Engineering,
Quality of retrofit. The quality of retrofit is what has a major effect on the unintended consequences of retrofit. A retrofit work properly done has much less probability of generating unintended consequences.	Householders	Householders do not know about retrofit. The quality of the work depends mostly on the installers. The quality of how they carry out the work will in the end affect the probability of facing unintended negative consequences	"Quality of retrofit"→ "Probability of unintended consequences"	Yekatherina Bobrova, PhD candidate at UCL Institute of Environmental Design and Engineering, (Bonfield, 2016)
Fragmentation of the market and installers' skills.	Householders	What affects the quality of retrofit is that usually they are not carried in a holistic way. You can call a plumber, he can suggest some retrofit measure but he won't be able to carry them out properly	"Fragmentation→ "quality of retrofit"; "Skills of installer"→ "quality of retrofit"	Yekatherina Bobrova, PhD candidate at UCL Institute of Environmental Design and Engineering
The performance of the retrofit measures are not all the same. They depend on how properly they are installed, on the level of maintenance they receive, and on how the households behave.	Retrofit installers	For example many ventilation systems do not perform to their designed standards, with poor installation and maintenance cited as reasons for further reductions in capacity (failure to achieve the energy savings anticipated from design data). Moreover, increased ventilation without heat recovery could lead to	"Quality of the retrofit"→ "Performance of the retrofit measure" , "Maintenance capacity"→ "Performance of the retrofit measure"; "Customer behaviour"→ "Performance of the retrofit measure"	Yekatherina Bobrova, PhD candidate at UCL Institute of Environmental Design and Engineering, (Bonfield, 2016)

		energy efficiency gains being offset by ventilation heat losses with GHG emission increased or remaining unchanged and increased fuel bills, especially so if systems are not understood by end users.		
Perspective: Decreasing energy demand in order to decrease the carbon emissions is more an interest for the policymakers than for the householders. Retrofitting their house is still not perceived as a problem from the majority of the householders. Since savings in the energy bills and thermal comfort seems to be not yet 100% guaranteed by the retrofit measures, it can be hard to imagine why people should start to care about it. Consumers engagement is an issue also highlighted by the Bonfield Report	Householders	Decreasing energy demand in order to decrease the carbon emissions is more an interest for the policymakers than for the householders. Retrofitting their house is still not perceived as a problem from the majority of the householders. Since savings in the energy bills and thermal comfort seems to be not yet 100% guaranteed by the retrofit measures, it can be hard to imagine why people should start to care about it. (quote from Yekatherina: *"It is not a problem of the people, but only of stakeholders")*	/ (perspective issue)	Yekatherina Bobrova, PhD candidate at UCL Institute of Environmental Design and Engineering; (Bonfield, 2016)
Lack of trust in the Government intentions and support to a low carbon future as one of the reason why the supply chain won't gear up. Uncertainty.	Industry stakeholders	*"People in the industry have got long memories"*. After the push of the previous Government and the subsequent cancelation of its flagship policy (Green Deal) and related schemes, the people in the industry that made investments went out of business as result of this. Because they were expecting the Government to provide a stable business context in order to flourish overtime. "*Now if you are a company and you had invested a lot on that, if the new*	"Industrial trust for making investments"	Clive Shrubsole, senior research associate, UCL Institute of Environmental Design and Engineering with long experience in the construction sector

		Government will tell you: let's go in that road again, what would you do? They won't get their fingers burn again". It is necessary to persuade industry and investors.		
Decrease in the industrial trust on the Government because Zero Carbon Homes has not be enrolled out yet and because of other direction take by the Government (e.g. policies in supporting of fracking). Moreover, "Brexit" can increase the general uncertainty at national level (and it might decrease the likeability for the Industry to undertake investments on retrofit capacity)	Industry stakeholders	The fact that the Zero Carbon Homes Scheme hasn't been released yet (although it was said that it would be out in 2016) decrease the confidence on the effort the Government will put on supporting a low carbon future. Moreover, other policies, for instance in support of fracking, show that the Government might be other priorities in its agenda. In addition to all of that, "Brexit" increases the overall uncertainty and it is high people tend to not make investments.	"Industrial trust for making investments"	**Clive Shrubsole,** senior research associate, UCL Institute of Environmental Design and Engineering with long experience in the construction sector
Assuming that the demand for retrofit suddenly and considerably increases, it could be that the industry doesn't have the capacity to meet the demand. It may require to import more.	Industry stakeholders	If the demand suddenly increases and the industry is not expecting it, it will require between 12 and 24 months to 12-24 months to get it up, calibrate it, and make it running. In the meanwhile it may be required to import in order to meet the demand.	"Industry capacity"; "time to adjust capacity" (estimated in 1-2 years)	**Clive Shrubsole,** senior research associate, UCL Institute of Environmental Design and Engineering with long experience in the construction sector
Installer skills. In order to install the proper EE measure it is required to the installer specific skills. These skills regards more the ability to understand the whole building and what can be installed and what can't, not just how to carry out the installation process. It takes time and experience to learn this type of vision/skills	Industry stakeholders	*"It doesn't take a huge amount of skills to put many simple interventions in such cavity walls insulations, but the problem is knowing and understanding about the building so that you don't put in something that is detrimental".* In a case in Wales it has been applied the	"Installer skills", "Time to gain skills, Skilled workers"	**Clive Shrubsole,** senior research associate, UCL Institute of Environmental Design and Engineering with long experience in the construction sector,

		same measures to different houses and that created more unintended consequences than benefits. Acquiring this type of skill takes time.		
The skills needed to carry out the right job in the right places seem to be low in the market.	Industry stakeholders	Previously retrofit measures were put in place by companies that were specialized in other things, so they were doing an additional work. That is probably not the best scenario because they do not understand the whole picture of what they are doing and they might install a measure that generate unintended consequences. Therefore, now it seems that in the companies this type of skills is low.	"Unskilled workers", "Skilled workers gap"	Clive Shrubsole, senior research associate, UCL Institute of Environmental Design and Engineering with long experience in the construction sector, http://theconversation.com/royal-commission-says-insulation-deaths-were-fault-of-the-governments-program-31113
If the demand increases, meanwhile the companies closes the skill gap what may happen? Unskilled people may try to meet the demand and they could carry out improper jobs.	Industry stakeholders	In the hypothetic case in which the demand will start suddenly to increase, while the other companies are acquiring the knowledge and proper capacity to carry out the right retrofit measure in the right place, there will be people willing to do satisfy the demand. Sort of "*cowboys*" willing to take the risk of carrying out the retrofit measure without holding all the necessary skills. It is reasonable to assume that the work they are carrying out won't be the highest quality possible,	"Unskilled workers" → "Skilled workers gap" → "Installers skills" → "quality of retrofit"	Clive Shrubsole, senior research associate, UCL Institute of Environmental Design and Engineering with long experience in the construction sector; Esfand Burman, research associate, UCL Institute of Environmental Design and Engineering with

		increasing the probability of unintended consequences.		long experience in the construction sector
Companies might see the financial gaining but they also see the financial risks involved with that. Before starting to make EE improvements in existing buildings, companies want to have minimized the potential risks (for example accumulating enough skills and expertise).	Industry stakeholders	*"If you do an activity with what you are not familiar with it is likely to carry a high degree of risk"*. *"People from the industry need to feel comfortable that what they are doing is not to come back to bite them back later on"*. Therefore, before to make EE improvements in buildings, companies needs to see the potential risks decreased. For example accumulating enough skills.	"Skilled workers" → "Potential risks" → "Propensity of companies to do retrofit"	Clive Shrubsole, senior research associate, UCL Institute of Environmental Design and Engineering with long experience in the construction sector
Lack of confidence in supply chain	Industry stakeholders	There is a lack of confidence in the industry (e.g. poor quality installation or assessments done in the past; actual savings differs from the potential savings presented to the households, etc.). To most of households the house is their most valuable asset, they are very careful before to undertake retrofit into their house.	"Quality of retrofit" → "Performance of the measures"→ "Credibility of the industry" → "Risk attitude of households" (Trust of households in the industry)	Esfand Burman, research associate, UCL Institute of Environmental Design and Engineering with long experience in the construction sector
Quality affect demand	Industry stakeholder	In the case retrofit demand increases, if the quality delivered is very poor then the households would not continue retrofit and the demand decreases.	"Quality"→"Credibility of the industry"→ "Demand"	Esfand Burman, research associate, UCL Institute of Environmental Design and Engineering with long experience in the construction sector

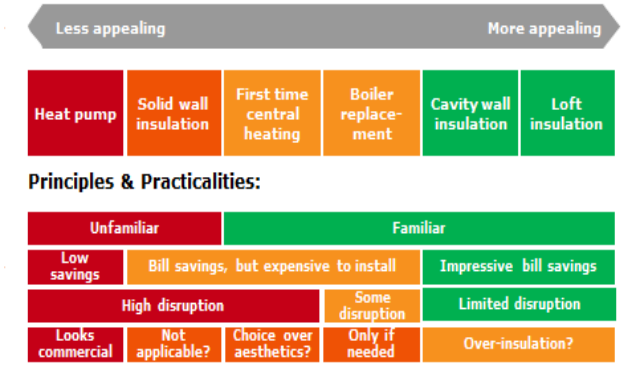
Performance of the measure	Households	The performance of the measures are directly reflected in the actual savings.	"Performance of the measures" → "Actual savings"	**Esfand Burman,** research associate, UCL Institute of Environmental Design and Engineering with long experience in the construction sector
Lack of supply chain skills	Industry stakeholder	At the moment, the supply chain seems not to have the necessary skillset to implement these measures (e.g. Green Deal assessors). "*Lack of skill in who assess and but also in who implement the technology*"	"Skills gap" (skills shortage)	Esfand Burman, research associate, UCL Institute of Environmental Design and Engineering with long experience in the construction sector
Low rate of skilled workers	Industry stakeholder	In the country there is a low formation of trained skilled workers	"Skilled workers inflow"; "Training"	Esfand Burman, research associate, UCL Institute of Environmental Design and Engineering with long experience in the construction sector
Staff turnover in the industry	Industry stakeholder	Construction industry is deeply affected by economic cycles: during growth periods it expands, while during crisis it reduces quickly. This results that during bad moments the industry tend to layoff or dismiss workers. Therefore, the shift in personnel in the construction industry is higher than in other types of industries. In this way, skills are	"Economic cycles"→ "Industry staff dismissed" → "Skills"	Esfand Burman, research associate, UCL Institute of Environmental Design and Engineering with long experience in the construction sector

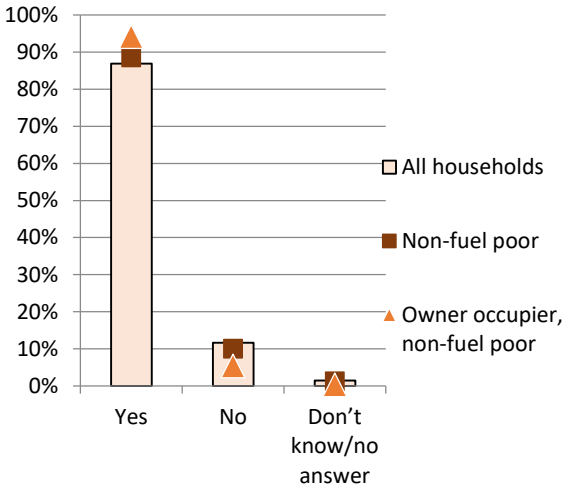
		lost and to recover them it takes time. This is an historical and endemic problem of all construction industry		
Perspective: The construction professional are not usually involved in this type of projects. The stakes of the industry many times seemed to be overlooked. To make a sound policy it is necessary to integrate in the decision process the industry.	Industry stakeholders	The construction professional are not usually involved in this type of project. The problems industry has don't even come across the radar of these people. *"You need stakeholders from every aspect in order to formulate good, sound policy. You cannot make policies in a vacuum. Because they [*policymakers*] don't think that way, it's not their fault, they do not have the experience"*.	/ (perspective)	Clive Shrubsole, senior research associate, UCL Institute of Environmental Design and Engineering with long experience in the construction sector
Even if the retrofit measures are installed correctly is it always economically convenient to retrofit? What is the probability that the projected costs savings from the measures installed do not exceed the loan repayments (or the investments if we set the payback time on a reasonable time range?)?	Householders	To what extent a householders can rely on the fact that the projected costs savings from the measures installed exceed the loan repayments (or the investments?)? Can we call these uncertainties as Uncertainty costs and how they could be measured? How do they affect the decision making process?	"Uncertainty costs"	(Rosenow & Eyre, 2016)
People perceive things as less valuable or significant if further away in time (temporal discounting), even if such things afford long-term benefits	Households	For example, people often 'discount the future' by preferring smaller immediate rewards (e.g., $5 now) over larger future rewards (e.g., $10 next year), and they may avoid actions that are costly in the short-term (e.g., outlaying time and money to purchase new energy-efficient appliances or making an effort to	"Temporal discount"→"Desired "payback time"; "Households discount rate"	(Frederiks et al., 2015)

		switch energy retailers), despite offering longer-term benefits (e.g., reduced electricity bills). This tendency to be short-sighted and make time-inconsistent judgements often leads to procrastination and inertia		
Households might aim to reach a satisfactory level of thermal comfort and saving instead pursue the optima solution	Households	People are satisfied by exerting only the effort needed to achieve a satisfactory rather than an optimal result; that is, settling for 'good enough' rather than 'best'. This can be reflected in the way they chose to retrofit	"Level of satisfaction"	(Frederiks et al., 2015)
General households' aversion to take risk (e.g. make investments in retrofit). Risk aversion leads households on the low-risk of energy-saving practices and investments that are safe, stable and secure, particularly where energy-efficiency technology is new, expensive, or not yet mainstream. Uncertainty around electricity supply, market prices, government policies and long-term financial payoffs make investing in energy-saving products and services seem like a risky decision for many consumers.	Households	People generally prefer to avoid risk even given the prospect of positive outcomes (i.e., gains). but more risk seeking when faced with certain losses or uncertain gains. Retrofit can be seen a risk, and therefore households might be reluctant to retrofit their house.	"Risk aversion attitude"	(Frederiks et al., 2015)
Fuel poverty. Concerns over the fuel poverty and the gap between the better-off and poor, with the neediest not benefiting from the policy.	Other Policy makers	Are the neediest truly going to benefits from the policy? Moreover, *"schemes can have on-costs such as increased installation/maintenance costs, reducing disposable income and creating stress"*	"Fuel poverty"	(Shrubsole et al., 2014)

Policy are not performance oriented but quantity oriented	Industry stakeholders	Policy makers are eager to increase the quantity but the tend to overlook quality. Increase in monitoring can increase the quality.	/perspective “Monitoring” → “quality”	Esfand Burman, research associate, UCL Institute of Environmental Design and Engineering with long experience in the construction sector
Maintenance cost	Industry stakeholder/ households	It need to be taken into consideration that some types of retrofit measure can have maintenance costs. Maintenance costs decrease the actual savings.	“Maintenance costs” → “Actual savings”	Clive Shrubsole, senior research associate, UCL Institute of Environmental Design and Engineering with long experience in the construction sector
Low cost of energy doesn’t incentivize people to go for energy efficiency	Other policymakers	The cost of energy is still too low to prompt households to invest in energy efficiency. Increase the cost of energy could make them more willing to invest. However, increasing the fuel costs will increase the people that live in a fuel poverty condition.	“Cost of energy” →”potential savings”; “Cost of energy” → “fuel poverty”	Esfand Burman, research associate, UCL Institute of Environmental Design and Engineering with long experience in the construction sector
Priority given to retrofit	Householders	Households have other priorities instead retrofit. They prefer to invest money on other options. Moreover, in these difficult economic conditions can decrease even further their available capital to invest.	“Disposable income” → “Priority given to retrofit”	Esfand Burman, research associate, UCL Institute of Environmental Design and Engineering with long experience in the construction sector
Income distribution and behaviour differences Based on the fact that the households prefer to pay for renovations with their saving, it might be	Households	Are there relevant differences in how people react to retrofit measures given their income level?	“Income distribution”, “Households capital	Domestic buildings: evidence on the able-

relevant for the discussion to look at their income and savings.			available for investments"	to-pay sector including owner-occupiers;
Technological development	Industry stakeholders	Industry is developing over time. We can't expect an huge increase in the measure efficiency as it is in other industries (e.g. IT). However a marginal improvement can be expected	"Marginal improvements" → "Technological level" → "Performance of the measure"	Esfand Burman, research associate, UCL Institute of Environmental Design and Engineering with long experience in the construction sector
Same savings can be obtained sometimes by changing energy supplier.	Industry stakeholders	Sometimes, instead than installing a retrofit measure (with all the related possible unintended consequences), it is possible to save the same amount of money just by changing the supplier and contract (e.g. school)	"Other suppliers" → "Cost of energy" → "Potential savings"	Esfand Burman, research associate, UCL Institute of Environmental Design and Engineering with long experience in the construction sector
Households' criteria for decision. Households include more criteria in their decision making process than just economic ones.	Households	Main criteria people look at when deciding whether adopt a measure(bold more important): - **Familiarity** - **Savings (compared to costs)** - **Disruption (time for installation etc.)** - **Quality guarantees** - Aesthetic benefit - Need for future maintenance (additional costs)	"Awareness" (familiarity); "Potential savings of the measure"; "Disruption of the measure" (Hassle factor); "Quality of the installation"; "Trusted information" (credibility)	"DECC Supplier Obligation Consumer Research: Summary Report"

Who households trust more. Households trusts more the opinion of family and friends than installers and Energy Saving Trust	Households	"Receiving information from trusted sources is particularly important. Family and friends are more trusted (34%) than both installers and tradespeople (18%) and the Energy Saving Trust (19%)"	Trusted information (credibility)	Domestic buildings: evidence on the able-to-pay sector including owner-occupiers
Appeal of the retrofit measures. Deep retrofit present a very low appeal to the households. They present high costs, lows savings and high disruption. From this point of view it is clear why households opt for light retrofit and why they do not consider deep retrofit. 	Households	Deep measures seems to be very undesired by the households, because they generate low savings and they are highly disruptive. It's difficult to understand why households should undertake them. On the other hand light measure (cavity wall and loft insulation) show high saving and have limited disruption. That's one of the reasons why they are spreading much faster than the deep measures. The question is: why should and households go for the deep retrofit? It doesn't seem to give them much benefits.	"Potential savings of the measure" → "Desirability of the measure"; "Level of disruption of the measure" → "Desirability of the measure";	"DECC Supplier Obligation Consumer Research: Summary Report"
Households' necessity of retrofit: lack of interest **Can you keep the living room warm in winter?**	Households	"*Focusing on the able-to-pay and particularly owner-occupiers, future policies are likely to need to tackle lack of interest and unwillingness to prioritise energy efficiency and low-carbon heating measures above other capital investments in the home. Our research shows that this is likely to be driven by a lack of perceived benefits (most owner-*	"Need for retrofit" (Priority for investment)	Source: English housing survey 2013 to 2014 (DCLG, July 2015), in 'Domestic buildings: evidence on the able-to-pay sector including owner-occupiers'



occupiers feel they can keep their home warm enough already) and lack of desire for the product compared to other more visible upgrades to the home."

Annex E: Second workshop transcripts

Workshop - 30th March 2017

MF1: Male Facilitator 1
MF2: Male Facilitator 2
DA1: Devil's Advocate 1
DA2: Devil's Advocate 2
M1: Male Participant 1
M2: Male Participant 2
M3: Male Participant 3
M: Male Participants

Coding scheme:

(variable name) = green

(contribution to a structural change)=

(discussion started by a DA) = orange

(generic interventions) = red (clarifications etc.)

START OF MAPPING PART

00:22:23

MF1: So we can start to discuss and see together the model. So feel free to go around, share, discuss, if you have notes, anything, questions.

First we want to ask to ask you to revise it, so if you see the flow is something that is not right, come here and we discuss it and next step is to add things that are missing, so we give the [inaudible] and you have some time for thinking about the [inaudible] ?

00:23:10

M1: So likelihood of defaults, default fraction. I don't know if we've seen any hard evidence that suggests there's a cordial relationship between people, better EPSs and lower default rates.

From the conversations we have with mortgage lenders, it sounds like the kinds of people that invest in energy efficiency are just generally people that are less likely … their working assumption is that those are people that are less likely to default, generally, because they may be from a particular social strata that priorities doing energy efficiency and therefore, you might get a slightly biased outcome, so that link, for me, feels quite weak and there's a lack of evidence around it at the moment and it could be quite a powerful driver for mortgage lenders, but it's not really there at the moment and when we talk to the Council for Mortgage Lenders, they did pick us up on this.

00:24:23

M2: I think the only driver is that thing about, if there were more defaults, which there aren't that many of at the moment, if the interest rates rise, you would think that they would want to take more concern over their affordability assessments and look at energy efficiency more. I don't know whether, necessarily, there would be a strong enough drive to get them to say 'well, we need to get legal improving their home; I think the driver would be 'oh, we've actually got to make sure we're taking account of this affordability more,' if you were starting to get defaults.

M3: Yes, so I think the only thing is we're in historically low interest rates at the moment and therefore level of debt distress is likely to be historically low, so the actual percentage difference between defaults of people that in different [inaudible] is likely to be a very, very weak signal at the moment and I agree, if you're getting to a much higher interest rate, a much higher interest rate is likely to have a more material impact, but that's maybe not likely to happen for another 10 years, five or 10 years.

00:25:29

M2: I think, from our discussion because we met with the Council of Mortgage Lenders recently and the strong driver is kind of lend more money, obviously … can I lend more money on this and the barrier is - one of the big barriers I think - is around trust in … does this actually save money? Does this actually save bills? Would you say that's fair?

00:26:10

M3: I would say that feels like a more powerful driver because given the current fiscal climate, the fact that they're losing business, buy to let mortgages, so they need to try and generate business from elsewhere and they saw this more as an opportunity as somewhere where they could increase their volume of lending, subject to their being evidence.

DA1: Also, with the paying customer, for example, through an energy efficiency improvement, reduce the monthly payments, that is totally uninteresting for them. (generic intervention)

00:26:42

M: I don't think it is, but I think they're saying there's a scepticism, about energy efficiency improvements reducing bills, so it's not that it's not interesting, they just say 'well, where's the evidence for the data?'

00:26:57

M: So the other thing that came up as well is that it's difficult for them to lend money o the basis of future cash flows, so they kind of assess you as you currently are and therefore, we got into talking about if you could have guarantees, if people could do work to their property and issue a guarantee, is that the kind of thing that you could lend against, if it was kind of an insurance back guarantee and it picks up on this point about the uncertainty about the actual improvement that will be driven by the energy efficiency measures and the degree to which they will be … the behavioural variance will counteract any energy efficiency improvement.

00:27:38

M: The other thing is that you could lend … isn't it also that you can lend on the basis of the improvement to the asset value? They were sceptical about whether it leads to an improvement in the asset value, so if you know that an improvement is going to lead to increase in the asset, then you extend the line of credit.

MF1: But the whole point is that improvement is going to happen?

00:28:16

M3: It's a bit like the default rate, it's the uncertainty of the lack of evidence makes it hard for them to … because they came across as very risk averse.

00:28:33

M1: This is key to the whole discussion, whether this increased the asset value. If mortgage lenders had that evidence, then they would, but they don't have the evidence.

There is one other thing, we're assuming that the interest rates are the same for a traditional loan and an EPC loan. When you spoke to the mortgage lenders, did they talk about that? It's just the way lenders work, not necessarily just default rates, it's actually the rate at which they can learn. So even if a particular market has a high default rate, at long as they can charge a higher interest rate, they might say to that actually, it might be a more attractive market for them because the really low interest rate markets are very, very competitive and everyone's lending and they're actually making a tiny spread on it, so a high default market doesn't mean to say that there won't be more capital to lend to that, that isn't the case, so if something's wrong with one of those circles, it's the loans repaying and capital shift of EPC lending, so you can have a higher default rate, as long as they can charge appropriately, that actually might increase the capital more

MF1: Obviously the interest rates are going to be …?

DA1: Interest rate and the repayment rate both influence their decision. (generic intervention)

00:30:05

M: Yeah, so it's what they can charge.

DA1: I think last time you mentioned that a reduction in the interest rate might be one of the policy options, right? (discussion started by a DA)

M: So one of the things we talked about is reducing capital as EPC requirements, of which it might mean that they are then prepared to lend at a slightly lower interest rate on greener investments, which could create a differential, potentially. They have certainly been incentivised to lend more, whether they actually pass that on in terms of at lower cost, as well as more, is another question.

00:30:53

M: It would be the volume would increase, so the volume would, but there wouldn't, necessarily, be a lower rate.

DA1: What was their reaction to it, how did they react to that? (contribution to a structural change)

00:31:08

M: Anything that allows them to do more lending … they kind of perked up at the idea of that. This question around whether it increases volume, or whether there would be an incentive to reduce costs on it. I guess that their rate is a reflection of the fact that they have to hold certain amount of capital against their loan book and that's got an associated cost to it, so if they're holding less capital, then they have less back office cost, effectively. So theoretically, they should be able to pass through their cost saving to customers, or at least a portion of that cost saving to customers because they won't have to hold as much capital against that loan.

00:32:01

M: I think it's more the opportunity cost of that capital, so rather than having secure government bonds, they're going to be actually investing in something and they could pass a proportion of that difference on to the consumer, dependent on how competitive the market is.

00:32:23

M: So instead of the amount of capital that they have to hold is an insecure asset, in a very liquid asset, is decreased, they can invest that in something with a higher return and they may - dependent on how competitive the market is - they may pass some of that on through a lower interest rate to consumers.

00:32:45

M: I think that's right and I think that competitive angle is key. So if other banks like the market, then the rates will come [inaudible] Other banks, who don't like the market, they'll charge as much as … so like the smart meter programme, you've got only two lenders, effectively, and they charge very, very high rates indeed.

00:33:06

M: Which means it's important to bring all people lenders on board with you to do something like this, which is where the voluntary stuff falls down, if you don't get everyone participating.

DA1: What [inaudible] so that they voluntarily ?? (generic intervention)

00:33:34

M: It depends on how credible that[inaudible] is and I think it depends on having agreement to cross government because otherwise, you can get into trouble going round threatening … (laughter)

00:33:59

M: I think we would have to issue a call for evidence, or something, that set out the prospect of doing something much harder edge, alongside some softer edge things, with a view that that would encourage them all to take action and do the softer edge things, rather than be regulated, but getting to a position where we'd be able to publish that would be quite challenging … obviously, within the confines of the room and the recording, it would be quite challenging to get that. I think it's plausible that we could get that.

I think the other thing is how many carrots we can offer because the more carrots we can offer, the more likely we are to get high participation, so if only those people that are agreeing to voluntary targets get these incentives and it's not spread across the market, then they're more likely to be willing to take on the targets in return for things like relaxing of capital adequacy requirements.

00:35:05

M: And then the other one is just directly subsidising their interest rate.

MF1: Now, we are going to the enforcement of the policy, so we can come back later, when we've settled the point. Do you have any other flaw that you can identify?

00:35:29

M: Just thinking about in that area, I think it's important to capture that … so we've got the trust bit, the other thing is … the flow for demand for measures is that still flowing in into …it needs to link in to the mortgage area.

MF1: Do you have any idea how the demand impact on the lenders, basically?

00:36:12

M: So where we've got the additional lending … because we'd got into a discussion with M3 saying 'okay, what happens when someone is doing up their home, then come to us, ask you for credit, presumably … yes, they do, obviously, that's something you go to your bank for quite often, or sometimes you'd probably go to an intermediary as well, but from the bank's perspective, they say … if we see like a demand for a certain product, or an opportunity around like solar panels, or something, then we might start offering something specific for that.

MF1: If the demand increased, most probably the demand for lending will increase and there could be some incentives, if they get lower interest for EPC measures, so should I draw a link from here to here? So lending for making retrofit.

00:37:28

M1: Yes, so consumers have got to see the benefits as much as the lenders, so it's not just the lenders thinking about increased cash flows as you made savings, increased asset value - that's all about the demand area too - so both parties have got to see that.

00:37:47

M3: Yes and I think the key is, I think this can be two way, I think this can feed back in terms of … maybe not straight to the demand, but at least to the awareness to something because if there is more demand and if they lend more, then it's like the prominence that they offer to people of that product for lending increases.

MF1: In the model, basically, you have here this connection … is it all the story, or are we missing something?

DA1: That is also kind of my question, is that all the story, the people who retrofit go to their bank. If you buy a car, or a caravan, you go to your car dealer and they offer you a financing plan; is there anything like that existing already? (discussion started a DA)

00:38:48

M: I think it depends very much on the supply chain. The supply chain do this atypically quite small, they are small building firms and they rely on people being able to access finance separately, so they just then charge for the work, rather than like you go to IKEA and they provide you the finance for your kitchen as well as the kitchen, you don't tend to have that

in this market, so people have to find funding from elsewhere and whether that's a home improvement loan, or whether that's going to their mortgage lender, or just using their own financing and we did some research, looking at how many people, when they do home improvements, how much is it people's own money, as opposed to borrowed money.

MF1: Eighty four per cent use their own savings, actually, so it is most of the market, unfortunately.

00:39:43

M: So that is something we should definitely try and capture within this.

M: So if you think of [inaudible] per cent, so what's the percentage you drop out because obviously, people will get it done and you're not capturing maybe the people who are like 'oh, it's so much hassle to go get the credit' because they don't want to go down the Green Deal route, it's all about financing, but I'm sure there's a drop off point there.

MF1: Can I say, they will be preferential lending, also incentive for people who want to retrofit, so there will be …

M: … and incentive.

MF1: Yes, kind of preferential … you go to the bank, they want to retrofit, just in five minutes, I withdraw my money and there's all the paperwork.

00:40:22

M3: The KFW loans seem to work in terms of encouraging people to do more than they would otherwise do.

00:40:33

M1: The German ones where they had zero per cent, basically.

M3: So there's a strong carrot there for people to actually do the work and that might reduce the potential drop off rate and it seems to be about people's … I guess the other challenge is people's willingness to borrow because they're perceiving it as borrowing money as opposed to … if you could de-risk that borrowing, I think that will make a difference … anyway, we're talking about the policy now.

MF1: I think this could be a preferential way for borrowing money for them, it could be an incentive.

M3: I don't know whether there's a market here already, but whether or not people doing work can offer guarantees on the work that they're doing in terms of the energy savings and whether that would have a positive loop within this system. Does that make sense?

M: Yes, in terms of credibility and more credibility from …

M3: You get a guarantee, an insurance backed guarantee that the work that you're doing is going to deliver the savings that you've been told and whether then mortgage lenders see that guarantee as something that they can lend against, or they're more willing to lend against it.

M: We can, for example, connect credibility of retrofit with this lending, but if we think about that insurance, if I think about myself, the [inaudible] will increase because not only do I have to go to the bank, but also I have to go to an insurance company.

00:42:21

M3: So you're reliant on the supply chain being able to offer you … so I'll come and do this retrofit work for you and as part of that, I will offer you a certificate, a kind of evidence, or a guarantee that this is going to deliver this many savings and you already see it in the non domestic market with ESCOs energy service companies and energy performance contract, where people say 'we're going to save you this much money and if we don't deliver this much money, we'll install extra work, or write you a cheque for the difference.' So I wonder if it's another link in this chain that we haven't really thought about.

00:43:02

M1: I don't want to go down the route too much … so you're offering a guarantee on the measure, not on the bills.

M3: That is what you'd need to look at further …

M1: Because there is an importance there, to [inaudible] the mortgage lender, do they really care what the ?? says, they just care …

M3: I think the way it works is it's a bill saving, so it's the actual energy saving in the non-domestic sector in terms of 'we are going to save you this much money. If we don't save you this much money, we will take remedial action.' So rather than measure, it's actually a saving they think they can deliver and they control for things like occupancy and stuff like that, as part of this, to account for behavioural changes.

00:43:54

M2: And [inaudible] changes is quite a big one. If you were told, no matter what, you'd save a certain amount of money off your bill, maybe you don't bother turning off your heating, or just put it up a couple of degrees, which you can't really account for, wouldn't guarantee it.

M1: So they are contractual stipulations and how they address that in terms of people continuing to use the building in the same way, or a similar way, rather than just suddenly opening all their doors.

DA1: Do they participate in the savings, in the energy performance contract, they participate in the savings, or they have an interest to install something, that generates the savings. (generic intervention)

M3: Exactly, so they get a proportion of the savings, but it depends on the different models because you can have these gain share models where the ESCO gets some saving and the householder gets some saving, or you can have other variances on that, but yeah, you're right, it's a kind of aligned incentive.

DA1: Do you have any evidence to how that translates to the domestic market? (discussion started by a DA)

M3: So we're starting to see potential new business models, where suppliers, or where installers could do work to a property and issue guarantees for performance, but they tend to be quite deep retrofit. So you've got companies like Energiesprong, which is a Dutch company, starting to look at the UK market.

We think that there are a number of barriers that are preventing this happening at the moment - and we're currently looking at it - but it allows you to close the link because one of the big issues is around uncertainty associated with the impact of the work and if we can address that issue, then …

00:45:53

M: … it just sits a bit centred in all these kind of areas, as we've been saying, it's like this uncertainty, what is this work going to do.

MF1: For example, you mentioned behavioural change. Is it like I can maybe put along these factors, there's determine the attractiveness, not strictly financial, but like there is thermal comfort. Maybe behavioural change is something that keeps people … 'I also have to change my habits.' Maybe people are less …?

00:46:31

M: With the way the technology is and everything, with the smart heating, into other stuff, we no longer speak about 'I have to change my behaviour,' it's all automated and that's where the future is going and that's within behaviour change, but really, it's just about how efficiently are you using … not even changing the fabric of the home, how efficiently is the thermostat being used, basically? Mostly, all the bad behaviour changes, user error, leaving it on for hours, that's where the waste comes.

M3: And so the ESCOs that you're potentially seeing will build off these kind of platforms, like Nest and things like that and they will use the data, to be able to work out the before and after and the degree of comfort taking and things like that you might get after an energy efficiency improvement. So you'll have quite a rich, data picture, where you'll be able to build some bankable propositions off the back of.

MF1: So it's a monitoring …?

M3: Yes a monitoring and a kind of accurate assessment is going to be really crucial in a lot of this.

DA1: Actual assessment of people's behaviour? (generic intervention)

M3: So the impact of the measure and understand the impact of a measure in the context of people's behaviour, I think …

DA1: It was one of the things [inaudible] mentioned that we discussed was if you have a deep retrofit, it might require a different behaviour from the customer, so if they continue to behave as they did, either because they just heat for the same amount of time, or because they continue not to ventilate … either inefficiency, but also severe, unintended consequences. It does really need the interlink with the customer's behaviour and also behaviour change that might be required if you deeply retrofit. (behavioural compliance)

00:48:39

M2: It was interesting because that came up in the Retrofit for the Future reports I was reading, in terms of once the work's been done to the homes, making sure that the homeowners are really aware about the new controls and how they have to operate them and that was important in terms of delivering the kind of savings, so I think it's important.

The question for me is the degree to which a lot of it can just be automated. If they are in the habit of always leaving the window open, that might have an impact on a house that's trying to be a passive house, for instance … that is a challenge, definitely a challenge.

DA1: It's a huge one because that creates, for example, if they're in the habit of never opening their windows and then they retrofit without having any other ventilation system and then they sit in a mouldy house and they tell their neighbours, so it can be quite a potential lever. (unintended consequences and all related connections)

00:49:42
M: So technology is quite a big solver to this problem, as long as you can make more and more stuff automated, use AI, or whatever, that's actually a way of solving this problem, apart from the obvious, by leaving the window open.

00:50:00
DA1: Is that so much technology, or is that something about being familiar, having lived with that, having the experience of a measure of how you go about it. (‘behavioural compliance’ and all related connections)

M3: I think it's about the techno/social interface, so it's about how new technologies, the feedback and interactions that new technology provides to humans, so at the heart of this, the most important thing that you are able to provide feedback to humans in terms of what they're doing might be having an impact, so you're already getting this with indoor air quality monitoring, where you get a load of feedback to homeowners about 'well, you need to open the window because you’ve done all this cooking, or you've sprayed all these chemicals around the house, so indoor air quality, there's already this kit and there's the potential for it all to become more integrated and once you do that, you can control for some of these things and people are aware because the problem is, at the moment, people won't know if there's mould growing behind their internal wall insulation and an indoor air quality device might allow them to assess that and they might be able to provide feedback to them, to encourage them to change their behaviour.

So I think it's once they’ve moved into the house, that there's an ongoing process of engagement with the homeowner in terms of how they optimise the performance of their house, rather than we install the kit and we leave.

00:51:36
M: So basically, I think there's a loop which goes from after the retrofit happens, then at the moment, as you said because of behaviour and lack of knowledge, you can end up getting the mould and you can also not getting the savings that the measure should deliver.

MF1: Shall we call it unintended consequences?

00:52:12
M1: Yeah, so it's two things, one is if I [inaudible] and then one is savings not delivered because of the behaviour change and you think one of the things that could moderate this, as you were saying, is technology which provides feedback, which automates the management of …

00:52:39
M: When you turn your dishwasher on, all those things, turning the heating …

M3: At the moment, that's really mediating with everything around the trust and the desirability and the measures because then people don't use it properly …

MF1: Can I try to re-frame it … so the performance of the measure, that could be a good way. So the performance …

00:53:07
M: It's like saving [inaudible] or savings delivered.

MF1: Kind of here, unintended consequences, by the behaviour, here and the performance, awareness, the idea of that, that's what you were saying, for …?

00:53:35
M1: Yeah, what I'm saying is it reduces the perceived savings from the measure, it reduces savings and so I'm feeding it back to these kind of loops, where you're thinking people don’t exactly …

00:53:53
M3: … that's the issue, if you don't address it … and also other things as well because it might be around retrofit desirability, so it might not just be monthly savings, it might be around the fact that my house feels overheated, so it's unintended consequences links to various things as well, it's not just about how much energy I save.

MF1: So do we see any other link from unintended consequences for the parts of the model?

M: We've got the rebound option here, if people have lower electricity bills, they just use more electricity, we've got that somewhere.

DA1: So that was energy savings not … you had a nice expression of that … not fulfilled, or something because of rebound, or because of many other behavioural things. (‘rebound effect’ and all related connections)

I just would like to bring up something again that you already [inaudible] because you're just developing technology, this stuff that you see that technology comes in with the measures, so I think we might need variables about that, to which extent there is technology about the measures, to which extent there is understanding of the occupants of the technology because I don't think if you do a loft insulation, or even if you do an external wall insulation, you necessarily then have knowledge of technological devices in your house; so they might come together, but they may also come together and there are different consequences. (‘technological development of deep retrofit’ and related connections)

00:56:09

M3: We're starting to see examples of where, in the US, Nest and going in alongside Johns Mandville, which is a big, fabric insulation provider, so they do technology and geo efficiency improvements, fabric improvements, at the same time and the idea is that that delivers bigger savings for some, it's bigger than the pot, these things work effectively together, so then the Nest thermostat, I guess, adapts how the building is being heated, based on this new, thermal performance to try and achieve, through automation, but for me, I would say that's more kind of a deep retrofit, where you're getting combinations of technology and fabric measures going at the same time and the single measures are more just like one thing.

00:57:03

M: There's no reason, at the moment, [inaudible] that would happen at all, it would never happen [inaudible] still saying people are selling the different products, you've got Google, basically and I suppose it could happen with a supplier offering [inaudible] heating; sometimes, the supplier might offer both the retrofit measure and slide heating control, but in a lot of instances, probably not.

MF1: Can we try to rebuild everything you said because I think it's quite important, like for example, this story would make sense, like performance, or effectiveness, for showing friends like the savings. So they are retrofit, retrofit performance and this is affected by the behaviour and the behaviour could be like rebound effect, or like mis-use, so also unintended consequences.

DA1: Understanding of the technology. So there are examples where there was a retrofit and, for example, a ventilation system was built and that report just put it off, or they had the new heating system, it was something technological and they just didn't know how to operate it, so they just stopped it completely. (generic intervention)

00:58:35

M: There's got to be some sort of technology follow-up, once something's been installed, actually, you have to know how to use it and that's often not the case.

DA1: Do they have a interest actually, do they have any incentive to spend the extra effort to inform the occupants? (discussion started by a DA)

(talking amongst themselves)

00:59:19

M3: … subscription services may allow them to offer things other than energy, it's like comfort and so things are Hive, for instance, and things associated with Hive controllers, that provide tailored feedback to the customers on an on-going basis, so there are new market opportunities for them, the question is, do they make as much money from doing that as they do just shifting units …

00:59:47

M: That is an interesting point though, is that model in the US, where it is actually in the supplier's interest to cut demand because of the [inaudible] day, with the heat demand. The suppliers don't want to shift more units than they actually … if they have to buy it, it's more expensive for them to get the suppliers, so it's actually in their interest to cut demand and there is a model, which Deutsche Bank have, which is based on that and they're actually financing the suppliers to install this stuff. So that's based on that whole daily diagram.

01:00:32

M: So we're looking at that as well because it can align incentives a bit better. You can control for things like performance effectiveness.

MF1: So, for example, we have retrofit performance effectiveness, so more savings. These are affected by the behaviour and the level of technology of the measure, also single measures because they are weaker, compared with deep [inaudible] comes from technology, but also affect behaviour because with [inaudible] maybe people [inaudible] feedback forms, you are using this retrofit, so [inaudible] mis-use, I understand when you talk about understanding, that creates mis-use, like a lack of understanding creates mis-use, so behaviour and then also rebound impacts on the behaviour, so finally on the effectiveness of the performance.

Technology [inaudible] follow up is people started to explain that it increases the behaviour, variable and also single measure degrees, technology ?? because deep measure, maybe they follow more the client, the consumer.

01:02:09

DA1: Could I make some suggestions. If you go do the technological follow up and you link that into understanding, rather than to behaviour and also, the single measure retrofit, you could also … you say the single measure we'd use as the performance effectiveness, what if you say it increases because it's simple, it's easier to make a single measure work than a combined measure, so maybe there is, first of all, the potential of the measure and then there is the [inaudible] to what extent it fulfils its original potential and mainly there is more risk in a deep retrofit than in a single measure. Is that right? (discussion started by a DA)

01:02:54

M3: I don't know what the evidence would be like … if the supply chain knows what they're doing and they did install it in one, particular measure, then you probably can have a greater degree of confidence, but they're doing something that's more complicated, more likely to have less … it's likely to be increasingly different for the homeowner and probably harder for the installer, so their level, the chance of them doing it as well is probably never, I guess, you could probably make that argument.

01:03:34

M1: This loop just brings in a whole, massive, other set of different behavioural things, so we haven't mentioned demographics, like housing stock and the age of the people in the housing stock. At which point, all of this is not going to happen and the demand and it goes back, so you need a younger demographic, just to get this stuff going and then you've got about 27 million homes, 10 of which may be old people. There are two bigger things to bring in to this, without technology and …

DA2: Also, some evidence suggests that installers tend to get advice on measures that seem to get bigger returns, ultimately, with the ultimate [inaudible] behaviour, whereas for the household, it might not be an option, like installing something your old lady who needs to actively get involved in changing filters and climbing to her loft to do that every three months. ('maintenance frequency' and all related connections)

01:05:18

M2: On a similar sort of thread, so on your perceived monthly savings … so I guess you've got to determine what the payback period is and what the discount rate is. Is that factored in there?

MF1: We have financial attractiveness … that's something we can discuss, how would we, for example, put in terms of equation …

M1: If banks knew that, they would be able to lend. That's the thing, you can't model the saving. It's easy to model an income stream pluses, but it's the saving, that's a massive thing, that is quantifiable, it's much easier.

M2: But if someone wanted a personal discount rate, how you would value, say 10 years down the line.

M: I see what you mean, so if you're 80 …

M2: … you'd rather have money now than in years, especially at 80.

01:06:27

M: A payback period.

MF1: So, for example, these are what we call financial attractiveness …

01:06:37

M: There's the value of the homes as well, it's not just the [inaudible] it's a return on the investment in terms of your ?

M1: And even if you're old, you often do things on the basis that your kids will benefit.

M3: What else do you put your money into, you just plough into the home, or save it for your kids.

M1: That's why, I think, you find empty nesters do quite a lot of investment before they retire, in their home.

MF1: That's return in terms of property value.

M3: I think the other thing, we're very much focused on savings, but I think the performance effectives links to all these other things like comfort and aesthetic impact, so if you have shoddy work done that wasn't very attractive, you'd put people off, even if it delivered the savings. If they do a good job, it will tick all of these boxes; if they do something that just delivers you savings, but it doesn't really improve your comfort, or doesn't deliver any aesthetic …

MF1: … so this is a point of plus, basically because if it was a proper job, your aesthetic should be perfect. Okay, just to get back on track …

M3: … if they did a proper job, your aesthetic could improve as well, I think the risk is that it does [inaudible]

DA1: Would they group, or would they just not decrease so much? (generic intervention)

01:08:26

M1: It depends … a solid wall insulation in a rubbish property, with ?? the rendering should definitely improve the aesthetic quality, whereas an internal wall insulation where you're taking away some of the thickness of the indoor of the room and the whole period features on the outdoor, it's going to decrease it.

MF1: So it's plus and minus?

M: It depends.

MF1: But you can reduce, for sure, the negative impacts, that's clear; it could also be a plus …

M3: … if they do it well and so we've seen good examples of where they do external solid wall insulation, more expensive, but it improves the aesthetic appearance of the house, rather than just bolted …

01:09:06

M2: … and I think this is a challenge, I guess, with the quantifying stuff, is that in some instances, you can see probably a dramatic aesthetic improvement, which makes the value of the investment really quite attractive, whereas in many instances, you [inaudible] quantifying the difference on that; there's a whole ream of properties, it's just like well … if you do solid wall insulation, it's not really that nicer.

M3: And most of our solid wall insulation is driven by ECO and ECO probably just encourages people to do the cheapest possible solid wall insulation, rather than one that has the best aesthetic appeal, which creates probably a negative feedback because then people see ugly, solid wall insulation and think 'I don't want to do it.' I don't know.

01:09:55

M: I don't know, I challenge that …

MF1: I think that's not just slightly typical [inaudible] energy performance, or just feedback ?? can have an effect on their word of mouth, physically, that's our main drivers for ?? model.

DA1: But is the [inaudible] model affected by the performance, or by the outcomes, kind of 'oh, I feel warmer.' 'Oh, it looks nice.' So that actually, those things affect the word of mouth. ('gained thermal comfort' and 'gained thermal comfort' connection to 'general public awareness about retrofit' and 'gained thermal comfort' connection to 'non-financial benefits') ('aesthetic impact' and 'aesthetic impact' connection to 'general public awareness about retrofit')

M: Yes, I think you're probably right.

DA1: Performance effectiveness is basically the accommodation for [inaudible] (generic intervention)

01:10:43

MF1: This is like before the retrofit, this desirability, let's say, so starting from the information that they have, then they retrofit and there should be some individual, where they experience the retrofit, so something … yeah, the experience of the retrofit, that depends also on the quality of installations.

Someone was mentioning that old people, they appreciate it more if the value of the house after retrofitting increases, that's why they could do it. Should we anchor this decision for …? Basically, if the house price of the [inaudible] increase, it's more likely to appreciate.

01:11:55

M: [inaudible] anchor, so that demand one as well, there's a demand for retrofit as well.

MF1: At the moment, yeah. The value that you see the house price increase if you have a retrofit house, so [inaudible] more, so then demand increase.

DA1: What drives the house price increase? (discussion started by a DA)

01:12:19

M: This is where we need to talk to RICS.

DA1: It's difficult to say that exactly [inaudible] (generic intervention)

01:12:25

M3: So we've had some work that has [inaudible] analysis, looking at the impact of EPCs, or correlation between EPCs and house price values, they suggest there is a link, but I …

M1: ?? impact and you can see the measure, like that's probably the thing that goes back and drives the value. The EPC value outright, whether it's B or C will, to some extent, drive value, but small, really small.

01:13:09

M: It's a regional thing too, so that the increase in the values in the south east are probably offset by stamp duty, or something; whereas if you are somewhere else in the country [inaudible]

01:13:22

M: So this is what the value is.

DA1: And by house category, right? A Victorian house probably has a lower EPC than a 1980s built house, but maybe the Victorian houses are more valuable [inaudible] energy efficient Victorian one; is that how you appraise them then, on the energy efficient Victorian one? (generic intervention)

01:13:46

M1: I don't know the extent to which the analysis control for similar house types and so a more efficient, Victorian property [inaudible]

M1: But then these are percentages, not absolute, so depending on the house.

01:14:07

MF1 So before we forget this concept, to what issues anchor the change in the house price, to something here, or something …?

01:14:12

M2: I think the interest rate differential … so we're talking about bank charges and different interest rates [inaudible] energy efficiency ?? that would have a significant impact on people's mindset.

01:14:30

M: [inaudible] being able to borrow, or lower monthly outgoings …

M2: Exactly.

MF1: So the price influences the interest rate.

M: The other way round.

DA1: The interest rate differential. (contribution to a structural change)

MF1: It's just not the demand that drives the price?

M2: The demand drives the price, but the demand …

M: … there's a link, I guess. The demand for retrofit would be increased if it was cheaper …

M2: … you could borrow at a cheaper rate and therefore your house would command a higher price.

MF1: But on the aggregate level, it would be the opposite.

DA1: The interest rate differential, that also drives demand? (generic intervention)

M3: Yes, if you know it's cheaper for you, your monthly outgoings would be lower if you were in a more energy efficient property, you would have thought, all things being equal, that would incentivise demand.

DA1: If the interest rate differential is given on to customers. (contribution to a structural change)

M3: Yes, so there's an assumption there about pass through to which that happens.

M2: And that should link in to your perceived, monthly savings as well; it's not just energy savings, but also interest savings.

DA1: So we need to distinguish the interest rate for banks and for customers? (generic intervention)

M2: Yes.

MF1: So it is interest rate differential for banks, or for a customer?

M2: What is charged to customers, so there is a differential, assuming it's competitive, then you can imagine there being a split between the interest rate charged to highly efficient properties and those of lower efficiencies and that would feed through to how much the customer thinks they will save per month and will impact how financially attractive the whole concept is.

DA1: But there is an entire model behind the interest rate for the customer, how that comes about and how that links back to the interest rate and the bank actually. (facilitation intervention)

M2: Yes.

01:17:04

M1: The house price percentage per band is driven by the demand, pure and simple, I think, that's what the value is, we don't set value. If people desire a house that's more efficient …

MF1: … since more people ask for it, it would become more …

M2: And it might not be that they're looking at it and saying 'that's a more efficient house,' it might be that the other features that happen to go with it, like improvement in the aesthetic quality is what they're really [inaudible] but that is creating the differential.

DA1: So you said the demand for retrofit, not the demand for housing, the demand for retrofit, that changes … (contribution to a structural change)

M2: I think houses that are more efficient, for whatever reason they are, are more desired, then you have that house price percentage per band. It's the demand for an efficient house, but as I say, that could be actually like a proxy, it might not be that they're looking saying 'this one is better,' it might be they're looking at the wall and saying 'this looks nicer than the one that's been newly rendered.'

DA1: If 90 per cent of the population want an energy efficient home, then you would expect [inaudible] (generic intervention)

M: [inaudible] made a simple point [inaudible] in terms of into the value of [inaudible]

MF1: Do you see any other mistake in the model, or do they continue to add new things actually?

M1: This is actually more like retrofitting … where's the light retrofit range … that's what increases … because it's basically a policy that we might do and hopefully will do, which is that when you make … and it also links in to the renovation thing, when you do renovation to your home, in terms of an extension, you have to do low cost measures for retrofitting your home at the same time, so you're going to extend, if you're going to build a conservatory, then you also have to, at the same time …

(talking amongst themselves)

01:19:51
M Habitable space.

M1: Okay, when you expand, then you have to do these other measures at the same time, it's like a regulation that we're going to put in place.

MF1: So when you do renovation, basically all the people have to plan a retrofit, right?
01:20:18
M3: Only where they're increasing habitable space. Where they're increasing habitable space, like doing a kitchen extension, or a loft conversion, they would also need to do wider energy efficiency measures at the same time.

DA1: Just in the new space, not … (generic intervention)

M3: In the new space, we would increase the thermal standards and in the whole property … lofts, cavities, hot water tanks.

DA1: So it's not right to use this term to express the fact that people who already retrofitted lightly, then go to … (generic intervention)

M3: … no, it's not. It's not about light retrofit when you are extending …

DA1: But if you extend your habitable space, you can be forced with a policy, just not doing [inaudible],but also retrofit, right? (generic intervention)

M3: Yes, so it's pushing people back into … anyone that goes there ends up automatically coming back into planning retrofit because they have to.

DA1: So if my house is lightly retrofitted …(generic intervention)

M3: … you wouldn't have to do it, if you'd already done it, you wouldn't have to do it.

DA1: So nobody will deeply retrofit, not anymore? (generic intervention)

M3: They might, if they're being encouraged to do these things, they might decide to go a bit further and do some other things at the same time, potentially.

MF1: Because [inaudible] like 2020, something like that. So once retrofit, lightly, 2020, it stops, if you cut of this flow, actually.

DA1: I think we just need to re-name it, it's not a full consequential [inaudible] (light to deep retrofit)

MF1: Do you have a better terms for it?

DA1: Deep retrofitting, or light to deep retrofitting? (light to deep retrofit\\repetition)

01:22:35
MF2: A question, I think something I heard, what happens if like forcing people to do energy efficiency and they are not so interested in that, they would probably go for the light retrofit, but is it the case that some measure … if I do this measure light, then I want to do a deep, I have to dis-install the light and so it's even more costly, it's even counter …

M1: I don't think so. It's more to do with the fact that in some properties … it's more to do with the type of property, you could very easily light retrofit some, you just do the cavity wall insulation, it's very cheap and the other requires the

solid wall insulation, different types of properties really. So there would be some properties, properties built after 1930/1940 with a cavity wall and with a hot water tank, so it doesn't have a combi-boiler, so it could be an older, semi-detached 1930s onwards houses.

MF1: Will it make sense because we talked about easy, medium, hard to retrofit, the last time, we didn't make sense just to say cavity wall and side wall because I think it's more available in terms of data about them, it's easier to say 'okay, cavity wall,' but it doesn't make sense, or it's not accepted like this? So associate cavity wall with easy to retrofit and solid wall with hard to retrofit. Will it make sense?

01:24:22

M3: There are other things you can do. I guess if you use it as a proxy … it's a proxy in terms of cost, it's going to be a lot more expensive.

DA1: How would you define light, medium and deep retrofit and do we also need to distinguish? [inaudible] I think you talked about that last time already, but if you could just repeat that. (discussion started by a DA)

M2: So do you want me to talk about it in terms of the number of measures?

DA1: Yes, what measures would you consider to be light retrofit, what would you consider deep? Is there a medium and, if so, which measures …? (discussion started by a DA\\repetition)

M1: I think you could probably say, things that were low hassle, low cost were probably light and things that were more hassle, more cost were going to be …

MF1: That's what you sent us last week, M1 … but, yes, [inaudible] certain point [inaudible] loft insulation and cavity wall can be kind of limited disruptions with easy to do. Boiler, first time central heating is kind of between [inaudible] so it might be deep retrofit for us at the moment. Do you think this is a good distinction?

01:25:49

M3: The only thing it doesn't really talk about doesn't really factor in these kind of smart technologies and I think a deep retrofit, for me, provably involves a combination of measures, involving some element of smart, to be honest, that would be my distinction here.

M2: Including what kinds of technology?

M3: Like metering, automated control, those kinds of things, which you wouldn't really get otherwise, that would be my only addition.

DA1: Even if we had an option of retrofitting [inaudible] standard without going to any technology solutions? (generic intervention)

M: I don't think, if you were to do solid wall insulation on its own, I wouldn't necessarily call that a deep retrofit.

DA2: But if you [inaudible] really deep insulation of all your house and just plenty of natural ventilation, just get aware of how it is done and in deep, significantly change your behaviour to make sure that your house is comfortable. (generic intervention)

M3: So I guess, when you talk about improving the insulation of your whole house, what are you talking about because that sounds like a lot of work, so that would probably be a deep retrofit for me.

DA2: Yes, but then it wouldn't include any technology, would it. (generic intervention)

M3: No, so I'm just saying, somewhere in here, we don't have ethnology at the moment and I think, at the most extreme end, a combination of fabric measures and technology will deliver you the biggest savings, I would have thought.

MF1: Smart technology, right? So insulation plus marks is a deep?

M3: Yeah, but the thing is, with smart technology, is it's cross cutting because it actually is not very disruptive, you can go in and install a smart thermostat very easily, it takes an hour for and E.ON guy to come in and install it, so it's appealing, but it also maximises, potentially, the impact of these other things.

01:28:02

M1: [inaudible] so much, it's like, to be honest, it's a separate kind of market probably with slightly separate drivers - I'm not saying we shouldn't include them, I think we should - but it's probably going to accelerate on its own course, quite unrelated to some sense, how much people are retrofitting their homes.

M3: So I think there is, potentially, quite a virtuous feedback loop in terms of people who do this become more aware and then they're more likely to … and that's where you're starting to see some companies that offer these thermostats and controls, then offering bolt-on, energy efficiency packages afterwards because they can develop a rich picture of what the house looks like and what kind of measures would work in that house.

DA1: I think the retrofit technology is an important one and last time, I think we distinguished between the light, medium and deep that light was on this side. You called medium a single installation of one of the deeper ones, by just having a heat pump and nothing else, or just having a solid wall insulation and then the deep one would be the combination of the deeper measures. Is there something that we need to capture about the combination of measures because that might … is there some supply chain skill involved in being able to just offer one thing really, offer them in combination.. (facilitation intervention)

M3: That's where you need architect, or engineers … if you were doing a combination of measures to make sure you minimise the risk of things like mould and stuff like that, so if you were to be doing solid wall insulation, you might need to have mechanical ventilation installed at the same time. So talking to some builders that do these kind of deep retrofits, it involves working with the designer, with the engineer, having a project manager that oversees all of the work together and it's certainly more complex proposition from the supply chain angle - it might be that the consumer only has one person that they deal with, like the project manager, so they don't see the complexity, but I think it's a slightly different supply change.

01:30:20

M1: That's the key differentiator though, one of them is then that it's a very different supply chain because you can still get a solid wall insulation job done by [inaudible] relatively few people and that does happen.

DA1: But you say then, it's a totally different thing of having a real deep retrofit, that's not what your subsidy programmes that you currently have triggered … (generic intervention)

M1: Yeah, that's triggered a single measure … on solid wall as well, definitely, there's a not insignificant amount of solid wall insulation being done and subsidy programmes, but it's very much that and that's it.

MF2: So it makes sense to have a single measure supply chain and deep, or an integrated, somehow, like in the sense that they offer not only that measure, but more measures and also some smart technologies to keep track, or maybe we can capture that effect in terms of this kind of retrofit also creating feedback in terms of awareness, more awareness of the people.

01:31:45

M1: If I was a minister, or an outsider, looked at that … the elephant in the room is where's the windows? That's the first question that comes to mind. I know we talked about why don't we have the experience of in the supply chain, replacement windows, why isn't that part of the whole …

M3: In terms of on here?

M1: Yeah, as a light retrofit. Presumably, it's the first thing and that's where …

DA1: It's what people do, but it's not really the most effective thing. (generic intervention)

MF1: So double-glazing here?

01:32:34

M1: … with the longest experience, going back 20/30 years of power, these retrofits work on the supply chain and how people pay for it, knowing that they're going to, hopefully, save some money.

DA1: Do people do windows because of energy efficiency, or are there actually other reasons to do with the windows? (discussion started by a DA)

01:33:00

M3: Again, you guys might have seen from my recent research, when prompted, people will point to that as something they did Also, you're right, probably it's noise and [inaudible] evidence of [inaudible] noise reduction.

01:33:18

M: Thermal comfort is as well [inaudible]

M: It makes the room warm.

M2: I think there is probably a strong link between double-glazing and property value because whenever I look at a properties on Zoopla, or whatever, it specifically states whether it's got double-glazing or not, it doesn't mentioned loft insulation.

01:33:40

M1: And there must be a big data set going back a long time.

MF1: It's also quite visible actually …

M3: And it's not something that's typically happened through any of our supplier obligations, it's very much a separate market because it's people that just go to Anglia Windows, who then charge £10,000 to replace three windows and

offer you a £5,000 saving, so it's very consumer led, it's not the kind of thing that we subsidise to date. Loft insulation as well, it's a completely separate supply chain.

M2: Do they offer financing?

M1: They do offer financing, with the bigger companies.

MF1: For now, we have two parallel supply chains, deep and single measure, but would it be possible, somehow … I mentioned a lot of people who do, for example, only boilers, a lot of people do only cavity, to create something like to put them together, a supply chain than called them is not like other people, but use those people, so somehow, the kind of flow from single measures to deep measures, would it be possible that that's maybe what we are interested in?

M: So the relationship between single and deep?

MF1: Yes, some people working on only single things, passing them into these stocks, or like deep [inaudible] that they are in contact with a project manager, so it's something that we maybe can think about, having a flow from here to here?

01:35:37

M: It's the other way round.

DA1: What exactly would drive that, what would that mean in reality?

M3: I'm guessing it's [inaudible] and this is where the super homes comes in and it's the idea that people start - it's a bit of a journey - so people start by doing one or two efficiency measures and they get the buck and they go a bit further and they do more and more and more. I don't know how strong the link is between these two different supply chains, but I think it's probably word of mouth and it's also a perceived benefit, if you feel you're getting benefit from having done these single measures, you might think about doing more, so it's partly your own, individual experience, I think, would encourage you to do more and then contact other people.

MF1: But would it be like another single measure?

M1: The other thing to think about is where that supply chain is and is likely to develop is in a particular area, which is around social housing, is around where people have a really strong incentive to just re-do the entire property and they don't necessarily get along with the people who actually live there; so they're either a developer, or they're a social housing animal and that's where that market that we're noticing at the moment is emerging.

So it's a different kind of one, whereas the single measures that are done at the moment are kind of all over the place. Some are in the same area in the social housing, but somewhere where we are interested in are the owner/occupier, so I think that's key to fed across, they're aiming at different markets at the moment, they're aiming at different consumer groups.

MF1: So they are quite separate.

DA1: And they are also completely separate companies. (generic intervention)

M3: I suspect so. The kind of people that might do these single measures might be British Gas engineers, for instance, doing your boilers, or they might be eco-installers doing lofts, or doing oil boiler replacements. They just do that, specialise in doing one and do it as effectively as possible. I think they are quite different.

MF1: Quite different, okay.

MF2: There is no chance that there is a figure that knows who to call, like the insulation company and the other company who do boilers, can make them work together in the same house, no?

M3: That would be a project manager, who might come in under the deep supply chain. I don't know … when I had my loft done under eco, some people just rocked up in a van and just rolled out insulation and left and really didn't speak to me much. So I don't think they're there to on-sell other services, or try and engage the customer in trying to do other work, if they've already done the statement.

DA1: And you're also not thinking about a mechanism and how to create the capacity for deep measures with individual installers that just have the capacity for one thing at a time. (generic intervention)

M3: What we're thinking about is probably trying to incentivise different thing that might encourage people to look at doing more than one measure, which might mean that you get a supply chain reconfiguration, which might mean we get more supply chain that's similar to this kind of deep retrofit market, but we haven't thought specifically about whether you can require your eco installer to go out and then have a conversation with the customer about …

01:39:57

M2: … I think, again, it's fair to say that we have tried to artificially create deep retrofit through our subsidy programmes before, by requiring multiple measures and things and it hasn't worked that well because of the way we tried to do it, I guess.

01:40:21

M1: I was going to say because of the way the market's structured, so effectively, you've trained your life to be a gas fitter, you pay your [inaudible] for that, you're not going to pay £1,200 a year to do other things … it's not like an Amazon, or a shop who can sell more than one product, it's not exactly a shop with a shop front, it's a man with a van.

M3: Bringing the whole thing together into like a [inaudible] offer is really complicated, which is why …

M2: … and even then, it will be different people within the company.

M3: They will sent out multiple people to do the work.

M2: Exactly, so you do the boiler, you do the loft insulation … they might do it at the same time.

M3: So effectively, it will be a virtual project manager, who will manage behind the scenes and say 'I'm going to send these three people out to do the work. Which is why, trying to create this whole, new model, it's very hard to do it ad hoc.

01:41:24

M3: We do it with the kitchens and we do it for bathrooms because the commercial appeal of those as a product, as a thing, is large enough to justify having the project manager on top of the tasks.

M2: What's the benefit of not doing it separately? Is there an additional benefit of one person doing it altogether?

M3: When we previously did this, we thought that because of the challenge in terms of the perceived benefits, if you do one measure, your actual perceived benefits are quite slight and intangible; if you do a lot of work, you can make a really noticeable difference to the home in terms of its aesthetic value, it's comfort, its energy savings, which will create a positive word of mouth loop …

M: … and, I guess, less hassle

M3: Exactly, less hassle and we're working on the basis that you're only going to have one or two shots at doing a retrofit in these homes, between now and 2050. So you could go at it and continually re-acquire that client and do a measure by measure approach, but the costs go up …

01:42:28

M1: If you think about our thing of trying to link it, where we talked about tax reduction or something, I suppose we talked about where can we do it, or even I think the stamp duty … where can you do it so that you incentivise the deeper retrofit, so that you start to create all of that that we're talking about actually having more of a product at the top of the market and then, hopefully, that other things fall into place, but if you think about where we sit and what we can actually do in terms of influencing the market, we can't go out there and train all the people to do it, but you can say 'well, let's give some extra incentives for doing it.'

DA1: With also incentives, you say giving some incentives; what we hear a lot from industry is they say they would invest in anything if the incentives were just constant, if they knew that they would still exist in three or five, or that many years time, so that seems to be a crucial element in them going into any direction. How can you ensure …? ('industry trust' and all related connections)

01:43:45

M1: You can't in a democracy, is the short answer, because any future politicians have the right to overturn in a new manifesto and a new mandate.

M3: What we're thinking about in the private rental sector and social housing is that you could have longer term targets to work towards and it gives you a visibility over the next 10 to 15 years in terms of the improvements and that was part of the reason for thinking about could you do something similar with mortgage lenders because at least it's set, so kind of a long term signal to the market that says, over time, they're going to have to improve this work and even if the actual short term incentives, or grants, or tax breaks ever flow, overall, there's still a signal in the background that's just driving increasing improvement.

If you look at a comparable sector, you're looking at something like vehicle emissions directive which requires fleet average of cars to improve over time. You've also got the government, every so often, injecting a bit of money, to try and encourage people to buy electric vehicles, by subsidising electric vehicles, putting people through at the top end and the idea is this is kind of short term and subject to political will, whereas this underlying trend of improving vehicles over time is just slowly pulling up the market and just doing this thing on its own wouldn't work, I don't think, to be honest.

MF1: Okay … [inaudible] industry trust, that you can have ?? investment ?? EPC ? to the consumers, give the direction to industry, right, okay and it should have a long term …

01:45:36

M1: What M3 is really talking about is the target … I guess it's a fraction of EPC capital then, but it's more …

M2: It's the projects we can set regulatory, or laws which can last some time. You can't set monies that last some time, is the short answer. So through law, we can set very long term signals, but we can't guarantee monies beyond … probably three years.

M1: We've got to put on here, unfortunately, to go with these incentives, we've got to put on here that the subsidy expectation delay impact, it's like deflation, you're not going to do something now because you're going to get a lower price in the week and there's that and we did talk about that last time, in the demand and the supply chain, just the expectation of government intervention is actually freezing current activity, so that's going to have to go somewhere.

MF1: So the subsidy's expectation is creating investment because they are waiting for the right moment to do that.

M1: If you were expecting a better entry point, just going to wait, so just the expectation is, in itself, blurring demand, demand for retrofit … it's increasing the whole thing.

MF1: So because of the delay in the system …?

M1: If I think there's going to be a subsidy next week, I'll wait …

MF1: So subsidy expectations …

M1: There is probably a more elegant way of saying that. It's when you're delaying action because of a … it's like the expectation of a subsidy, rather than the subsidy itself.

M3: The point is, if you invest and then tomorrow, a subsidy came along and somebody who had waited for that subsidy to come along, then they are going to be compatibly better, they're ?? better. So investing at the wrong moment is the key point and that could be too late.

MF1: So subsidy expectation works on the industry, or on the customer?

M1: The customer …both.

MF1: Both … can I draw an arrow?

M1: Yes.

DA1: That also works strongly on the communication of the industry to the customer (generic intervention).

M3: And penalties? Is there the same standard for penalties, than incentives?

M1: If penalties were going to come in yeah, and that's the same as a subsidy ending and when that ends, by December 31st, you get a massive amount of activity and then it drops off a cliff in January, that's the same, it's just the reverse of that, so a penalty would be the same as a subsidy ending, effectively.

M3: But with a penalty, so if you introduce a penalty, saying that we're going to introduce a penalty as of this date, do people start to take action pre-emptively? So this idea of diesel vehicles in London being penalised, people are starting to sell diesel cars way in advance of that.

M2: You can see that now.

M1: Which maybe pushes us more towards the kind of …

M2: That would have an implication on costs though.

M1: Well, it depends how you design the penalties.

M2: If you did a kind of set date [inaudible] reverse, from now on there is a massive penalty, you suddenly increase demand, which would allow the company to increase the cost.

M1: We're talking about incentives, so we should be talking about penalties and incentives in the same breath and thinking about how they could work … even if it's just to sweep up at the lower end of the market.

M: What are the objectives of today?

M1: It's just to try … this is the map off the back of our last workshop, which is trying to fill in the gaps, to work out anything we're missing in here, other relationships in their model, which allows them to then build a more robust and unique

model, where we [inaudible] show relationships. So this is the key thing that we're talking about here is the retrofit … so this is the lenders, this is about retrofitting factors, household retrofitting factors, this is about the supply chain and how the different supply chains may work.

01:51:09

M: It's really helpful actually, in trying to …

M1: In understanding relationships?

M: Yeah, well also segmenting the problem.

M1: So what it allows us to do is work out if we do particular interventions, what it might do.

M3: Effectively, they can choose to go anywhere. Manufacturers obviously have very strong links because they make the products … it's still interesting. We've been talking about, for a while, the idea of some kind of pay for performance.

M2: I think that's a really good idea.

M3: And that allows you then to top to pilot measures that might not be [inaudible] compliant, but where people feel that they can at least deliver larger energy savings, which then helps us build up evidence to then be able to, potentially, include them in SAP.

M2: The difficulty at the moment, the thing I've got, which is you're not effectively measuring measure performance, which is where we're having difficulties with house performance. So are you including measures like when the phone company rings up and says [inaudible]

M3: Well, we'll need to think about this. We, ultimately, leave it to the companies to decide how they achieve the outcome, it could be a mix of … it's likely to encourage deeper retrofit and a range of both fabric and behavioural measures.

M2: It's almost certainly going to be because again, cost would drive it, so it will be … because most [inaudible] basically, ?? demand, exactly what happens on the grid is they just ?? customers and say 'don't use much energy.'

M3: So what's happened in the US where they've done it is you've got Nest, partnering with people like Johns Mandeville, fabric insulations, they do smart thermostats and then they do a bunch of energy efficiency improvements, fabric improvements at the same time.

M2: But if you are driven by cost, which stakeholders are, in this case [inaudible] electricity market, to see what happens.

M3: That's a good point, we have to think about that and think about whether you control …

M2: … to be honest, I think the need turn their thermostat down might be a behavioural issue which you wanted to do.

M1: Yeah, I think what you'd want to do is you'd want to do it together, so if you do it, it would be part of fabric improvements, rather than just on its own, maybe. So you'd have the fabric improvements and then behavioural …

M3: I think that's even worse [inaudible] If you're saying that you need both fabric and behavioural ?? for measuring household performance, trying to work out what proportion ?? behavioural is going to be.

M: Hard.

M2: Yeah and so many components for behavioural as well and they all kind of link together.

M1: So ?? innovation, but yeah.

M: I think you need a really good kind of metric and this is what they're developing in California, this is what we need and …

01:54:55

M2: The California one, it's interesting though because they're not …

M3: They're not what?

M2: It's a straightforward reduction of the household … it's really easy because you don't need to ascribe it to anything, it's really easy, as soon as you need to ascribe it to something …

(01:55:10 to 01:59:50 - not transcribed) BREAK

MF1: I would like to ask you to brainstorm, like two or three variables that you are think are missing in the model because maybe we are just missing something, that didn't come up in discussion, they are overlooked, so we can be assured that everything is in sight and then, when you are done, I would like to ask you to start to place them on the map, where you think is relevant.

02:06:35

M2: The wider economic outlook, when you're making the investment, will feature into … if you're in the middle of a recession, you're not going to make a best investment.

This is what I was saying, so the relative attractiveness of this versus other things and then ditto for the economic markets, so the lender's market will come into this market, if the market [inaudible] other markets.

M2: And the other one I was thinking of as well is the economy scale and supply chain will push them down either … they thought they could do really well be focusing on one thing, or focusing on the deep retrofit.

M3: I've just written down 'skills' which isn't very helpful and you've probably discussed it already … I didn't quite know where to put it. I think it basically comes out of college. You go to college, you learn one thing, you set up a small business in one thing and then the fact that we want a different model doesn't affect the way that we …

(Talking amongst themselves)

DA1: What exactly do you mean by that? (generic intervention)

M3: If you have this, it's likely to increase the desirability and leads to people more actively telling other people, through word of mouth …

DA1: Who gives feedback and whose work? (generic intervention)

M3: There's a question, so it might be at the moment, people do the work and then go, but actually, what you want is people that do the work and then continue to provide advice. It's a service, rather than just a one off bit of work. Less turnover sales of homes making straight potential for deeper retrofit. So if we were assuming that deeper retrofits are going to be more invasive and increase hassle factor, if there are people more likely to be staying in their homes, less likely to be moving, then … you've kind of got that already.

Willingness of other actors to contribute to retrofitting … commission might increase the desirability, financial attractiveness … so it's you are paying for most of the costs, but other people might be contributing to that cost because there might be benefits to them and then, I guess, something around the capability, the supply chains respond to demand for deeper retrofit.

02:10:15

DA1: We still have quality and monitoring … then the technological development of deep retrofit, which might sit between the deeply retrofitted and the costs, so that if you do a lot, then that technology becomes cheaper to do the same thing, or you connect more. ('quality' and related links) ('monitoring') (connection between 'technological development of deep retrofit' and 'suppliers cost for SM') (connection between 'technological development of deep retrofit' and 'suppliers cost for DR')

DA1: Then we have the household side on the one hand, there are sustainability concerns and the preference for energy efficiency. ('households sustainability concerns' and related links) ('households preference for energy efficiency' and related links)

02:11:21

M: It's five to eight percent of people … it seems to be relatively constant, it seems to more that stage of life thing.

DA1: We talked about technology and particularly the deep retrofit that you would see together with technology, but also there might be a question of maintenance, the maintenance costs and also the maintenance frequency that has an effect on how good the retrofit actually performs. ('maintenance costs' and all related links)

M3: That's true, if it produces maintenance costs, then that's another …

DA1: Cost and also performance … (generic intervention)

M3: And that's on the of the things that Energiesprong … reduced maintenance costs as well as energy savings.

M1: It's the consumer retrofit tax credits; in other words, the money you pay, you just take off your tax and that will just kick start the whole …

MF1: So basically, the upfront cost, it could be lower?

M1: It could be here, it could be here. It just means that you know, for you, it's going to be netted out, you're not going to be spending anything and that's how, in the US, they tend to incentivise most energy schemes with a tax credit.

MF1: I don't know if everybody heard what you were saying, what are your variables. This one was …? It's this one, right?

M3: Yes, it's limited to this one, if there's less turnover, it will be harder for people to do deeper retrofit, assuming that there's lots of hassle and disruption … less turnover of property sales might make it harder and we're in a climate where people are staying in their existing houses for longer.

M1: Could house prices go up, irrespective of sales? If the energy value is reflected, I don't know …

M2: What about people who don't move, the cost of doing like the next step up, or whatever, it's so hard.

MF1: How strong is the link?

M3: I don't know, it's just in my head.

M1: But building work and refurbishment, generally, are related to change in ownership.

M3: My argument is extensive building work - deep, more incentive works, it's more likely to happen around the time that people move.

02:14:20

M1: So a correlation between it.

M3: Yeah, so maybe a correlation.

MF1: This one, can you explain capability of supply chain to respond to …

M3: … demand for deeper retrofit. So if there isn't much of a market there, then if we were to enact changes that led to demand, it's whether or not there would be the capability to respond to that demand.

M1: It's a limiting factor. Any policy that we do, where we're trying to incentivise the deeper retrofit, whether the tax deductions, or whatever, the impact is going to be really heavily limited by the fact …

MF1: … but it cannot be up to the industry to provide the measures … that's quite important, actually.

MF2: Will it create an incentive for that industry to grow?

M3: Yes, if there is a demand, then there will be a response, but I guess it's how quick that response is. You might have to signal the fact that you're going to be doing something …

M1: … another five years, or something.

M3: Yeah, exactly.

MF1: [inaudible] because I think it's very important, like there's an increase that increases the stock of the supply chain, right?

M3: Yeah.

MF1: It depends on the investment, I assume.

M3: Yeah.

MF1: And on this, we can call as 'time' basically?

M3: Yeah and skills, I guess skills is linked in there, isn't it.

MF1: Yeah, sure. You put skills, do you think [inaudible] like to connect the skills to the supply chains.

M3: Yes, for deep retrofit, yes … it's not just deep retrofit, it could also be … the classic one I'm thinking of is the major delays up in [inaudible] where because most of the supply chain weren't trained in how to install condensing boilers, so they fought it tooth and nail. It was only because British Gas trained all their installers …

M3: … it got through.

M1: Yes because basically, half the market could do it, half the market couldn't, so they had to learn to come up, but until then, there was no incentive to re-train, to be able to learn a new product.

MF1: So the technology goes also to the stock of the supply chain, right [inaudible] new technology, we need new skills, that's what you are saying.

M1: Yes.

DA1: So it reduces the skills, until they are really rebuilt. (contribution to a structural change)

M3: Yes. Basically, you're [inaudible] skilled and again, it has to be [inaudible] make sure [inaudible] everyone skills up to be … so they [inaudible] information packs and therefore, lots of people had spent thousands of pounds and wasted it. If you remember heat pumps, everyone changed up to heat pumps - most of them don't ever install heat pumps -

because the demand wasn't there, so therefore, effectively, from their perspective, wasted lots and lots of money, so at the moment, no-one is re-training for anything.

MF2: So would it make sense to have supply chain as a stock, but it's not really specifying whether it's a skill …

M3: So the question for me is the existing skills are there, but the challenge is more bringing those skills together and that might be the challenge, it might take time to identify that there are four or five different sub-contractors you might need to be able to do some work on a property and if it's the first time you've done it, developing those relationships … so there's a skills issue and then having trusted subcontractors you're prepared to work with.

02:18:18

M2: But then it's reinforcing the time and the cost and hassle needed for you to aggregate those skills is reflected in the cost to the consumer, so from the consumer's perspective, it's better to do it measure by measure because the alternative is an aggregator that's …

M1: … it's that really good point where we always bet down to chicken and egg. People say 'oh, there's no demand.' We say 'oh well, there's no product.'

M2: Consumers are happy with the market where they're going measure by measure, then the alternative is [inaudible] takes time to [inaudible] We've got evidence from the Green Deal on this, so look at the Green Deal legislates, see the ones that did. It wasn't received in Scotland [inaudible] single measure and we just plugged them really hard.

The ones that failed were the ones that tried to aggregate [inaudible] Green Deal offer, but the additional cost wasn't attractive to consumers.

DA1: Do we need to distinguish what drives the size, whereas also what drives the capability of the different supply chains? It could be different things and one capability seems to be linked to skills and so on, but you can drive the size without improving capabilities and skills. (discussion started by a DA)

M3: The incentive will drive the size, but it won't necessarily improve the capability.

02:20:02

MF1: Since we are talking about the supply chain … can you just explain the tailored feedback to consumers?

M3: So this is a kind of positive, reinforcing loop; so if consumers perceive that there's a benefit, but they don't really have hard evidence, they won't be as talkative, but if they get a monthly feedback report saying well, having done this, it's delivered x, y and z, then they're much more likely to be able to spread it via word of mouth.

DA1: And the tangibility … ('tangibility' and all related connections)

M3: … tangibility, yeah, it makes it much more real for them and they can tell their money saving expert friends that they've saved this much money from doing this work and it starts to create a virtual circle, but if you don't give them the numbers, or the evidence, then it's harder for them to convince other people.

The only other one I had was willingness of other actors to contribute to retrofitting, which might improve the financial attractiveness, so I'm thinking about local authorities, clinical commissioning groups, DNOs.

MF1: So we can be more rigorous, also we need to start from this part, from supply chain, we are still missing perhaps some information .. so DA1, I think you put the technological development and so far, it is different to the supply chain. Do we see any other connection?

M2: Yes, one bit you really need and which I think is a bit weird and out there, imagine this was the market, we had a new product and say it was fairly prescriptive, we would be starting with product desirability going to doing something and then following it through. So the technology development has to lead through in to product desirability, or something, or retrofit desirability because the things that … aesthetic appeal, non-financial benefits, all of this stuff [inaudible] desirability got to be where the innovation comes from.

MF1: So you say like if there is something new, people want that thing new because …?

M2: Desirability of product … the place we've got that on the board at the moment is aesthetic impact, but product desirability is the short answer and innovation tends to be quite good at product desirability; so it is that loop over, it's quite an indirect loop on the amount that's …

DA1: Not only aesthetic, it is on all of them. Basically, it's something like the retrofit desirability that is already there, but specified for different products. (contribution to a structural change)

M3: But you obviously can have cheerleader products.

DA1: Like the windows. (generic intervention)

M3: Yeah, just in a bundle. You lead on one thing, so you bundle something in at the same time. We do [inaudible] places.

MF1: Do you see any other connection?

DA1: I would say that technology drives down … well, technology is influenced by how many …. what's the install base and then it drives down costs. (connection between 'retrofitted stock' and 'technological development of deep retrofit')

MF1: Does everybody agree?

All: Yes.

MF1: And this lowered the cost, here.

M2: It might not lower the cost, but it may increase the efficiency… it might be more expensive insulation, but it would have twice the effect.

MF1: Because of the performance you are seeing.

M2: Yeah, so that the cost to the consumer may be higher.

02:24:14

M: Or lower, [inaudible]

M3: This is what I really, really hate (laughter). As much as I love it …

M2: … it starts getting messy.

M3: Yeah.

MF1: Is that all the story of the technological development?

M3: No. I mean, the other thing is obviously, technology develops in ways which don't work in the other way too, that's all I was thinking.

MF1: How much time does it take to improve the technology, for example?

M3: What do you mean?

DA1: A significant improvement on the performance, for example. (generic intervention)

M3: It depends on what you mean by significant.

MF1: Fifty per cent, kind of …

M1: The thing is about technology that they'll say is they kind of limit to it, we're not … to really improve, you need - as I think we've got here - the scale of delivery.

M3: The technology, we're up against the hard laws of physics, so we're pretty close … we can probably squeeze an extra 10 to 20 per cent out of the law in those things.

MF1: In how much time?

M3: A few years … but genuinely, that's not where the problem is, the problem is, nobody wants these things, so it's aesthetics. I don't want to keep banging on about this, but its looks, its noise, it's the fact that … if these were iPhones, we wouldn't be having this conversation because the market would do it. If we were selling any other visual product, we'd have focus groups and consumers in and that's what we'd be doing, we'd be doing this for consumers and testing it on them, so that's where I think the technological innovations [inaudible]. It will be things like noise, it will be looks, it will be attractiveness; it will also be, as you were saying, installation and delivery process, like the 3D printing … 3D printing has an opportunity here, I think.

02:26:13

M2: The technological improvements might not improve how effective the product is, it could improve the desirability of that product.

M1: So if you want to have a policy or something, that's something we are doing and funding, so the aim of doing all those things, making the product easier to install, so you bring down the installation time, bring down the hassle factor and make it just an easier product to get to know. It might not always reduce the cost, but it will b without the hassle.

MF1: More desirable.

M1: Yeah, exactly.

DA1: When I think of external wall insulation, for example, I would say there is a cost factor as well, like if you do that multiple times, then you drive down the cost of external wall insulation. (contribution to a structural change)

M2: And economies of scale.

M3: You'd think so, unfortunately it's a question of how bespoke, for external installation each installation has to be because of the accumulation of stuff on the outside of the house each time, so …

M1: … and somebody could do it for a lot cheaper, like when then do some scale things and then like some of those …

M3: … with a lot of planning, yes. So easy ones to do … yeah.

M2: You're spreading your fixed costs.

M3: You're spreading your fixed costs, that's true.

M1: And more profits.

M3: Yes, true.

DA1: So how many properties would you need to retrofit in order to drive down costs by … I don't know, 50 percent or 20 per cent? (generic intervention)

M3: It would just be the installation costs. So we know that 20,000 isn't … 50,000 we are achieving on, actually is insufficient.

02:28:03

M1: But it's more about if you're doing a ton of them in the area and you've got the supply chain built up and then it's all those efficiencies, from what we understand, you can bring the costs down and we know solid wall insulation being like £6,000 I think, which is significantly cheaper than the £10,00 that … so if you were [inaudible] and you could say 'fine, maybe you could bring it down by 40 per cent,' if you, literally, just had a whole change built up and you were doing it home by home in the area and the whole system was really efficient.

M3: But you need to fix the market for that.

M1: Yeah … so those ones, they will have been doing it to local authority, so they know that they can do it in the buildings, they don't have to worry about demand.

DA1: I'm not asking what is happening at the moment, I'm asking like 'okay, if this was [inaudible] (generic intervention)

M3: No, but what we're saying is the UK market, the issues don't come around the size of the total market of the UK, it will be around the fact that because most of this relates to delivering installation, it's about the numbers within a very small geographic area, so it would probably be easier to do cross reduction in pockets …

M1: … if you think you've got a model there, like some people can deliver it really, really efficiently, but only in very isolated instances at the moment; they'd do best to think about okay, well that's maybe your target of late, if you can have a wider model and a company that could do that in an area, then you'd say yeah, maybe you could drive cost down by 40/50 per cent from what it is currently.

02:30:00

MF1: How does the economy of scale we are talking about works? So it depends on the stock … ?

M3: Physical transportation, so basically, how much does it cost to drive from one site to another, how many can you do within a fixed time period under that contract for that period, so it's, basically, the cost of petrol and scaffolding costs.

MF1: What do you mean, scaffolding costs?

M3: (talking over) … and then you can just move it down the road to the next one. It's cheaper than if you had dismantle it all, take a couple of weeks and fit it all up, so it would be too expensive.

M1: If you were to buy insulation for 100 homes as a company, or whatever, the cost per home would fall as well.

M2: It does, but not … yeah, you're right, it does … if you're buying enough, so for example, what the housebuilders do is they work out five years in advance what they need and they put in a bit with a call off section on it that says, basically, 'I'm bidding you the x amount I'm prepared to buy at this price. If you ever reach this price, we will buy it' and then they wait for that period to come along. So if you've got a large enough market, it's going to be there, then that's what you do and then you hedge against … but you get the idea, you can start doing that kind of thing

M2: That's when you get the proper economies of scale ..

DA1: But to what extent are they? What numbers? (generic intervention)

M3: So for housebuilders, you're looking at … housebuilders need tens of thousands of product a year and they need to know it's there. They're okay because they're in a market which, effectively, they fix themselves, so demand massively outstrips supply. The market we're looking at, there isn't the demand, so you're guessing, so you can't do this thing because you can't know in advance what the state of the market's going to be in five years time, but housebuilders pretty much do.

02:32:00

MF1: So there's going to be so much economy of scale, you would say, here?

M3: The people who were doing this already [inaudible] because ?? company, they own most of the products, they have a product called MyHouse, which allows them to do deep retrofit where you choose a company and what brands they have, but they are struggling to find a customer, to be honest because there is no customer who thinks like that. They've got massive economies of scales as a manufacturer because they're huge and suppliers, they're huge and they've also got large installation as well, but that has to be a …

MF1: … supply and demand.

M3: Yeah.

MF1: So we have these things, like are red, we don't know much, we have talked a lot, now lets' try to give rule and then maybe even if it's not complete … so what would be the costs depending on the main thing?

M1: You're also breaking it down to cost … there's the installation cost, there's the materials cost and [inaudible]

MF1: So fixed material costs … is it? Does it make sense, yes or no.

M3: How big is the company?

MF1: Okay, so like a company size in the sense that the bigger is the size of the company and the lower is the cost, right? I guess.

M3: In general. I was just thinking that … the problem is, we're talking about so many things at different levels, so the man in the van, effectively, it's just in time purchase because you don't know what business you're going to get and if you run out halfway through, you pop down to Wickes, or something; whereas if you're a big company, it's still just in time, but you do it through warehouses and then you offset your cost of material import by … I dunno, hedging on the …

02:34:51

M1: Are we trying to find out what are the costs?

M3: Mmmm.

M1: So obviously, cost of goods is one, clearly, regardless of what size company it is and then you've got employment cost and then you've got financial cost, you've got those three things. Then you've got operating costs going [inaudible] they're going to have to buy those goods however, effectively, they never do that; so you've got costs of things and then you've got costs of sales, which is like employment costs …

DA1: Also, labour, in general. (contribution to a structural change)

M1: And that's part of that, so then you've got the other bit, which is labour and then you might have some interest expense, just financial costs, it's really those three things. It's gross margin, operating margin and then …

MF1: … plus financial costs, like taxis.

M2: Interest payments/debts.

02:36:00

M1: So looking at the single measures in particular because you've got it split out there because I think if you then add on … the point about if you're look at the deep retrofit, you've got to add on that factor, all the transactions, costs and difficulties that we've been talking about, which make doing a deep retrofit much more expensive than just the sum of its parts.

MF1: As far as [inaudible], maybe you have more knowledge about the lending part, lenders' things?

M1: Possibly. I think the one thing I'd add in terms to do with policy incentives is the idea you shock the system to get it going, given that you were saying there is no demand for this product, actually, you need quite a substantial shock to the system and I'll put the US example there, which is this tax credit; so actually, in the UK, x amount of money on retrofitting your house, you just get the whole lot back, so you just write it off against your tax and that's how most US renewable subsidies work out.

So effectively, you're paying nothing and obviously, that's an extreme measure, it would actually create a serious stock to the system and of course, once you do that, then there a lots of objections, 'oh you can't do this, can't do that,' but you have to think in terms of 'actually, we need to really shake this up, to get it moving and we get this feedback, even in the North Sea, with all the infrastructure and stuff and you get people coming back and saying 'what you need to do is give the system a serious shock, not just play around with a few incentives, you need to change this really quickly because as you say, there's no demand there at the moment.

M3: That's what they do on the non-domicile, as opposed to domesticised, that's exactly what they do on the … so climate change levy exemptions were the way of doing this for non-domestic buildings and then, if you choose products from the energy technology list, you get tax breaks on those.

02:38:27

M1: So, for the consumer, you've already got stamp duty, but I'm thinking, this idea of shocking the system of a really substantial one, so you'd have to limit it, effectively, but if you're going to spend £10,000 actually, you're just going to take that on your tax bill and it's obviously going to impact one part of the market and not another part, but it will actually create an immediate incentive for people and the market would come into being quite quickly.

M3: So for business, it's straightforward because it's tax or business, but consumer, which bit of the tax were you thinking about.

M1: The easiest way for consumers if your income tax, you actually just take it straight off your income tax and then, suddenly, you have a demand because at the moment, clearly demand is an issue. If people start thinking 'I'm going to spend £10,000, I might as well buy some of these things, they're not actually unattractive and then you get a supply chain … clearly, with the building trade and everything else, there are all sorts of issues that could arise, but they would arise anyway because this is the building trade. If you're going to do something, you need to make it really quite … good luck with that, I have to leave now and go to another meeting.

02:40:23

MF1: You put quality, DA1, here, close to skills. Can you explain what you were thinking when you wrote it.

DA1: Yes, the skills have a great impact on the quality of the work that is done and the quality of the work then also … you have the performance down there, that affects the performance and also monitoring of the process, for example, also affects the [inaudible] (connection between 'SC skills' and 'quality') (connection between 'monitoring' and 'quality')

M: It also affects the aesthetic impact.

DA1: Yes, all of the ones on the left. (contribution to a structural change)

MF1: And monitoring, sorry, what do you think should …?

DA1: Monitoring of, for example, it could be monitoring of [inaudible] building the job, so it's the monitoring of the … (generic intervention39)

MF1: … of the quality, okay.

DA1: It depends on whether you see this as disagreeing/agreeing. (facilitation intervention)

M1: The policy element is pretty huge and it's important to have that, it links the skills, it links to the … I think we've got it elsewhere, if business substantially increases, like actual shocks to the market, all those types of things tend to decrease quality, don't they, would you say M2, like a dramatic rush.

02:42:09

M3: What we're thinking about is … so there come a point where the market collapses because effectively … or TV reports, or news reports say that there are problems with this and then everyone rushes out at the same time.

DA1: It can set off a positive as well as a negative … word of mouth, right? (connection between 'measure performance' and 'word of mouth effect)

M3: So you've got word of mouth. I think then general public awareness about retrofit going to more people planning to buy, word of mouth obviously can go the other way and create a negative loop as well.

DA1: So then word of mouth is knowing about okay these things have been done, so that comes from the retrofitted stock, but whether that's actually a nice word, or a really bad word, depends on what they see, either in the quality, or also in the desirability and I think we had several poor performers. (connection between 'measure performance' and 'word of mouth effect\\repetitions)

MF1: So we should connect, at the moment, performance and word of mouth, just to give the idea that if the performance is negative, word of mouth can be negative.

M3: So the performance then links to skills, good, yes, it works.

MF1: This one, I think was from you M …

M2: And so the idea is that, dependent on where you are in the economic cycle would have an impact on whether you decide to make, on some of these, quite a substantial investment. So if you're in the middle of a recession, no matter what the benefits you think will be in 10 years, you probably won't make that big investment at this current moment in time. You may think about doing it later, but …

02:44:03

MF1: … so this was for the homeowners …

M2: … and mortgage providers and businesses.

MF2: How would we somehow quantify that, is there a measure for that?

M1: A good one is to look at … it's a bit of a proxy, but looking just generally, how much people are investing in their homes because that's ultimately what we're asking about and that ebbs and flows, as Osman says, with the business …

MF1: Somehow, it goes on the same trend of area regeneration rate would be …

(02:44:56 talking over)

M1: … so not just the amount of money people have, but just a general confidence in …

M3: … yes, I think confidence is a big factor for every player in this market.

DA1: Yes, that's an important point, confidence. (contribution to a structural change)

MF1: Okay, we have the confidence of the industry at the moment, the trust. I think with this one, for the customer, there is credibility? Could be? Also the lenders, do they have the same issue?

M3: Hugely. The interest rate is meant to cover risk and then [inaudible] the lower the risk, the lower the interest rate.

MF1: Trust … DA1, you were mentioning something?

DA1: Yes, we have the market fragmentation out there, so when we now start to move from the industry to the customer side, we need to get a clearer picture of what exactly we mean by market fragmentation and how it influences the credibility and the quality and performance and these things. (facilitation intervention)

02:46:24

M1: We've been talking about a lot of things like a lack of standards. We were talking about a fragmentation in terms of ethic, which I think is important, any measure and any coherent finance offer, or anything like that, combined together what you were going to say M2 …

M2: I was just going to say you looking at hundreds of thousands of tiny businesses, that's what you're talking about and the strength in that is it means that each [inaudible] has to be specialised and it has credibility because they're local and known and also they have been changed to a specific standard in a specific thing … it's basically, you are dealing with a market that consists of hundreds and thousands of small business.

MF1: It seems positive to me.

M2: Yes.

M1: But also, the negative is [inaudible] trying to influence out with any kind of policy is very hard, so you're not dealing with a few, big glares …

M2: That's why we deal with the energy suppliers so often because it's so much easier.

DA1: So is market fragmentation then a proxy for the number of campaigns? Whereas market fragmentation, there are single market focused instead of [holistically] and deep retrofit focused. What exactly do we want to understand …? (facilitation intervention)

M: The policy side, it's probably, for these purposes, it's probably the latter, so if we're coming up with a different policy and we look at the cost of delivering it, the fact that you're dealing with hundreds and thousands makes it really, really expensive, but that's a policy design issues. For these purposes, it's probably just the consequence of having hundreds of thousands means that a certain number of things fall out of it. So your risks are a lot higher if you diversify, if you re-train, your risks are a lot higher, as a business person.

M3: It will be harder to ensure how effective the performance measure is because everyone will [inaudible] they might be trained to say, but they might have a different approach to doing something, which would make it difficult to ensure a level of quality of energy efficiency, which would make it difficult for lenders to back that up.

MF1: To trust …

M3: Yes, trust becomes weaker.

MF1: So fragmentation is number of companies, would it be okay …

DA1: No, it's the other one. (generic intervention)

M3: I don't know, necessarily, whether the number …. It's more of the fact that you're trying to drive a number of different measures and behaviours and not the same person can do all of them and that's a limiting factor, it makes is really difficult for us as the main consumer.

MF1: We can try to construct it a little bit because I think it's a quality issue actually. So who does single pure measures … could have, to some extent, lower quality … no.

M2: Not necessarily because with double-glazing, there is one, massive player.

MF1: So how does it reflect … the number of [inaudible] on the ??

DA1: So [inaudible] fragmentation, we might be able to understand one of the impacts, one is the number of companies and the other one is currently do the companies have the capabilities for deep retrofit, which means they are not fragmented because they can draw things together, or do they just have the capabilities for single measures, or for known measures at all, so they all drive fragmentation and then, if they are fragmented, that does not impact the quality of single measures, or light retrofit, but it does impact the quality of deep retrofits. (facilitation intervention)

02:51:26

M: Pretty much. The other thing to not is if you are trained in two measures … say you're trained to do three, you would still only focus on one measure because the profit margin on one is likely to be higher than any other, so if demand was equal, you would still just focus on one because your profit margin on that one is the largest. So even when you've got people trained to do, say, gas boilers and heat pumps, profit margin on gas boilers is higher because they install quicker and cheaper, they can do more in a day, blah, blah, blah, so you'd still only do gas boilers and you never do the other measures either, so it's like the eco effect, just because theoretically, everything is the same, everyone still …

M1: … there are better margins on something.

M: Exactly, so just the logic of the market means that, effectively, everything drives you towards just doing one measure.

MF1: To optimise.

M Yeah, to optimise professionalism specialisation.

MF1: Profit margin … but what creates profit margin because we talked about cost and then you mentioned the price and just for a percentage to that cost …

02:52:37

M: … and subsidy benefit. So if you knew the market was getting subsidy, then you add that subsidy benefit into you profit margin.

MF1: Everybody go there.

02:52:46

M: Unless people can only do certain things, so only certain people can install a gas boiler because you need the certification to do so, whereas loft insulation it would be less. There's a driver in the size of the company, if you have these small companies, or online ?? it's always going to be easier for them to just do the single measure thing, whereas if a bigger company is doing it, they can bundle up a few, different things and know that they'll get added value for margins from that.

02:53:26

M: Unless they take more than one person on because then labour costs are proportionate the tasks and again, we probably don't tend to train them on more than one.

MF1: You say that [inaudible] fragmentation, better credibility… like fragmental means like I do only this, but I do it properly and so this more credible in terms of single measures.

02:54:02

M: That's logic, I can't prove that, but there was a logic there. I can prove it in number of deaths from gas boilers, which has declined remarkably, which is why we don't even think about …

MF1: So we can think about credibility, deep and light, something like that also.

02:54:26

M: Yeah, but I think also, again, having lots of small ?? team specialised skills, there's an almost slightly imperceptible fear and lack of trust factor that drives other larger organisations, getting involved in it because when we speak to the Council of Mortgages, it's 'who do I deal with?' All the mess down there is [inaudible]

02:54:54

M: The same happens to us, that is exactly the same problem, so regardless of who's doing it, whether it's us or another party, the market fragmentation just means the cost of delivery, or any measure of delivery, is just that much higher. It's basically hundreds of thousands times £20 as opposed to £4 or £5.

02:55:25

M: Does it not have an impact on how nimble the supply chain is, if there's loads of small players, it can react faster to a change in market condition then and massive players have made huge investments in one, particular area.

M: Yeah, I think, probably to an extent.

M: Maybe, I dunno.

MF1: To go back … so you say that lenders would trust bigger companies, compared to … so maybe it's something we have to pay attention to.

DA1: Just to summarise what you said because I think that was a really important thing that you said actually, if you have lots of market fragmentation that can enhance the credibility for single measures and that creates different types of feedback loops, so you might have a reinforcing feedback, what will really drive single measures that actually the answers are the deep measures because they work in a contrary way, that for single measures, market fragmentation increases credibility, but for deep measures, it increases the credibility because there, you need them to be able to integrate in their thinking. (facilitation intervention)

02:56:51

M: Totally. You need one person who can bring it together who the customer can trust, which means less fragmentation layers, otherwise, the other model, you're just getting a local builder to come and do a single measure, you'd trust more. That's a good point.

DA2: Or, if you are to operate with single measures to do a deep retrofit, you kind of have to become an expert yourself and then where do you get the information from about how to [inaudible] so that would also be … thinking about a homeowner become a manager of the project, where did he get feedback from to do such a thing? (generic intervention)

02:57:52

M: It's probably unlikely for a homeowner ever to manage that kind of project on their own, it's like more it would be, as you were saying, in that area of a deep retrofit intermediary, no single person could do a lot of the measures, as we were saying, combined, or as ?? was saying, it's rare.

DA1: Would it make sense, instead of talking about deep supply, deep measures supply chain, to talk about the intermediary supply chain, a number of intermediaries over companies that can integrate different expertise in the same company; homeowners just interact with the project manager, something like that. That, or in addition? That you have the intermediaries in addition to also maybe companies who can do everything under one roof, or that you also maybe have the companies doing everything, plus you have the intermediaries than can draw together others. (facilitation intervention)

02:59:01

M: I think it only works … the customer is only one person in any of these markets and then you have a kitchen retrofit, or someone, it might be the store front you go into and then ask for kitchens, but then all the rest of it is behind the scenes, usually.

MF1: So both of them, just whatever comes. It's okay having ... like the company is having deep retrofit, or people dealing with you and organising deep retrofit with single installers - is it both of them, with these two groups of providers.

02:59:46

M: I guess so, yeah.

DA1: And then the big players would then be [inaudible] and so on … (generic intervention)

03:00:00

MF1: Okay, shall we move on.

M: There's another feedback to the consumer where they might get information around surveyors and other groups who are likely to actually tell you - or values - if you get someone round to value a house, if you get an estate agent round, all these types of things, people who are likely to say to you 'well, if you want to increase the value, you should consider …' I think people get their homes valued quite often, it's the standard thing to do and depending on … yeah, I think it's just that point that it's not the place that you get the knowledge from and the nudge to do that kind of work could really come from someone who's got knowledge about what improves the value, or the quality of your property.

MF1: Would it make sense, to connect this thing to the fraction of renovations, considering retrofit? People who renovate because they want to improve their house and probably they are suggested by these kind of consultancies. So if they suggest to retrofit more, this fraction would be higher.

MF2: [inaudible] you asses the value, the price of your house and where you are aware, you can facilitate some financial gains, that's why you move to retrofit because that's what I understood, that's [inaudible] are the both only one ??

03:02:16

M: As in what, as in which link of the two is …

MF2: Yeah, or if there is both, or if they are different.

MF1: Can you explain what you mean.

MF2: So you have a price and then we [inaudible] financial documents. I was thinking it could be like a frequency of house buyer assessment, then can be combined with the house price, so ?? if you check the house price, you became more attractive to the retrofit maybe.

M: There's something like … all the way up here in terms of tax deduction and tax incentive and … maybe it's already in there, but I just feel like there's a point that the intermediary recommending the kind of retrofit to do, but I guess it all depends on all the other things, like it all depends on the desirability incentives.

M: For some of the works theoretically, so the equivalent of this is Scotland. So Scotland, basically, we do community NG, they have a service that just holds your hand through the entire process, but the fact is that's state funded and Scottish funded and they act as the intermediary and they take you through it and guide you through with the bits that you need for the project as it goes along, so it's that kind of intermediary.

MF2: It's expensive?

M: Yeah.

MF2 And a place for that as well, right?

M: It does in Scotland, for [inaudible]

03:04:05

M: If we go back to the intermediary point, it's probably lacking in the system and the moment and maybe you can park the one about the …

M: … well, I think there's something there, for example, estate agents, so the answer is that there are these intermediaries, but the intermediaries aren't pushing the sort of products we're looking for. So what you traditionally get is 'oh okay, first of all, can we rename one of your things with an extra bedroom?' That's your biggest win, followed by the usual de-cluttering and painting it magnolia, so the advice you get - because it's linked to the price that you pay for a house - eventually, they'll get on to the energy efficiency measures, but they'll probably put [inaudible] conversion extension for that.

I think, if you don't have central heating, that will come pretty high and eventually double-glazing might get there, possibly, depending what it's replacing.

M: So they're there, influencing this and they come back, all the way back to the demand, they tell you things on the basis of what interest rates …

M: It comes back to my earlier one, which is this is all competing with other things the householder could be doing with the spare money in this space, which won't necessarily be the kind of things that we were talking about.

M: It does come back to that thing, that's why whenever we think of our tax breaks, we think about increasing the profitability, or incentive to do this in relation, or in addition to these other thins because, as you were saying, there's some real, strong competitors and that's the space we're in basically, competing with loft conversions.

DA1: All of the intermediaries, they seem then to be able to … if there is a benefit, they are in the position of strengthening the awareness of that. (generic intervention)

03:06:13

M: It we could show there was a consumer benefit, they would reinforce that, going round. I think that at the moment, it's a bit hard and the fact that they need an incentive to do it, demonstrates that it's not there. So again, if these produces worked, they wouldn't need government incentives, but when they're given an incentive, it tends to suggest that they don't work.

M: M3 just wanted to quickly put one more thing up there, which was on like how the PRS sector regulations influence …

MF1: … on second, because we didn't connect intermediaries to anything so far, sorry, so they work on the awareness, we said, here, on the fraction …

M: It's parameters of the awareness, but they also just … where's all the bit about them doing it instead of other retrofit?

MF1: So here.

M: And there, the link to them actually promoting it, it's definitely a complete move because it comes back to wherever they value it.

MF1: So this one is connected … intermediaries. So if intermediaries see the …is it, or the other way around?

M: Yeah. Also, it's not only the value, it's also the … maybe I was thinking about the attractiveness of the measures and stuff because estate agents know what the people are look for basically, like what do people want in their homes.

03:08:14

DA1: Maybe desirability. (contribution to a structural change)

M: Yeah.

M: Is it not just so the value of the house, but how quickly you can sell it as well. They're not necessarily the same. So you have got really high end properties that are really difficult to shift because they're so expensive, but if your house is ready to move in, it's already got all these energy efficiency measures, would the sale go through quicker, maybe? I don't know.

M: Are you suggesting it's not a perfect market? (laughter)

M: It comes back to what we said earlier, the driver of this stuff would be if we could demonstrate improved convenience over comfort and cost, so convenience would be good, if you'd show that the house with these things was more convenient to operate …

M: … easy to shift.

M: Yeah, if you could lose … I was thinking about, yeah, easier to shift in some senses, but again, that comes back to an aesthetics of what it is and the ones that I'm thinking about, ones where you lose radiators. If, for example, under floor heating was a retrofit measure, I could pretty easily sell that on because you lose radiators and the radiators take up space and they're ugly and so, in convenience terms, probably the cost is, if anything, slightly worse, but in convenience terms, I can sell that, do you see what I mean? On aesthetics, convenience terms, they are the things they're looking for … and space, you could convert space into a value as well, in house value terms.

So things that are smaller, things that are prettier, things that are more convenient, I can really easily sell, or give you a financial value for [inaudible] Reduced running costs, in comparison, are tiny.

03:10:13

M: But it's a really important link because it's not, wherever you can, necessarily about bringing down the cost of the measures always, it's always like how much do they … as you say, directly improve your set of impacts, that increases the amount that people will be … If find it easier to say 'get these things because it will sell.'

DA1: That's what customers basically desire and how each of the measures that you might want to put in scores on those things. (generic intervention)

M: Yeah, which is a different chart to the way we chart [inaudible] energy saves, so our thing, so the reason for us choosing our measures is how much energy they're saving, therefore how much carbons have changed, say. The chart is completely different and the ones we're looking at, the ones with the almost complete mis-match. So I'd probably find it easier, in some respects, to sell a Google nest than I would a £30 programmable thermostat, just because I could show a nut value from that in terms of these other things, even though probably, you ?? 90 per cent of the benefit ?? in one sense, but people will pay a lot more for convenience and comfort.

MF1: So we have a viable convenience, okay and where should we put convenience?

M: It's a driver.

MF1: So no financial benefits … convenience.

M: You could probably cost convenience at some point.

MF1: So it's both financial and [inaudible]

M: Yeah.

That's a question I had also for me because we talk about increasing the price of energy efficiency, but the reflection of energy efficiency on the price, but is it that contrary to the fact that yeah, I look for low cost things. So maybe one thing is the value of how much people value things and how much it cost because the price makes me feel like I don't want it, it costs too much.

03:12:25

M: That box is, I think, more about how you would use the stick measures rather than the carrot measures, so there you're looking at … your price is right irrespective of your setting. You're doing [inaudible] whereas yeah, on the regulatory side, your language tends to be very terse and direct, this stuff's all marketing. This is about improving product desirability, so you're lowering the need for these interventions because effectively, the market does the lifting for you. So if the language is around a different set of things … so you talk about value etc., etc., it's just that I think the context we're actually talking.

M: I think the retrofit desirability, did you do any direct link to the estate agents and everyone kind of recommending it because you don't even need more people to be doing it, you just need more people to be desiring it, to then recommend it instead of other retrofit.

MF1: We had a link from the beginning and probably it's through this way? From this one, this box, how it is reflecting on the price and to financial attractiveness.

03:14:02

DA1: That was a different one. On the retrofit desirability to the communication of agents about it. (connection between 'retrofit desirability' and 'intermediaries')

M: Because they know what people like.

03:14:25 - 03:15:07 (Talking amongst themselves)

MF1: I want to keep 10 minutes to go through all the various issues you mentioned, so we know what you are talking about. So DA1, you were mentioning household sustainability concerns and there was some willingness of other actors to contribute to retrofit … that's probably connected, okay.

DA1: Yes and the sustainability concern originally was paired with the preference by energy efficiency, so with the idea … well basically, what you said, they like convenience, they like aesthetics, they don't like greenness. (generic intervention)

M: Some don't and some do.

DA1: You said five to eight per cent. (generic intervention)

M: It's actually sufficient to build a business on with a high profit margin on the offer, yes it's enough.

MF1: I think it was you DA2, is availability of credit option over you?

03:16:09

M: I think that was me … availability of …?

MF1: Credit options.

M: Credit, yeah, finance option, yeah.

MF1: So it would make it more desirable to do it, or more financially attractive.

M: Yeah because I think, as we've talked about a bit before, there is basically 0 per cent on windows on stuff, 0 per cent finance and there isn't that on insulation measures, or things like that. So again, if you're thinking about the comparison between different products, it's what I can get on 0 credit.

MF2: Something like reduced interest rates, something like that?

M: Yeah. As we said … it's funny, we were talking about it the other day, weren't we M2 because even the 0 per cent, it's just cooked in to the cost somewhere else, but it would affect, I think, a clear credit offering, it doesn't matter if,

financially, you're being fleeced because they are cooking it into the cost of the measure, but the coherent package, you see 0 per cent finance and that's attractive and that doesn't really exist at the moment. Again, if the measure's attractive, then …

MF1: So is the perception of a good deal, like regaining

M: Yeah.

M: Or the ability to straight costs, depending on your financial circumstances. So effectively, like you said, it's like when you buy clothes through one of these catalogues, it's in the measure cost, it's in the cost of it up front, the cost of borrowing is built into the cost up front, but the fact it says zero on it

03:18:03

M: I think it really is about directly … it's not a financial thing necessarily, but it directly links the desirability. It's more to do with are there people offering like a clear, easy bundle package for a consumer because the drop out point on the customer journey is when you realise that the measure is expensive and then you realise that you have to go out and find the credit for it yourself.

M: Desirability [inaudible], you have the desire to do it and then there's an affordability element to it as well. So it's the next step, you want to get your windows double glazed, how you pay for it and you fall at that hurdle, maybe.

M: I think, honestly, it's partly two-way, there are two things because I think you can probably get your windows double glazed partly because someone's selling them to you at 0 per cent finance, so you think 'okay, that sounds like a good thing to do I'm not paying any surcharge, I'm not the lender of the money - even if you are … it's also, again, basically, you've this up somewhere …upfront cost. So what's one of the key things, the measures that we're talking about in common, they tend to have larger upfront costs, so I'm interested in that bit.

If you have a company that offers … I've got the finance at 0 per cent, I've got the measure …

MF1: So the [inaudible] is [inaudible] connected to this one?

M: Yeah.

MF1: I'll put already here, if you don't mind.

M: Yeah.

MF1: So would it make sense also to [inaudible] you said … so maybe that you could be the reason why there is a connection between ?? Then we have household's preference for EE, that should be ?? desirability.

03:20:20

DA1: Yeah. (contribution to a structural change)

MF1: Does everybody agree with that … okay.

MF2: It is very connected to like attribute other things, like the priority, low priority.

MF1: So the priority they give to energy efficiency …

M: Over the [inaudible]

MF1: The same, perfect … and I think one of the last ones ?? desirability versus other …

M1: It's the same thing, but for lenders. So lenders will only go to this market if they think they'll make more money in this market compared to doing similar things in different markets … so cars, I'm trying to think of other markets, but things that traditionally …

M: Or credit cards, or whatever. So all the things that we're talking about …I'd try and keep that, make it … yeah.

MF1: Shall we also pick up PRS from M3? Can someone explain …

M: Yeah, so what he's saying there is the fact that you have a set of regulations requiring private rented accommodation to improve, I think we talked about it a bit last time, is here is pretty much exclusively owner occupiers on this map, but the fact that you have regulations on the rented properties improving and the general stock of those properties improving over time has a number of effects into this. Over supply of houses which were really rubbish, into the owner occupier market from the private rental sector market for a start.

03:22:18

M: So there's a negative on the stock, basically. It's increasing the non-retrofitted stock.

M: Yes, it's increasing the owner occupier port of retrofitted stuff, yes. So do you get it because you're putting a regulation on rented properties to improve, if you can't rent the property because you have to improve it to a certain degree, you just sell it and someone buys it outright, to own, because then you don't have the regulation in this area.

So because you're saying you can't rent a property unless it's at least E, which is what we're saying, and if you can't improve it for that amount, you just sell it and you sell it to someone who … so all those properties start to bleed in to this area; you've got low quality properties that are probably hard to retrofit.

MF1: Is this price already in place?

M: I think it started in [inaudible]

MF1: So this ?? increase the ??

MF2: Then more people buy house or sells house.

MF1: But they don't retrofit them.

M: It's always at the lower end. So it's [inaudible] stock which is poor, if you've got that somewhere.

DA1: It shifts … it sells off the retrofitted, so they drop and they go back to the susceptible non-retrofit, so it inverses the flow in some way. (contribution to a structural change)

M: Yes, exactly.

MF1: So we go back.

M: Yeah.

03:24:00

M: Coming back to size of market, quote rented stock is for the domestic sector … I can't remember the percentage of this … is it 15? We don't know. Anyway, how many ?? G rated houses are there, there's not many. So it causes demand for products of about 100,000. If we believe that economies of scale drove supply chains, then in terms of product distribution, then you would see prices coming down, so it might positively improve the market and improve the install of suppliers livelihood. Of course, it may also drag them out of the owner occupier sector, but …

M: I think it's the thing to be aware of and it's important in many ways.

M: Yeah, it's whether, basically, you get more money doing the private rented stocks, they're desperate to hit the April deadline …

M: … any beyond, if we can extend it.

DA1: But what do you see in the actual numbers, you're probably monitoring this already, do you see … (generic intervention)

M: … we are, yeah.

DA1: Do you see that the old housing stock is already being sold? The rented housing stock? Do you see that the retrofit has already started? (generic intervention\\repetitions)

M: Yes, but the thing is, we don't do tenure of sale, nobody reports tenure of sale, so you wouldn't know whether they are POS going out into owner occupier, or whether they've always been owner occupier.

M: It's had an impact on the values, like the value of properties.

M: Yes, it has done. It's also, in non-dom sectors, it's really had a massive effect and will continue to do so, even if it's in the owner occupier where you can't rent.

03:26:28 - someone leaves the meeting

M: The supply chain is, as you were saying, it's difficult to say because it should lead to an expansion because it's a considerable expansion in the demand in the sector, but it's just whether it just pulls everyone to that one area, like our policies tend to do, pull people towards doing those types of properties. So it might have … what is the best link …?

DA1: And probably does not deeply retrofit the [inaudible] they would then just barely meet the … (generic intervention)

M: … not where it is at the moment, yeah. On the whole, it's going to drive one or two measures and considering landowners, they're very unlikely to want to do anything more than they have to do.

DA1: So they will just stop …? (generic intervention)

M: I think it effects the … I'm trying to look where … it's within the supply chain part … I think there's something, maybe, that we've got around installers, the amount of installers doing either kind of retrofit in the owner occupier market … it must be somewhere around.

03:28:59

M: Yeah, exactly. It's kind of …

MF1: So PRS stimulates the supply chain for single measures.

M: Kind of, but in some ways not because it stimulates them for the other market that we're talking about. Yeah, if you're taking the market as a whole, it does. It probably is one market, yeah. It's a complex thing because … do you see what I mean, the installers who just chase the kind of incentives and the profits will go straight to just focusing on private rented sector properties.

M: That's where the monies are and if you think about just a general capacity of it … it might cause an expansion in capacity I suppose, you might get more people come in.

DA1: Are you also saying that it might actually decrease the availability of that part of the supply chain for …? (facilitation intervention8)

M: In the short run, while it adjusts.

M: Yeah, but there's very few people who demand measures that are outside of the subsidy schemes anyway.

03:30:06

MF1: Okay, so it's [inaudible]

M: It should and it could lead to expansion, I think. You've got the valuation and then you've got … ?? mainstream. I just wanted to catch … because we didn't quite do the lenders trust thing. So that goes to, what links to that is the perceived … there was a huge one we had about the return the savings and everything from the measures. Basically, the lenders say …

MF1: So this one influenced the trust of the lenders.

M: Yeah. That one does … is there a credibility one which is linked at some point to quality and all those types of things? Yes, that's already linked, it's part of the loop, isn't it.

MF1: It goes through and [inaudible] performance and then performance, I think, goes to …

M: That is the one I was looking for, the performance. Their concern goes on a number of things, the performance is really … yeah, on everything.

DA1: It's not on the financial savings, it's also does it deliver what people want from it, like even if it's aesthetics, or something else like that. (connection between 'measure performance' and 'lender trust') (connection between 'reliability of EPC' and 'retrofit credibility L/D')

03:32:03

MF1: Okay, quality and credibility, or effectiveness, could it be?

DA1: Credibility and performance of the measure, one of those, just make a shadow variable, so that we know that … (connection between 'measure performance' and 'lender trust'\\repetitions) (connection between 'reliability of EPC' and 'retrofit credibility L/D'\\repetitions)

MF1: Performance, I think was everything.

M: And finally, the quality also, they're not the only ones of course who lend, you have unsecured lenders who lend on like anyone who's not lending on the asset, on the basis of the asset they own, so any other kind of finance option, who will be responsible for the measure installed if it goes wrong, that's the difference between a secured and non-secured lender. So you've got the availability of the financing options. It's a little bit complicated because like a bank isn't the only person who could feasibly lend you the money …

M: … you could put it on the credit card, if you wanted to.

M: Yeah, or you could have a personal loan, which wouldn't be against your home and on that, when it's lending like that, then you have the Consumer Credit Agreement and the person who lends you the money is responsible for the thing they lend you the money on, so if the installation is crap, they're liable, so poor quality installation decreases their willingness to get involved in the market and lend on it.

DA1: [inaudible] and such things, something we, in general, need to talk about? (facilitation intervention)

M: Those kinds of things helped a lot and that's ? that's what some of those things are trying to address.

MF2: ?? lenders are secure, unsecured …

03:34:18

M: It's based on the … secured lender, you're lending on the value of the asset of the home, rather than not doing so, which is like a personal finance loan would be different.

DA1: So one time it's the asset of the value of the home and the other time is kind of the measure. (contribution to a structural change)

M: Yes, exactly and so the lender doesn't have the same issue around they're not liable for the thing installed, but they have a credibility issue with lending and they just have, as we talked about, if in any sense they're lending on the basis of savings, or anything for the types of products we're talking about, they mainly trust in the savings installed.

MF1: We are getting to a closure … are you satisfied? Do you think something is missing?

M: I think we've covered a lot. Something will come up at some point, in which case, I'll just drop you guys an email.

MF2: Possibly a big, big question now is we have talked about some policies and all this model processes going on; what is the main question we want to explore? What is it we want to know after all this effort of modelling? We want to create a model able to simulate … it would be not so much expert prediction, but more understanding … to improve the understanding of this map, so of the reality, let's say. So what would be the highest priority to check, like what happens if I do this, or …?

03:36:40

DA1: In an order of priority. (generic intervention)

M: We discussed it a bit in the first session, but the first one is around … a lot of it is to do with the kind of mortgage market in the sense it's like one is what if you have a target on the mortgage lenders to … like the kind of thing that M3 was talking about, of improving the stock of the homes they're lending to.

The other is what would be the impact of a couple of the incentives that we talked about for mortgage lenders, like the capital lending requirement be relaxed, like the reduction on the interest rate that they're lending …

MF1: So they can add more and the different interest rate, you …

M: Yeah, exactly.

MF1: Both of them are real?

DA1: One is kind of the re-financing that is done with a different interest rate and the other one is their own capital that they need to reserve it. (generic intervention)

03:38:11

MF2: So this one, could it be like lending more money?

M: Even lending more money, or lend at a lower rate - assuming that it's competitive.

MF2 So is it kind of the same thing, or not? So they lend more money if they … okay and interest rate, maybe they lend more money because they attract most people, something like that?

M: Yeah, it's different. There are different ways of achieving …

MF1: So we try to change the way the market here will shift.

MF2: So it would be important to understand … stamp duty?

M: Yes, it goes out the same … say you offer ..

MF1: You don't pay the stamp duty when you buy …

M: What it's most likely to be is you offer a rebate from the stamp duty, if you make some improvements in the period after you buy your home.

M: A year or so.

M: So you take it, or lose it - so once you buy the home, do those improvements - so it's a little rebate that way and potentially also, a fine that would be capturing the same properties that perhaps with IPRS, so if you're selling that property, you can still sell it, but it's going to cost you a bit more on top.

MF1: So it works double sides.

M: Double sided, exactly.

MF1: You retrofit, you pay, you get some money back and if you ?? you pay more.

M: Yeah and you probably equal out the fine in the terms of a rebate that you receive. Potentially, the rebate applies for more than just the properties at the bottom end, you could offer it to a wider array of people on the basis that [inaudible] but the two would somewhat equal out.

03:40:12

DA1: And the fine would just apply to lower efficiency housing, not to all who do not retrofit (generic intervention) …

M: And right at the bottom.

M: So there's that and the final one - and this is a little ... as you've probably got from the discussions, is a little bit more complicated to capture - is around the tax.

MF1: So the consumer has retrofit tax credit?

M: Yeah, kind of. The problem is that it's a complex area, to get exactly how it intends to work. I don't know whether it's easier just to … the aim is that when you do retrofit, either at the same time as doing renovation, then there's a deduction on the cost of the whole work. So it actually can come in a number of different ways, the vehicle through which you would do it in would be a result of the kind of tax laws are there, but basically, it's trying to directly get in in that area … so that you're doing the same at the same time, or say okay, if you're doing your renovations to your home, if you also do the insulation, like it's going to be an additional saving, but say only at that time, or something, so again[inaudible]

DA1: There would be a reduction to the entire renovation, not only to the retrofit. (generic intervention)

M: Yeah, but not at a cost that would be ridiculous, not at the cost that would be more than the cost of the measure, say, it probably wouldn't make any sense.

MF1: And if I just retrofit, I wouldn't get any support, right.

03:42:10

M: No, you would still get it, but there wouldn't be as strong … the incentive would probably be the thing. So the reduction would be a lot more if you were doing …

MF1: Because it's a percentage of the … kind of here, should be a percentage of the profit.

M: Otherwise we'd be driving people to retrofit their kitchens, like doing strange things, so that would cover it.

MF1: So the revision we apply to all the retrofit, but it depends on the amount of money they want to spend. So if they just do loft insulation, it doesn't impact so much, but if they are reforming their kitchen, maybe …

M: … and in the loft at the same time.

MF1: Yeah, they will get a discount.

M: The whole package.

M: I wouldn't worry, no-one retrofits …

MF1: I was thinking of representing the model and if we can put it here, like on the reduction on the up-front cost and we can anchor the reduction here to the …

M: … the idea would be that you would only attract it if it was deep retrofit, so you wouldn't just be able to do your loft insulation and then get a massive discount, that wouldn't make any sense, but if you were going to do a substantial improvement to the property, then you could gain a substantial reduction. So if you think of a large renovation that's taking place, if you're going to make it really efficient at the same time, you can get a significant reduction.

DA1: Would the reduction be larger than the cost of the retrofit part? (generic intervention)

M: No, I don't think so, no.

DA1: Why don't you just then say 'okay, you get a 50 per cent reduction on the retrofit part.' (generic intervention)

M: Yeah … I think it could …there's detail still to be worked out on it, I think you're right, that could be the way of doing it.

03:44:12

M: I think it starts to get a bit messy, as in your builder might say … I dunno.

M: If you could make it work that way, then I think that works just as well, but it's trying to, as you say, try and tie it at the time to the trigger point because then it makes sense to do it at the same time, otherwise I don't think it will have much

effect. It could work in that respect. It is probably, ultimately, a presentational issue about how … it's about limiting the money, there will be a limit on whatever you do, it's not a completely ridiculous bung where you're overpaying on subsidy for something, but it will be designed in such a way that it looks like 'oh, we really should do this at the same time.' So presentation of what it's actually budged out, but the reality is, it wouldn't exceed the cost of the retrofit, but it would be an incentive to do it at the same time.

DA1: If you lower your income by the amount that you pay on retrofit and don't pay income tax on that part. (generic intervention)

M: I think income tax credits are quite tricky. The tax deductions on your income … that sounds like a salary kind of thing.

DA1: If you say 'oh this year, I spent £5,000 on retrofit, therefore I can lower my …' my income is basically lower … (generic intervention)

M: … that's like a salary sacrifice, basically, that's what you get [inaudible] but actually, it's also another thing that …

DA1: … but that's not what you were thinking. (generic intervention)

M: No, that's one of the others, that's a final one. It really is the delivery mechanism for achieving the same ultimate goal, but yeah, that's a tax deduction in a different way.

03:46:11

MF1: So the last mechanism is this one.

MF2: ?? actions on renovations?

M: It's somewhat different.

DA1: And the tax reductions on the renovations, how do they then come in if it's not via the income tax? What tax is that, is it sales tax that you don't pay? (generic intervention)

M: Exactly … the VAT is already reduced - this would be one mechanism that you do - the VAT's already reduced for the energy efficiency project, but you could say for the whole retrofit, for the whole renovation, you could reduce the VAT, but cap the amount that doesn't make it like a ridiculous … you could be doing a £100,000 improvement to your property and that would make … yeah, design it in such a way that it would make it void out, that would be one mechanism that could work.

END OF THE MAPPING PART

WRAP UP AND FEEDBACKS

MF1: Before we close the session, I would like to ask you both for feedback on what you think about what DA1 and DA2 did because it was quite some differences from what we do usually, I think as participants, they were putting variables, they were suggesting places actually. Did you feel any difference?

M: As M3 said, it's good to have challenge and more input, I think it works well.

MF1: Did they have any issue with …? Nothing?

M: I thought it was quite useful, just a different thought process.

M: Working in a different way.

M: For avoiding group thinking think it's really important … because we will all ultimately work together and work on [inaudible] it's good to have a challenge.

MF1: That's good to hear, actually.

M: You got trust

03:48:16 to 03:50:36 - background chat

DA1: I would just like to ask you what you got out of the day.

M: I think I got, again, a deeper understanding of where some of the pressure points are, I think we got into some really interesting stuff around all of the things around the desirability and how that feeds back into the market in terms of intermediaries, through estate agents and everything and how important that is and getting down to the fact of all these elements are not to do with value and financial value that are really, really important for driving this market and then the complexity of our different markets around one geared to deliver single measures and one certainly not and finally, it was actually just interesting having the PRS and again, reminding ourselves that there is one market driver already that's going to push the kind of thing we're trying to achieve, so to summarise, actually putting things together,

it's about the performance of the measures and again, seeing that there are things in there that there has always been questions around behaviour and everything, but as we start to draw it together, we see some of the trends that are happening and the automation of the new technology, which might finally start to answer some of those issues and the barriers that have prevented all of the other players being involved in the market.

03:52:13

It's really good to strengthen those things and think like we'll see what they come up with and suggest as well, but it feels like there's some real pressure areas around performance and trust in that and then some things around the market and then some things around the value propositions for customers that are very important and it would be good to know, as we look at our policies, like how much they might address it and where the shortfall might still be, but we'll see.

I'm fully aware that these things don't answer it in the whole, so as always, seemingly things like everything … y'know it was very telling, yeah.

MF1: It was your first time?

M: Yeah, I came to this not having a really rough idea of how this all fitted together and then I just realised, it's a bit of a mess. The main takeaway is it's useful that we highlighted the areas where there are hurdles that the market itself is not crossing and that we, as government, where we can try and help and alleviate those problems, it's useful for policy [inaudible] .

M: It is because we have a quid pro quo market based approach and I think, finally, people are starting to understand that it's very complicated. For a market to work properly often requires intervention, like many leaders.

M: And the right amount, otherwise …

M: Yeah, totally.

03:54:13 - 03:55:20 - background chat

M: I think, in terms of the impact of the work inter-departmentally, it would help if we drew in a few other people, but we can do two different sessions.

03:56:05 - 03:57:28 - background chat.

M: To be perfectly honest, we're aiming for July, but depending on how conversations go with Treasury, if they say 'you can't publish these types of policy ideas in a call for evidence until we've had more discussion,' then it will be pushed back and I'm just trying to be realistic on how things often come around here, they get pushed back a lot. So we do have an aim to get it done before the summer, but I can't give a certainty on whether that will happen or not.

Annex F: Correspondence between Devil's Advocate inputs and structure

*Structural input in the script**	*Corresponding structure in the map**
"Rebound effect"	"Rebound effect"
"Probability of unintended consequences"	"Unintended consequences"
"Probability of unintended consequences"→ "Negative word of mouth"; "Speed of negative word of mouth"	"Unintended consequences" → "Measure performance" → "Word of mouth effect"
"Quality of retrofit"→ "Probability of unintended consequences"	"Quality" → "Measure performance"
"Energy use" depends on the "EE level of the house" and on the "Compliance of householders behaviour with the new retrofit measure"	"Behavioural compliance" → "Measure performance"
"Fragmentation→ "Quality of retrofit"; "Skills of installer"→ "Quality of retrofit"	"Market fragmentation" → "Standards" → "Quality"; "SC skills" → "Quality"
"Quality of the retrofit"→ "Performance of the retrofit measure"; "Maintenance capacity"→ "Performance of the retrofit measure"; "Customer behaviour"→ "Performance of the retrofit measure"	"Quality" → "Measure performance"; "Maintenance frequency" → "Measure performance"; "Behavioural compliance" → "Measure performance";
"Industrial trust for making investments"	"Industry trust"
"Industry capacity"; "time to adjust capacity" (estimated in 1-2 years)	"Capability of response to demand"
"Installer skills", "Time to gain skills, Skilled workers"	"SC skills"
"Unskilled workers" → "Skilled workers gap" → "Installers skills" → "Quality of retrofit"	"SC skills" → "Quality" → "Measure Performance"
"Quality"→"Credibility of the industry"→ "Demand"	"Quality" → "Measure performance" → "Uncertainty Costs" → "Perceived costs"
"Performance of the measures" → "Actual savings"	"Measure performance" → "Perceived monthly savings"
"Economic cycles"→ "Industry staff dismissed" → "Skills"	"Business Cycles"
"Uncertainty costs"	"Effectiveness uncertainty"
"Monitoring" → "Quality"	"Monitoring" → "Quality"
"Maintenance costs" → "Actual savings"	"Maintenance costs" → "Financial attractiveness"
"Disposable income" → "Priority given to retrofit"	"Households preference for energy efficiency"
"Marginal improvements" → "Technological level" → "Performance of the measure"	"Technological development of deep retrofit" → "Measure performance"
"Trusted information (credibility)"	"Tailored feedback to consumer on impact of their work"

* the symbol '→' stands for a causal connection

Annex G: Facilitator's second workshop memo

London 30th March 2017

Yesterday we performed the second workshop of the BEIS-UCL project for studying the homeowners retrofit uptake. It lasted more than 4 hours, there were 5 participants and we (the research team) were 4. Overall, it can be considered successful. N. and K. played the DAs in these session while V. and I were the facilitators. We introduced the DAs experiment to the participants in the beginning. They seemed very willing to try a new setting that could improve their understanding and the model. One of them clearly said "*it is very nice to be challenged*". The word enthusiastic is maybe to strong but 'I got good vibes' from the participants when we said we want to try the new DA. We started the session with a recap of the previous session and the we described the new version of the system map (that we called 'hybrid map') and at the end we let the participants (including the DAs) to made all the modifications on the structure they though it was needed. Then we asked to them to brainstorm some variable that they believed important and missing in the system map. After that, in a round robin we discussed all these variables. The impression I got was that all the variables provided by the DAs were discussed and then accepted (with or without any adjustment). It seemed that the participants liked the session. For example, one of them needed to leave before the conclusion. After he left he sent a message to another participant asking to introduce a new variable that he just came up with in the map. This 'extra effort' done by him shows that there was interest. I think that everything went smooth and I didn't see any conflict or tension in the group. It important to note that the DAs didn't interfere with the facilitation of the workshop except at the end of the session when V and I were facing some troubles to depict in the map a group of concepts suggested by the participants (I have to admit that I was tired in that part and could be that I was not focus enough). In that moment, one of the DAs intervened and took the floor as a facilitator helping in clarifying the concept. However, I feel that among the research team there was a lot of team-work during the session (e.g. we respected our roles and accepted to be 'treated' differently, we tried to make the life of each other as much easy as possible, the two facilitators facilitated in an harmonic way in which there was a continuous change between being the modeller and the facilitator, etc.) and I think it was crucial for the good outcomes. At the end, participants expressed appreciation for the session and also for the new setting.

Giovanni Cunico

Annex H: Stock and flow model documentation

Model settings

Model settings: Initial Time = 0; Final Time = 600; Time step = 0.5; Unit for time = Month; Integration method: Euler

This setting represents a simulation period of 50 years, since the time frame to analyze was chosen to be 2000-2050. This choice was made because the long term UK emission reductions' targets are set for 2050.

A test was conducted to assess whether the time step was appropriate for a correct integration and 0.5 appeared to be adequate.

The software used to build the model was Vensim PRO. It was needed since the free version does not allow to use arrays (called 'subscripts' in the software). Below are reported: first, a table with the specifics of the arrays used; second, a table in which all the variables in the model are described (equation, unit and a comment explaining the meaning for each variable are reported); lastly, the excel file in which the external real data used to 'feed' the model are outlined. All these information have been reported since they are all necessary to replicate the model used in this research.

Model subscripts (arrays)

Subscript name	*Subscript items*	*Subscript description*
SC resources	techno, labour, skills	Script used for the three different type of investments the supply chain (SC) can do: technology, labour and skills.
SC type	Single ,multi	Script used to account for the two type of supply chain: single and multi. Single supply chain refers to installers that are able only to deliver one measure. Installers that are part of the multi supply chain are the ones who are able to install more than one measure at the same time in an intervention.
stamp duty band	up125, up250, up925, up1500, over1500	Script used to group the houses purchased based on the stamp duty band they are part of.
buyers type	mortgage, stamp, both	Script used to divide the three type of house buyers that consider retrofit because of the two policies. They can consider retrofit because they are offered with a green mortgage, because they are eligible of stamp duty rebate or because of both.
EPC score	epcAB, epcC, epcD, epcE, epcF, epcG	Script used in the model to represent the different categories of EPC certificates. Certificates A and B have been grouped together because their performances are very similar from a broad perspective. Moreover, this choice is commonly done in literature.
extent	zero, one, two, three, four	Retrofit extent indicates a continuum of the number of measures installed in a property. If there are only few measures installed, we can refer to that property as "lightly retrofitted", whilst if the number of measures installed is close to the maximum available, the property can be named "deeply retrofitted. Therefore, in the model, extent zero indicates houses with zero retrofit measures installed, while extent one refers to dwelling with one retrofit measure installed and so on.
interventions	n, g, b, l, i, gb, gl, gi, bl, bi, li, gbl, gbi, gli, bli, gbli	Intervention is a combination of retrofit measures that can be installed. Therefore this script is used to group all the 16 possible combination of the four measures considered in the model simulations (cavity and solid wall insulation are mutually exclusive in the model simulations). Here the initial letter of every measure is used to create the combination. For example, 'gbl' means a combination of glazing, boiler and loft insulation. 'N' stands for the choice of doing nothing.
measures	insulation, loft, glazing, boiler	Here the measures considered in the model are reported. Not to forget that cavity and solid wall are both categorized as insulation and they run separately in the model (there is a switch to pass from a simulation in which cavity is considered to one with solid).
renovation type	amenity, efficiency, extension	Script used to take into account three different type of homeowners considering to top up their amenity and generic renovation with retrofit. First, people that started with only an amenity renovations and consider retrofit because installers' recommendations (amenity); second, people that decided already by themselves to top up their renovation with energy efficiency measures because aware (efficiency); and third, people doing house extension renovations and forced to consider that because of policy reason (extension).

Model Variables and Equations

Variable name[10]	*Equation*	*Unit*	*Comments*
Accumulated capacity gap for measures	[SC type,measures]= INTEG (measures capacity gap accumulation[SC type,measures]-measures capacity gap reduction[SC type,measures], 0)	Interventions	Cumulative number of retrofit interventions done
accumulated measures	SUM(Installed measures[measures!])+ alternative insulation installed measures	measures	All the installed measures, also including the one of wall insulation that are mutually excluded by the scenario selection
Accumulated number of measures per intervention under ECO	INTEG (accumulation of number of interventions, 0)	measures*Month	Cumulative of the intervention done under ECO subsidies
accumulation of number of interventions	number of measures per intervention*STEP(1,ECO start)	measures	Flow of the intervention done under ECO
actual bill savings by intervention	energy price*actual energy savings by intervention[interventions]	GBP/Interventions/ Month	Real bill savings. They can differ from the expected ones (e.g. low quality installations can decrease the savings generated by a measure , or households increasing house temperature compare than before experience a decrease in the bill savings expected)
actual budget percentage for training	MAX(budget percentage for training,1-budget percentage for technological investment)	Dmnl	The budget of investments in workforce is calculated based on what is not invested on technology. However the function makes sure that not everything is invested in technology and that always something is invested in training
actual energy savings by intervention	("avg energy consumption for non-retrofitted households"-energy consumption by interventions [interventions])/ interventions per households	kWh/Month/ Interventions	Here the actual energy savings are calculated subtracting the energy consumption after an intervention to the energy consumption of non-retrofitted households
Added value to property of measures	INTEG (change in measures added value to property[measures],Popularity of measures[measures]*max added value[measures]*"reference non-financial attractiveness per measure"[measures]/SUM("reference non-financial attractiveness per measure" [measures!]))	Dmnl	How much a measure is believed to add value to a property for reasons excluding energy savings

[10] In the variable name the scripts used are reported only in case the equations differ for some items of the script. Otherwise, they can be found in the variable's equation.

additional investing capacity due to green mortgage	(1-no restrictions on additional mortgages)* MIN(upfront cost for consumer[SC type,interventions],lenders restrictions on additional mortgage [interventions])	GBP/Interventions	Since the lenders have no restriction to the investment for the retrofit, the investing capacity for buyers going through green mortgages correspond to the minimum between the cost of the intervention and the additional cash lent
additional investing capacity due to stamp duty rebates	(1+buyers flexibility for additional payments to avoid stamp duty)*maximum rebate from stamp duty usable to retrofit	GBP/Interventions	Total investing capacity of buyers that consider retrofit because stamp duty reasons
adjustment time for backlog	2	Month	How quick the supply chain can adjust the workforce in order to cover an eventual capacity gap. The value is an educated guess made by researchers since no data were available
affordability by buyer type	SUM(retrofit affordability for buyers[SC type!,interventions!,buyers type])/ELMCOUNT(SC type)/ELMCOUNT(interventions)	Dmnl	Here the affordability is calculated by the reason buyers are considering retrofit
affordability by renovations type	SUM(retrofit affordability for renovations[SC type!,interventions!,renovation type])/ELMCOUNT(SC type)/ELMCOUNT(interventions)	Dmnl	Here the affordability of renovators considering to top up their renovation with retrofit is calculated per each renovation type (amenity, directly efficiency, in case policy is activated also extension)
affordability steepness	0.8	Dmnl	Inclination of the tangent function for the affordability. The less inclined the more flat is the function and therefore the more spread is the affordability. This results in the fact that the range around the precise investing capacity is broader. The value of this function has been selected in order to fit best the reference modes
aggregate measures uptake rate	IF THEN ELSE(Potential for retrofit measures to install[measures]>0, MAX(0,SUM(retrofit rate by measures[SC type!,measures])),0)	measures/Month	Total monthly rate of measure installed
alternative insulation energy savings	cavity wall scenario*solid wall savings+ (1-cavity wall scenario)*cavity wall savings	kWh/Month/ measures	The alternative energy savings for cavity wall and solid wall. When cavity wall scenario is on, this variable reports the solid wall values in order to consider them when simulating the scenario. It works also vice versa.
alternative insulation INIT distribution	cavity wall scenario*solid INIT distribution+ (1-cavity wall scenario)*cavity INIT distribution	Dmnl	The alternative stock distribution for cavity and solid depending on the scenario that is run in the model
alternative insulation installed measures	cavity wall scenario*solid exogenous installed measures+(1-cavity wall scenario)*cavity exogenous installed measures	measures	This variable accounts for the wall insulation measures installed that are not calculated by the model because of the scenario selection (in the model cavity wall and solid wall are mutually exclusive)
alternative insulation popularity	IF THEN ELSE(cavity wall scenario>0.5, exogenous popularity of solid wall, exogenous popularity of cavity)	Dmnl	The two popularity for cavity and solid are reported here. When the cavity scenario is on, external solid wall popularity is taken into account and vice versa

alternative insulation retrofitted fraction	IF THEN ELSE(cavity wall scenario>0.5, exogenous retrofitted fraction for solid, exogenous retrofitted fraction for cavity)	Dmnl	The alternative retrofitted fraction for cavity wall and solid wall. When cavity wall scenario is on, this variable reports the solid wall values in order to consider them when simulating the scenario. It works also vice versa
automatization in use	SMOOTH1(automatization potential , delay to implement automatization , automatization potential)	Dmnl	These is the actual automatization in use in the system. The potential automatization that is develop through technological developments takes time (delay function) to be implemented in the system
automatization potential	SUM(Retrofit technology[measures!])/ELMCOUNT(measures)	Dmnl	The automatization potential can increase due to technological improvements. Here it is averaged
avg added value of renovations	0.06	Dmnl	This is the average value added to a property by a generic renovation. it is used as reference
avg affordability for buyers	SUM(affordability by buyer type[buyers type!])/ELMCOUNT(buyers type)	Dmnl	Here the affordability are integrated in one variable
avg affordability for renovations	SUM(affordability by renovations type[renovation type!])/ELMCOUNT(renovation type)	Dmnl	Here all the affordability for renovators topping up are integrated in one variable since they are all the same
avg boiler duration	120	Month	Data retrieved from grey literature. Source: http://www.doityourself.com/stry/the-average-boiler-life-expectancy
avg disposable income	20000	GBP/Month/ households	UK households average disposable income. Educated guess made by researchers
avg energy bills	avg energy consumption per household*energy price	GBP/Month/ households	Average expenditure on energy bills
avg energy consumption for non-retrofitted households	reference consumption for non-retrofitted households 2000-energy consumption adjustment	kWh/Month/ households	The reference non-retrofitted household energy consumption in 2000 is taken as a reference point. Then it is subtracted by external factors than retrofit that impacted the energy consumption (energy consumption adjustment)
avg energy consumption per household	SUM(energy consumption by interventions[interventions!]*estimated retrofitted fraction by intervention[interventions!])	kWh/Month/ households	Average energy consumed by household
avg homeowners property sales	reference avg homeowners property sales*risk taking attitude by economic cycles	households/Month	Average number of property sales per month multiplied by economic cycles. It is believed that economic cycle can increase or decrease the amount of sales depending whether the sector is in a boost or decline period
avg installers working time	240	Month	It is assumed a worker stays in the industry for 20 years
avg mortgage size	167000	GBP/Interventions	Average mortgage size retrieved from grey literature. Source: http://www.zoopla.co.uk/discover/property-news/banks-approve-an-average-mortgage-amount-of-167000/#4jK8D2303r3DPzGd.97
avg number of measures per intervention under ECO	ZIDZ(accumulated number of measures per intervention under ECO,MAX(Time-ECO start,0))	measures	This variable calculates the average number of measures installed per intervention under ECO

avg popularity of retrofit	(SUM(Popularity of measures[measures!])+alternative insulation popularity)/ELMCOUNT(measures)	Dmnl	Here the all the popularities of different measures are counted and averaged in order to calculated the average retrofit popularity. In this case alternative insulation popularity helps in taking into account the popularity of the different insulation scenario
avg probability of measures failures	(max unintended consequences probability*(1-workforce skills[measures])+min unintended consequences probability*workforce skills[measures])*households behavioural compliance[measures]	Dmnl	This is the average probability of a measure to fail. It depends on the skills of the workforce that weight the probability of having a failure, and on the households behavioural compliance
avg profit per measure installed	profit margin*reference prices for individual measure[measures]	GBP/measures	This is the average profit installers gain per measure
avg quality of installed measures	ZIDZ(Installed measures weighted by quality[measures],Installed measures[measures]+Failed measures[measures])	Dmnl	A number between 0 and 1. It represents how good is the average quality of the installations: if 1 it is very high, 0 the opposite
avg renovation rate	total housing stock*renovation fraction	households/Month	The fraction times the total gives the number of amenity renovations that are done
avg significance of fuel costs	avg energy bills/avg disposable income	Dmnl	This variable represents how important are energy bills on the homeowners income
avg stamp duty	SUM(avg stamp duty per band[stamp duty band!]*estimated property distribution per stamp duty band[stamp duty band!])	GBP/households	The average stamp duty is calculated multiplying the property distribution by band per the relative average stamp duty. Then they are all summed
avg stamp duty per band[up125]	0	GBP/households	Average stamp duty per house purchase range. This value is for the range 0 GBP up to 125000 GBP Source: https://www.gov.uk/stamp-duty-land-tax/residential-property-rates
avg stamp duty per band[up250]	1250	GBP/households	Average stamp duty per house purchase range. This case is for the range 125000 GBP up to 250000 GBP Source: https://www.gov.uk/stamp-duty-land-tax/residential-property-rates
avg stamp duty per band[up925]	19375	GBP/households	Average stamp duty per house purchase range. This case is for the range 250000 GBP up to 925000 GBP Source: https://www.gov.uk/stamp-duty-land-tax/residential-property-rates
avg stamp duty per band[up1500]	65000	GBP/households	Average stamp duty per house purchase range. This case is for the range 925000 GBP up to 1500000 GBP Source: https://www.gov.uk/stamp-duty-land-tax/residential-property-rates
avg stamp duty per band [over1500]	181250	GBP/households	Average stamp duty per house purchase range. This case is for houses more expensive than 1500000 GBP Source: https://www.gov.uk/stamp-duty-land-tax/residential-property-rates
avg time before deciding	2	Month	Time people that are considering to do a renovation need before to take a decision
avg time for backlog customers drop out	3	Month	Average time customers that want a retrofit intervention are willing to wait because the supply can not satisfy their demand before to stop wanting that intervention

avg time for WF adjustment forecasts	12	Month	The reference time the supply chain use as horizon to estimate what size the future workforce should be when it makes forecasts of demand. It is equivalent to the time the supply chain needs to adjust the workforce in excess. Educated guess made by researchers
avg worker wage	1700	GBP/workers/ Month	It is an educated guess made by researcher and supported by grey literature
awareness spreading by word of mouth	contact rate*retrofit visibility[measures]*potential fraction by measure[measures]*retrofitted fraction by measure[measures]	1/Month	Here the 'positive' word of mouth of retrofit is calculated. Measures' visibility, households contact rate and measures' installed fraction are multiplied in order to estimate the 'positive' word of mouth
backlog adjustment time	3	Month	This time represents the months needed by the supply chain to detect and fulfill the backlog
backlog interventions drop out	Backlog of interventions[SC type,interventions]/avg time for backlog customers drop out	Interventions/ Month	If the backlog demand for retrofit is not satisfy in reasonable time the households wanting to do an intervention change their mind and decide to not undertake the retrofit intervention anymore
Backlog of interventions	INTEG (interventions backlog accumulation[SC type,interventions]-interventions backlog depletion[SC type,interventions]-backlog interventions drop out[SC type,interventions],0)	Interventions	Accumulation of retrofit interventions not fulfilled by supply chain
bank interest rate	0.005	1/Month	This is the bank interests rate on deposits
believed monthly savings	potential savings[SC type,interventions]*retrofit credibility[SC type,interventions]	GBP/Interventions/ Month	The potential savings then are discounted for the credibility of the retrofit industry. 0<Retrofit credibility<1. If credibility is low the believed monthly savings are lower than the potential because homeowners do not completely believe the expected savings declared by the industry
benefits attractiveness	financial attractiveness[SC type,interventions]*relative importance of financial benefits+ "non-financial attractiveness per intervention"[interventions]*(1-relative importance of financial benefits)	Dmnl	Here the financial and non-financial attractiveness are integrated in one variable and weighted
budget for upcoming month	expected profits for manufacturers for investments horizon[measures]/investments horizon	GBP/Month	The monthly budget for investments is calculated dividing by the time horizon the expected profits for manufacturers (these last were calculated for that time horizon)
budget percentage for technological investment	0.05	Dmnl	This is percentage of the supply chain investment invested in technology development. Estimation made by researchers sine no data were available
budget percentage for training	0.05	Dmnl [0,1]	This value is an educated guess and represents a the minimum fractional investment in training

buyers awareness of stamp duty rebates	1	Dmnl	In case the stamp duty rebate policy is activated, the percentage of buyers that when purchasing a house are aware of the possible stamp duty rebate in case they retrofit an inefficient property
buyers distribution [mortgage]	ZIDZ(fraction of buyers considering retrofit because of green mortgages but not stamp rebate,fraction of buyers considering retrofit because of green mortgages but not stamp rebate+fraction of buyers considering retrofit because of stamp rebate but not green mortgages+fraction of buyers considering retroift because of both stamp rebates and green mortgages)	Dmnl	Buyers considering retrofit distributed according to the reason why they are considering it (stamp duty, green mortgage, and both)
buyers distribution [stamp]	ZIDZ(fraction of buyers considering retrofit because of stamp rebate but not green mortgages,fraction of buyers considering retrofit because of green mortgages but not stamp rebate+fraction of buyers considering retrofit because of stamp rebate but not green mortgages+fraction of buyers considering retroift because of both stamp rebates and green mortgages)	Dmnl	Buyers considering retrofit distributed according to the reason why they are considering it (stamp duty, green mortgage, and both)
buyers distribution [both]	ZIDZ(fraction of buyers considering retroift because of both stamp rebates and green mortgages,fraction of buyers considering retrofit because of green mortgages but not stamp rebate+fraction of buyers considering retrofit because of stamp rebate but not green mortgages+fraction of buyers considering retroift because of both stamp rebates and green mortgages)	Dmnl	Buyers considering retrofit distributed according to the reason why they are considering it (stamp duty, green mortgage, and both)
buyers drop out ratio	ZIDZ(SUM(demand for retrofit from buyers[SC type!,n]), potential demand from buyers)	Dmnl	Fraction of buyer that after considering retrofit decide not to do anything
buyers flexibility for additional payments to avoid stamp duty	0.5	Dmnl	Buyers willingness to top up even more the amount of money free up by stamp duty by the 50% in order to avoid to pay the stamp duty. 50% is and educated guess made by researchers
Buyers planning retrofit	INTEG (buyers starting to consider retrofit because of green mortgages but not stamp rebate +buyers starting to consider retrofit because of stamp duty rebates-potential demand from buyers	households	Stock of buyers considering to retrofit their new property they are purchasing

	,(buyers starting to consider retrofit because of green mortgages but not stamp rebate +buyers starting to consider retrofit because of stamp duty rebates)*avg time before deciding)		
buyers starting to consider retrofit because of green mortgages but not stamp rebate	fraction of buyers considering retrofit because of green mortgages but not stamp rebate*avg homeowners property sales	households/Month	Flow of buyers starting to consider retrofit only because of green mortgages and not because stamp rebate.
buyers starting to consider retrofit because of stamp duty rebates	stamp rebates eligible and aware fraction*avg homeowners property sales	households/Month	Flow of buyers starting to consider retrofit only because of stamp duty rebates. It is calculated based on the average number of property sales in the UK
buyers' investing capacity[SC type,interventions,stamp]	additional investing capacity due to stamp duty rebates	GBP/Interventions	Investing capacities per buyers reason for considering retrofit
buyers' investing capacity[SC type,interventions,mortgage]	additional investing capacity due to green mortgage[SC type,interventions]	GBP/Interventions	Investing capacities per buyers reason for considering retrofit
buyers' investing capacity[SC type,interventions,both]	additional investing capacity due to stamp duty rebates+ additional investing capacity due to green mortgage[SC type,interventions]	GBP/Interventions	Investing capacities per buyers reason for considering retrofit
cavity exogenous installed measures	GET XLS DATA('energy.xlsx', 'Sheet1' , 'A' , L2')	measures	Here the cavity wall measures installed are calculated separately and then, when the solid wall scenario is running, exogenously introduced in the model
cavity INIT distribution	1-solid INIT distribution	Dmnl	Since solid wall and cavity wall are mutually exclusive, the fraction of cavity walls is obtained with one minus the solid wall distribution
cavity wall savings	1200/12	kWh/Month/ measures	Cavity wall energy savings per month. Source: DECC/BEIS report: 'NATIONAL ENERGY EFFICIENCY DATA-FRAMEWORK Summary of analysis using the National Energy Efficiency Data-Framework (NEED)' June 2016
cavity wall scenario	0	Dmnl	In this model cavity wall and solid wall are mutually exclusive. When the switch is on (1) the model simulates cavity wall and when it is of (0) it simulates solid wall. These are visible under the 'insulation' names.
certification bodies quality	effort intensity in enforcing monitoring quality+ (1-effort intensity in enforcing monitoring quality)*certification bodies quality without any enforcement	Dmnl	The actual quality certification bodies use in their work. It depends on the reference quality and on the external effort made by external entities in enforcing high quality work in certification bodies

certification bodies quality without any enforcement	0.7	Dmnl	This value between 0 and 1 represents the quality certification bodies (the entities in charge of monitoring retrofit) use in their work. 1 the quality is maximum and 0 minimum. It is set lower than the maximum, because during interviews with experts in BEIS it has been said that certification bodies do not do a perfect job and they need to be controlled too by external entities
change in measures added value to property	potential for measures increase in added value[measures]*pressure to increase measures added value[measures]/changing time for added value to property	1/Month	Flow accounting for changes in the measures added value to property
change in perceived interventions prices	difference in prices[SC type,interventions]/past prices retention time	GBP/Interventions/ Month	Rate of change in perceived prices by homeowners
change in perceived market volume	(market volume for retrofit by measure[SC type,measures]-perceived market volume[SC type,measures])/perception time for perceived market volume	GBP/Month/Month	Rate through which change in market volume are perceived by the actor in the market
change in price premium per EPC band	housing market reactiveness in price change* (mortgage premium for EPC band-house price premium per EPC band)*STEP(1,EPC mortgage policy starting time)	1/band/Month	Units: Flow representing a closing gap between the mortgage premium for EPC band given by lenders and the actual price premium per EPC band in housing prices. In this flow the adjustment time is the housing market reactiveness in price change due to policy changes
changing time for added value to property	120	Month	Time needed to homeowners to fully appreciate a measure as an added value to a property
CO2 emissions per kWh	0.271	Kg/kWh	United Kingdom housing energy fact file (2013): taking data about households energy consumption, number of households and CO2 emissions from households we get the emissions per unit of energy
CO2 emitted from residential stock	INTEG (residential stock emissions, 0)	Kg	Accumulation of the CO2 emitted from the residential stock
competitive alternatives for amenity renovations	0	Dmnl	Other alternatives for amenity renovations than just retrofit measure
compulsory retrofit for extensions switch	0	Dmnl	This switch allows to test a policy that makes all compulsory for all the renovators to top up with retrofit
consumers experience of measures benefits	(1-relative importance of financial benefits)*thermal comfort by measure[measures]+relative importance of financial benefits*measures performance on bill savings[measures]	Dmnl	Here the benefits (non-financial benefits as thermal comfort and financial benefits like performance on bill savings) of a measure installed are aggregated and weighted by homeowners preference for financial or non financial benefits
contact rate	0.08	1/Month	How frequently households meet and talk about retrofit. This constitutes the contact rate
contribution from other actors	0	Dmnl	The fractional contribution other actors in the retrofit system could give in order to decrease the retrofit upfront costs for homeowners

contribution to skills of newly hired	MAX(0,reference skills of new workers*SUM(workforce growth[SC type!,measures]))	workers/Month	This flow represents the new workers hired weighted by their skills
cost of a maintenance intervention[SC type]	50	GBP/Interventions	This is the cost of maintenance intervention. It is an averaged value and based on information found online by researchers that believed them to be reasonably realistic
cost of hiring	MAX(0, training costs for junior[measures]*desired hiring[SC type,measures]+projected wage costs[SC type,measures]*(desired hiring[SC type,measures]-projected retiring[SC type,measures]))	GBP	Here the costs of hiring the desired workforce are estimated based on the training costs and wage costs. To this costs are subtracted the workers retiring in that time span
costs for senior training[measures]	2000	GBP/workers	Educated guess on the costs of training workforce for a skills improvement
current EPC distribution [epcAB]	0.037	Dmnl	Housing stock distribution based on the EPC (Energy Performance Certificate). A is very efficient while G is very inefficient. http://nesstar.ukdataservice.ac.uk/webview/index.jsp?v=2&mode=documentation&submode=abstract&study=http://nesstar.ukdataservice.ac.uk:80/obj/fStudy/7518&top=yes
current EPC distribution [epcC]	0.285	Dmnl	Housing stock distribution based on the EPC (Energy Performance Certificate). A is very efficient while G is very inefficient. http://nesstar.ukdataservice.ac.uk/webview/index.jsp?v=2&mode=documentation&submode=abstract&study=http://nesstar.ukdataservice.ac.uk:80/obj/fStudy/7518&top=yes
current EPC distribution [epcD]	0.421	Dmnl	Housing stock distribution based on the EPC (Energy Performance Certificate). A is very efficient while G is very inefficient. http://nesstar.ukdataservice.ac.uk/webview/index.jsp?v=2&mode=documentation&submode=abstract&study=http://nesstar.ukdataservice.ac.uk:80/obj/fStudy/7518&top=yes
current EPC distribution [epcE]	0.195	Dmnl	Housing stock distribution based on the EPC (Energy Performance Certificate). A is very efficient while G is very inefficient. http://nesstar.ukdataservice.ac.uk/webview/index.jsp?v=2&mode=documentation&submode=abstract&study=http://nesstar.ukdataservice.ac.uk:80/obj/fStudy/7518&top=yes
current EPC distribution [epcF]	0.05	Dmnl	Housing stock distribution based on the EPC (Energy Performance Certificate). A is very efficient while G is very inefficient. http://nesstar.ukdataservice.ac.uk/webview/index.jsp?v=2&mode=documentation&submode=abstract&study=http://nesstar.ukdataservice.ac.uk:80/obj/fStudy/7518&top=yes
current EPC distribution [epcG]	0.012	Dmnl	Housing stock distribution based on the EPC (Energy Performance Certificate). A is very efficient while G is very inefficient. http://nesstar.ukdataservice.ac.uk/webview/index.jsp?v=2&mode=documentation&submode=abstract&study=http://nesstar.ukdataservice.ac.uk:80/obj/fStudy/7518&top=yes
defection rate	MAX(0, DELAY1(aggregate measures uptake rate[measures]*fraction of retrofitting leading to failures[measures] , delay to manifest unintended consequences))	measures/Month	Rate of measures installed that are defected and become failed measures. It depends on the quality of the installation and on the delay a poor installation need to show its low quality and become a failed measure

delay to implement automatization	48	Month	The time a new technological enhancement in automatization needs before to become systematically installed in the system
delay to manifest unintended consequences	12	Month	The delay a poor installation need to show its low quality and become a failed measure. This estimation is based on the educated guess of Clive Shrubsole (UCL researcher)
demand for retrofit by interventions[SC type,interventions]	:EXCEPT: [SC type,g],[SC type,i],[SC type,l],[SC type,b]= (demand for retrofit from buyers[SC type,interventions]+ SUM(demand for retrofit from renovations[SC type,interventions,renovation type!])) *interventions per household	Interventions/ Month	Total demand for retrofit (buyers, renovators, retrofit as amenity, and old boiler replacements) by intervention
demand for retrofit by interventions[SC type,b]	(demand for retrofit from buyers[SC type,b]+SUM(demand for retrofit from renovations[SC type,b,renovation type!]))*interventions per household+(retrofit measures installed as amenity[boiler]+old boilers replacement)/2/measures per intervention	Interventions/ Month	Total demand for retrofit (buyers, renovators, retrofit as amenity, and old boiler replacements) by intervention
demand for retrofit by interventions[SC type,g]	(demand for retrofit from buyers[SC type,g]+SUM(demand for retrofit from renovations[SC type,g,renovation type!]))*interventions per household+retrofit measures installed as amenity[glazing]/2/measures per intervention	Interventions/ Month	Total demand for retrofit (buyers, renovators, retrofit as amenity, and old boiler replacements) by intervention
demand for retrofit by interventions[SC type,l]	(demand for retrofit from buyers[SC type,l]+SUM(demand for retrofit from renovations[SC type,l,renovation type!]))*interventions per household+ retrofit measures installed as amenity[loft]/2/measures per intervention	Interventions/ Month	Total demand for retrofit (buyers, renovators, retrofit as amenity, and old boiler replacements) by intervention
demand for retrofit by interventions[SC type,i]	(demand for retrofit from buyers[SC type,i]+SUM(demand for retrofit from renovations[SC type,i,renovation type!])) *interventions per household + retrofit measures installed as amenity[insulation]/2/measures per intervention	Interventions/ Month	Total demand for retrofit (buyers, renovators, retrofit as amenity, and old boiler replacements) by intervention
demand for retrofit from buyers	SUM(buyers distribution[buyers type!]* MAX(0, relative intervention desirability[SC	households/Month	The demand for buyers is constituted multiplying the potential retrofit demand from buyers per their distribution based on the reason why they consider to retrofit, per their

	type,interventions]* retrofit affordability for buyers[SC type,interventions,buyers type!]* estimated retrofit potential fraction by intervention[interventions]* potential demand from buyers))		specific affordability to retrofit, per the potential available in the housing stock, and per the relative intervention desirability
demand for retrofit from renovations before affordability cut [SC type,i,buyers type]	potential demand from buyers for potential fraction[buyers type,i]*(relative intervention desirability[SC type,i]/(relative intervention desirability[SC type,i]+relative intervention desirability[SC type,n]))+potential demand from buyers for potential fraction[buyers type,gi]*(relative intervention desirability[SC type,i]/(relative intervention desirability[SC type,i]+relative intervention desirability[SC type,g]+relative intervention desirability[SC type,gi]+relative intervention desirability[SC type,n]))+potential demand from buyers for potential fraction[buyers type,li]*(relative intervention desirability[SC type,i]/(relative intervention desirability[SC type,i]+relative intervention desirability[SC type,l]+relative intervention desirability[SC type,li]+relative intervention desirability[SC type,n]))+ potential demand from buyers for potential fraction[buyers type,bi]* (relative intervention desirability[SC type,i]/(relative intervention desirability[SC type,i]+relative intervention desirability[SC type,b]+relative intervention desirability[SC type,bi]+relative intervention desirability[SC type,n]))+potential demand from buyers for potential fraction[buyers type,gbi]* (relative intervention desirability[SC type,i]/(relative intervention desirability[SC type,i]+relative intervention desirability[SC type,n]+relative intervention desirability[SC type,g]+relative intervention desirability[SC type,b]+relative intervention desirability[SC type,gb]+relative intervention desirability[SC type,gi]+relative intervention desirability[SC type,bi]+relative intervention desirability[SC type,gbi]))+ potential demand from buyers for potential fraction[buyers type,gli]* (relative	households/Month	Here the demand for retrofit from renovators willing to top up their renovation with retrofit, and already distributed based on the potential, is distributed based on the intervention desirability. There are 16 different equations for the same variable because there are 16 different interventions. The equations are so long because for each the specific intervention desirability all the different buyers that can potentially install the intervention must be taken into account. This needs to be done for all the 16 possible combinations.

	intervention desirability[SC type,i]/(relative intervention desirability[SC type,i]+relative intervention desirability[SC type,n]+relative intervention desirability[SC type,g]+relative intervention desirability[SC type,l]+relative intervention desirability[SC type,gl]+relative intervention desirability[SC type,gi]+relative intervention desirability[SC type,li]+relative intervention desirability[SC type,gli]))+ potential demand from buyers for potential fraction[buyers type,bli]* (relative intervention desirability[SC type,i]/(relative intervention desirability[SC type,i]+relative intervention desirability[SC type,n]+relative intervention desirability[SC type,b]+relative intervention desirability[SC type,l]+relative intervention desirability[SC type,bl]+relative intervention desirability[SC type,bi]+relative intervention desirability[SC type,li]+relative intervention desirability[SC type,bli]))+potential demand from buyers for potential fraction[buyers type,gbli]* (relative intervention desirability[SC type,i]/(SUM(relative intervention desirability [SC type,interventions!]))))		
demand for retrofit from renovations before affordability cut [SC type,b,buyers type]	potential demand from buyers for potential fraction[buyers type,b]* (relative intervention desirability[SC type,b]/(relative intervention desirability[SC type,b]+relative intervention desirability[SC type,n]))+potential demand from buyers for potential fraction[buyers type,gb]* (relative intervention desirability[SC type,b]/(relative intervention desirability[SC type,b]+relative intervention desirability[SC type,g]+relative intervention desirability[SC type,gb]+relative intervention desirability[SC type,n]))+ potential demand from buyers for potential fraction[buyers type,bl]* (relative intervention desirability[SC type,b]/(relative intervention desirability[SC type,b]+relative intervention desirability [SC type,l]+relative intervention desirability[SC type,bl]+relative intervention desirability[SC	households/Month	Here the demand for retrofit from renovators willing to top up their renovation with retrofit, and already distributed based on the potential, is distributed based on the intervention desirability. There are 16 different equations for the same variable because there are 16 different interventions. The equations are so long because for each the specific intervention desirability all the different buyers that can potentially install the intervention must be taken into account. This needs to be done for all the 16 possible combinations.

type,n]))+potential demand from buyers for potential fraction[buyers type,bi]* (relative intervention desirability[SC type,b]/(relative intervention desirability[SC type,i]+relative intervention desirability[SC type,b]+relative intervention desirability[SC type,bi]+relative intervention desirability[SC type,n]))+ potential demand from buyers for potential fraction[buyers type,gbi]* (relative intervention desirability[SC type,b]/(relative intervention desirability[SC type,i]+relative intervention desirability[SC type,n]+relative intervention desirability[SC type,g]+relative intervention desirability[SC type,b]+relative intervention desirability[SC type,gb]+relative intervention desirability[SC type,gi]+relative intervention desirability[SC type,bi]+relative intervention desirability[SC type,gbi]))+ potential demand from buyers for potential fraction[buyers type,gbl]*(relative intervention desirability[SC type,b]/(relative intervention desirability[SC type,b]+relative intervention desirability[SC type,n]+relative intervention desirability[SC type,g]+relative intervention desirability[SC type,l]+relative intervention desirability[SC type,gl]+relative intervention desirability[SC type,gb]+relative intervention desirability[SC type,bl]+ relative intervention desirability[SC type,gbl]))+ potential demand from buyers for potential fraction[buyers type,bli]* (relative intervention desirability[SC type,b]/(relative intervention desirability [SC type,i]+relative intervention desirability[SC type,n]+relative intervention desirability[SC type,b]+relative intervention desirability [SC type,l]+relative intervention desirability[SC type,bl]+relative intervention desirability[SC type,bi]+relative intervention desirability [SC type,li]+relative intervention desirability [SC type,bli]))+potential demand from buyers for potential fraction[buyers type,gbli]*

	(relative intervention desirability[SC type,b]/(SUM(relative intervention desirability [SC type,interventions!]))		
demand for retrofit from renovations before affordability cut [SC type,g,buyers type]	potential demand from buyers for potential fraction[buyers type,g]*(relative intervention desirability[SC type,g]/(relative intervention desirability[SC type,g]+relative intervention desirability[SC type,n]))+ potential demand from buyers for potential fraction[buyers type,gb]* (relative intervention desirability[SC type,g]/(relative intervention desirability[SC type,g]+relative intervention desirability[SC type,b]+relative intervention desirability[SC type,gb]+relative intervention desirability[SC type,n]))+ potential demand from buyers for potential fraction[buyers type,gl]*(relative intervention desirability[SC type,g]/(relative intervention desirability[SC type,g]+relative intervention desirability[SC type,l]+relative intervention desirability[SC type,gl]+relative intervention desirability[SC type,n]))+ potential demand from buyers for potential fraction[buyers type,gi]* (relative intervention desirability[SC type,g]/(relative intervention desirability[SC type,i]+relative intervention desirability[SC type,g]+relative intervention desirability[SC type,gi]+relative intervention desirability[SC type,n]))+potential demand from buyers for potential fraction[buyers type,gbi]* (relative intervention desirability[SC type,g]/(relative intervention desirability [SC type,i]+relative intervention desirability [SC type,n]+relative intervention desirability[SC type,g]+relative intervention desirability [SC type,b]+relative intervention desirability [SC type,gb]+relative intervention desirability[SC type,gi]+relative intervention desirability[SC type,bi]+relative intervention desirability[SC type,gbi]))+potential demand from buyers for potential fraction[buyers type,gbl]*(relative intervention desirability[SC type,g]/(relative intervention desirability	households/Month	Here the demand for retrofit from renovators willing to top up their renovation with retrofit, and already distributed based on the potential, is distributed based on the intervention desirability. There are 16 different equations for the same variable because there are 16 different interventions. The equations are so long because for each the specific intervention desirability all the different buyers that can potentially install the intervention must be taken into account. This needs to be done for all the 16 possible combinations.

	[SC type,b]+relative intervention desirability [SC type,n]+relative intervention desirability[SC type,g]+relative intervention desirability [SC type,l]+relative intervention desirability [SC type,gl]+relative intervention desirability[SC type,gb]+relative intervention desirability[SC type,bl]+relative intervention desirability[SC type,gbl]))+ potential demand from buyers for potential fraction[buyers type,gli]* (relative intervention desirability[SC type,g]/(relative intervention desirability [SC type,i]+relative intervention desirability [SC type,n]+relative intervention desirability[SC type,g]+relative intervention desirability [SC type,l]+relative intervention desirability [SC type,gl]+relative intervention desirability[SC type,gi]+relative intervention desirability[SC type,li]+relative intervention desirability[SC type,gli]))+potential demand from buyers for potential fraction[buyers type,gbli]* (relative intervention desirability[SC type,g]/(SUM(relative intervention desirability [SC type,interventions!]))))		
demand for retrofit from renovations before affordability cut [SC type,l,buyers type]	potential demand from buyers for potential fraction[buyers type,l]* (relative intervention desirability[SC type,l]/(relative intervention desirability[SC type,l]+relative intervention desirability[SC type,n]))+ potential demand from buyers for potential fraction[buyers type,bl]* (relative intervention desirability[SC type,l]/(relative intervention desirability [SC type,l]+relative intervention desirability[SC type,b]+relative intervention desirability[SC type,bl]+relative intervention desirability [SC type,n]))+ potential demand from buyers for potential fraction[buyers type,gl]* (relative intervention desirability[SC type,l]/(relative intervention desirability[SC type,g]+relative intervention desirability[SC type,l]+relative intervention desirability[SC type,gl]+relative intervention desirability[SC type,n]))+ potential demand from buyers for potential	households/Month	Here the demand for retrofit from renovators willing to top up their renovation with retrofit, and already distributed based on the potential, is distributed based on the intervention desirability. There are 16 different equations for the same variable because there are 16 different interventions. The equations are so long because for each the specific intervention desirability all the different buyers that can potentially install the intervention must be taken into account. This needs to be done for all the 16 possible combinations.

fraction[buyers type,li]*(relative intervention
desirability[SC type,l]/(relative intervention
desirability[SC type,i]+relative intervention
desirability[SC type,l]+relative intervention
desirability[SC type,li]+relative intervention
desirability[SC type,n]))+ potential demand
from buyers for potential fraction[buyers
type,bli]* (relative intervention desirability[SC
type,l]/(relative intervention desirability
[SC type,i]+relative intervention desirability
[SC type,n]+relative intervention desirability[SC
type,l]+relative intervention desirability
[SC type,b]+relative intervention desirability
[SC type,bl]+relative intervention
desirability[SC type,li]+relative intervention
desirability[SC type,bi]+relative intervention
desirability[SC type,bli]))+ potential demand
from buyers for potential fraction[buyers
type,gbl]*(relative intervention desirability[SC
type,l]/(relative intervention desirability
[SC type,b]+relative intervention desirability
[SC type,n]+relative intervention desirability[SC
type,g]+relative intervention desirability
[SC type,l]+relative intervention desirability
[SC type,gl]+ relative intervention
desirability[SC type,gb]+relative intervention
desirability [SC type,bl]+relative intervention
desirability[SC type,gbl]))+potential demand
from buyers for potential fraction[buyers
type,gli]* (relative intervention desirability[SC
type,l]/(relative intervention desirability
[SC type,i]+relative intervention desirability
[SC type,n]+relative intervention desirability[SC
type,g]+relative intervention desirability
[SC type,l]+relative intervention desirability
[SC type,gl]+relative intervention
desirability[SC type,gi]+relative intervention
desirability[SC type,li]+relative intervention
desirability[SC type,gli]))+ potential demand
from buyers for potential fraction[buyers
type,gbli]* (relative intervention desirability[SC
type,l]/(SUM(relative intervention desirability

	[SC type,interventions!]))) potential demand from buyers for potential fraction[buyers type,gb]*(relative intervention desirability[SC type,gb]/(relative intervention desirability[SC type,g]+relative intervention desirability [SC type,b]+relative intervention desirability[SC type,gb]+relative intervention desirability[SC type,n]))+ potential demand from buyers for potential fraction[buyers type,gbi]*(relative intervention desirability[SC type,gb]/(relative intervention desirability [SC type,i]+relative intervention desirability [SC type,n]+relative intervention desirability[SC type,g]+relative intervention desirability [SC type,b]+relative intervention desirability [SC type,gb]+relative intervention desirability[SC type,gi]+relative intervention desirability[SC type,bi]+relative intervention desirability[SC type,gbi]))+ potential demand from buyers for potential fraction[buyers type,gbl]* (relative intervention desirability[SC type,gb]/(relative intervention desirability [SC type,b]+relative intervention desirability [SC type,n]+relative intervention desirability[SC type,g]+relative intervention desirability[SC type,l]+relative intervention desirability [SC type,gl]+relative intervention desirability[SC type,gb]+relative intervention desirability [SC type,bl]+relative intervention desirability [SC type,gbl]))+ potential demand from buyers for potential fraction[buyers type,gbli]* (relative intervention desirability[SC type,gb]/(SUM(relative intervention desirability[SC type,interventions!]))) potential demand from buyers for potential fraction[buyers type,gl]* (relative intervention desirability[SC type,gl]/(relative intervention desirability[SC type,g]+relative intervention desirability[SC type,l]+relative intervention desirability[SC type,gl]+relative intervention desirability[SC type,n]))+ potential demand from buyers for potential fraction[buyers		
demand for retrofit from renovations before affordability cut [SC type,gb, buyers type]		households/Month	Here the demand for retrofit from renovators willing to top up their renovation with retrofit, and already distributed based on the potential, is distributed based on the intervention desirability. There are 16 different equations for the same variable because there are 16 different interventions. The equations are so long because for each the specific intervention desirability all the different buyers that can potentially install the intervention must be taken into account. This needs to be done for all the 16 possible combinations.
demand for retrofit from renovations before affordability cut [SC type,gl, buyers type]		households/Month	Here the demand for retrofit from renovators willing to top up their renovation with retrofit, and already distributed based on the potential, is distributed based on the intervention desirability. There are 16 different equations for the same variable because there are 16 different interventions. The equations are so long because for each the specific intervention desirability all the different buyers that can potentially install the intervention must be taken into account. This needs to be done for all the 16 possible combinations.

	type,gbl]* (relative intervention desirability[SC type,gl]/(relative intervention desirability [SC type,b]+relative intervention desirability [SC type,n]+relative intervention desirability[SC type,g]+relative intervention desirability [SC type,l]+relative intervention desirability [SC type,gl]+relative intervention desirability[SC type,gb]+relative intervention desirability[SC type,bl]+relative intervention desirability[SC type,gbl]))+ potential demand from buyers for potential fraction[buyers type,gli]*(relative intervention desirability[SC type,gl]/(relative intervention desirability [SC type,i]+relative intervention desirability [SC type,n]+relative intervention desirability[SC type,g]+relative intervention desirability [SC type,l]+relative intervention desirability [SC type,gl]+relative intervention desirability[SC type,gi]+relative intervention desirability[SC type,li]+relative intervention desirability[SC type,gli]))+ potential demand from buyers for potential fraction[buyers type,gbli]* (relative intervention desirability[SC type,gl]/(SUM(relative intervention desirability [SC type,interventions!]))) potential demand from buyers for potential fraction[buyers type,gi]* (relative intervention desirability[SC type,gi]/(relative intervention desirability [SC type,i]+relative intervention desirability[SC type,g]+relative intervention desirability[SC type,gi]+relative intervention desirability[SC type,n]))+potential demand from buyers for potential fraction[buyers type,gbi]* (relative intervention desirability[SC type,gi]/(relative intervention desirability[SC type,i]+relative intervention desirability[SC type,n]+relative intervention desirability[SC type,g]+relative intervention desirability[SC type,b]+relative intervention desirability[SC type,gb]+relative intervention desirability[SC type,gi]+relative intervention desirability [SC type,bi]+relative intervention desirability		
demand for retrofit from renovations before affordability cut [SC type,gi, buyers type]		households/Month	Here the demand for retrofit from renovators willing to top up their renovation with retrofit, and already distributed based on the potential, is distributed based on the intervention desirability. There are 16 different equations for the same variable because there are 16 different interventions. The equations are so long because for each the specific intervention desirability all the different buyers that can potentially install the intervention must be taken into account. This needs to be done for all the 16 possible combinations.

	[SC type,gbi]))+potential demand for potential fraction[buyers type,gli]* (relative intervention desirability[SC type,gi]/(relative intervention desirability [SC type,i]+relative intervention desirability [SC type,n]+relative intervention desirability[SC type,g]+relative intervention desirability [SC type,l]+relative intervention desirability [SC type,gl]+relative intervention desirability[SC type,gi]+ relative intervention desirability[SC type,li]+ relative intervention desirability[SC type,gli]))+ potential demand from buyers for potential fraction[buyers type,gbli]*(relative intervention desirability[SC type,gi]/(SUM(relative intervention desirability [SC type,interventions!])))		
demand for retrofit from renovations before affordability cut [SC type,bl, buyers type]	potential demand from buyers for potential fraction[buyers type,bl]* (relative intervention desirability[SC type,b]/(relative intervention desirability[SC type,b]+relative intervention desirability[SC type,l]+relative intervention desirability[SC type,bl]+relative intervention desirability[SC type,n]))+ potential demand from buyers for potential fraction[buyers type,gbl]* (relative intervention desirability[SC type,bl]/(relative intervention desirability [SC type,b]+relative intervention desirability [SC type,n]+relative intervention desirability[SC type,g]+relative intervention desirability [SC type,l]+relative intervention desirability [SC type,gl]+relative intervention desirability[SC type,gb]+relative intervention desirability[SC type,bl]+relative intervention desirability[SC type,gbl]))+ potential demand from buyers for potential fraction[buyers type,bli]* (relative intervention desirability[SC type,bl]/(relative intervention desirability[SC type,i]+relative intervention desirability[SC type,n]+relative intervention desirability[SC type,b]+relative intervention desirability[SC type,l]+relative intervention desirability[SC type,bl]+relative intervention desirability[SC	households/Month	Here the demand for retrofit from renovators willing to top up their renovation with retrofit, and already distributed based on the potential, is distributed based on the intervention desirability. There are 16 different equations for the same variable because there are 16 different interventions. The equations are so long because for each the specific intervention desirability all the different buyers that can potentially install the intervention must be taken into account. This needs to be done for all the 16 possible combinations.

	type,bi]+relative intervention desirability[SC type,li]+relative intervention desirability[SC type,bli]))+ potential demand from buyers for potential fraction[buyers type,gbli]* (relative intervention desirability[SC type,bl]/ (SUM(relative intervention desirability [SC type,interventions!]))))		
demand for retrofit from renovations before affordability cut [SC type,bi, buyers type]	potential demand from buyers for potential fraction[buyers type,bi]* (relative intervention desirability[SC type,bi]/(relative intervention desirability [SC type,i]+relative intervention desirability[SC type,b]+relative intervention desirability[SC type,bi]+relative intervention desirability[SC type,n]))+ potential demand from buyers for potential fraction[buyers type,gbi]* (relative intervention desirability[SC type,bi]/(relative intervention desirability [SC type,i]+relative intervention desirability [SC type,n]+relative intervention desirability[SC type,g]+relative intervention desirability [SC type,b]+relative intervention desirability [SC type,gb]+relative intervention desirability[SC type,gi]+relative intervention desirability[SC type,bi]+relative intervention desirability [SC type,gbi]))+ potential demand from buyers for potential fraction[buyers type,bli]* (relative intervention desirability[SC type,bi]/(relative intervention desirability [SC type,i]+relative intervention desirability [SC type,n]+relative intervention desirability[SC type,b]+relative intervention desirability [SC type,l]+relative intervention desirability [SC type,bl]+relative intervention desirability[SC type,bi]+ relative intervention desirability [SC type,li]+relative intervention desirability[SC type,bli]))+potential demand from buyers for potential fraction[buyers type,gbli]* (relative intervention desirability[SC type,bi]/(SUM(relative intervention desirability [SC type,interventions!]))))	households/Month	Here the demand for retrofit from renovators willing to top up their renovation with retrofit, and already distributed based on the potential, is distributed based on the intervention desirability. There are 16 different equations for the same variable because there are 16 different interventions. The equations are so long because for each the specific intervention desirability all the different buyers that can potentially install the intervention must be taken into account. This needs to be done for all the 16 possible combinations.
demand for retrofit from renovations	potential demand from buyers for potential fraction[buyers type,li]* (relative intervention	households/Month	Here the demand for retrofit from renovators willing to top up their renovation with retrofit, and already distributed based on the potential, is distributed based on the

before affordability cut [SC type,li, buyers type]	desirability[SC type,li]/(relative intervention desirability[SC type,i]+relative intervention desirability[SC type,l]+relative intervention desirability[SC type,li]+relative intervention desirability[SC type,n]))+potential demand from buyers for potential fraction[buyers type,bli]* (relative intervention desirability[SC type,li]/(relative intervention desirability[SC type,i]+ relative intervention desirability[SC type,n]+relative intervention desirability[SC type,l]+relative intervention desirability[SC type,b]+relative intervention desirability[SC type,bl]+relative intervention desirability[SC type,li]+relative intervention desirability[SC type,bi]+relative intervention desirability[SC type,bli]))+potential demand from buyers for potential fraction[buyers type,gli]*(relative intervention desirability[SC type,li]/(relative intervention desirability [SC type,i]+relative intervention desirability[SC type,n]+relative intervention desirability[SC type,g]+relative intervention desirability[SC type,l]+relative intervention desirability[SC type,gl]+relative intervention desirability[SC type,gi]+relative intervention desirability[SC type,li]+relative intervention desirability[SC type,gli]))+ potential demand from buyers for potential fraction[buyers type,gbli]* (relative intervention desirability[SC type,li]/(SUM(relative intervention desirability [SC type,interventions!]))))		intervention desirability. There are 16 different equations for the same variable because there are 16 different interventions. The equations are so long because for each the specific intervention desirability all the different buyers that can potentially install the intervention must be taken into account. This needs to be done for all the 16 possible combinations.
demand for retrofit from renovations before affordability cut [SC type,gbl, buyers type]	potential demand from buyers for potential fraction[buyers type,gbl]* (relative intervention desirability[SC type,gbl]/(relative intervention desirability [SC type,b]+relative intervention desirability[SC type,n]+relative intervention desirability[SC type,g]+relative intervention desirability [SC type,l]+relative intervention desirability[SC type,gl]+relative intervention desirability[SC type,gb]+relative intervention desirability [SC type,bl]+relative intervention desirability[SC type,gbl]))+	households/Month	Here the demand for retrofit from renovators willing to top up their renovation with retrofit, and already distributed based on the potential, is distributed based on the intervention desirability. There are 16 different equations for the same variable because there are 16 different interventions. The equations are so long because for each the specific intervention desirability all the different buyers that can potentially install the intervention must be taken into account. This needs to be done for all the 16 possible combinations.

	potential demand from buyers for potential fraction[buyers type,gbli]*(relative intervention desirability[SC type,gbl]/ (SUM(relative intervention desirability [SC type,interventions!]))		
demand for retrofit from renovations before affordability cut [SC type,gbi, buyers type]	potential demand from buyers for potential fraction[buyers type,gbi]* (relative intervention desirability[SC type,gbi]/(relative intervention desirability [SC type,i]+relative intervention desirability[SC type,n]+relative intervention desirability[SC type,g]+relative intervention desirability[SC type,b]+relative intervention desirability[SC type,gb]+relative intervention desirability[SC type,gi]+relative intervention desirability[SC type,bi]+relative intervention desirability[SC type,gbi]))+ potential demand from buyers for potential fraction[buyers type,gbli]* (relative intervention desirability[SC type,gbi]/(SUM(relative intervention desirability[SC type,interventions!]))	households/Month	Here the demand for retrofit from renovators willing to top up their renovation with retrofit, and already distributed based on the potential, is distributed based on the intervention desirability. There are 16 different equations for the same variable because there are 16 different interventions. The equations are so long because for each the specific intervention desirability all the different buyers that can potentially install the intervention must be taken into account. This needs to be done for all the 16 possible combinations.
demand for retrofit from renovations before affordability cut [SC type,gli, buyers type]	potential demand from buyers for potential fraction[buyers type,gli]* (relative intervention desirability[SC type,gli]/(relative intervention desirability[SC type,i]+relative intervention desirability[SC type,n]+relative intervention desirability[SC type,g]+relative intervention desirability[SC type,l]+relative intervention desirability[SC type,gl]+relative intervention desirability[SC type,gi]+relative intervention desirability[SC type,li]+relative intervention desirability[SC type,gli]))+ potential demand from buyers for potential fraction[buyers type,gbli]* (relative intervention desirability[SC type,gli]/(SUM(relative intervention desirability [SC type,interventions!]))	households/Month	Here the demand for retrofit from renovators willing to top up their renovation with retrofit, and already distributed based on the potential, is distributed based on the intervention desirability. There are 16 different equations for the same variable because there are 16 different interventions. The equations are so long because for each the specific intervention desirability all the different buyers that can potentially install the intervention must be taken into account. This needs to be done for all the 16 possible combinations.
demand for retrofit from renovations before affordability cut [SC type,bli, buyers type]	potential demand from buyers for potential fraction[buyers type,bli]*(relative intervention desirability[SC type,bli]/(relative intervention desirability[SC type,i]+relative intervention desirability[SC type,n]+ relative intervention desirability[SC type,b]+relative intervention	households/Month	Here the demand for retrofit from renovators willing to top up their renovation with retrofit, and already distributed based on the potential, is distributed based on the intervention desirability. There are 16 different equations for the same variable because there are 16 different interventions. The equations are so long because for each the specific intervention desirability all the different buyers that can potentially install the

	desirability[SC type,l]+relative intervention desirability[SC type,bl]+ relative intervention desirability[SC type,bi]+relative intervention desirability[SC type,li]+relative intervention desirability[SC type,bli]))+ potential demand from buyers for potential fraction[buyers type,gbli]* (relative intervention desirability[SC type,bli]/(SUM(relative intervention desirability[SC type,interventions!])))		intervention must be taken into account. This needs to be done for all the 16 possible combinations.
demand for retrofit from renovations before affordability cut [SC type,gbli, buyers type]	potential demand from buyers for potential fraction[buyers type,gbli]*(relative intervention desirability[SC type,gbli]/(SUM(relative intervention desirability[SC type,interventions!])))	households/Month	Here the demand for retrofit from renovators willing to top up their renovation with retrofit, and already distributed based on the potential, is distributed based on the intervention desirability. There are 16 different equations for the same variable because there are 16 different interventions. The equations are so long because for each the specific intervention desirability all the different buyers that can potentially install the intervention must be taken into account. This needs to be done for all the 16 possible combinations.
demand for retrofit from renovations	MAX(0,demand for retrofit from renovations before affordability cut[SC type,interventions,renovation type]*retrofit affordability for renovations[SC type,interventions,renovation type]/2)	households/Month	Here all the households that desire to top up their renovation with and that are 'cut off' by affordability reasons. This number constitutes the demand for retrofit from renovation. It is divided by two because there are two competing supply chain (and therefore to not double count them)
demand from boiler replacements	old boilers replacement/measures per household	households/Month	The number of old boilers substituted per household is assumed to be one
demand from buyers	SUM(demand for retrofit from buyers[SC type!,interventions!])- SUM(demand for retrofit from buyers[SC type!,n])	households/Month	Retrofit intervention demand from buyers because of policy direct impact
demand from renovation drop out	SUM(demand for retrofit from renovations[SC type!,n,renovation type])+potential demand from renovations[renovation type] - SUM(demand for retrofit from renovations[SC type!,interventions!,renovation type])	households/Month	Households that were considering to top up their amenity renovation with retrofit, but that in the end prefer to not do anything
demand from renovations	SUM(demand for retrofit from renovations[SC type!,interventions!,renovation type!])- SUM(demand for retrofit from renovations[SC type!,n,renovation type!])	households/Month	Households demand for topping up with retrofit their amenity renovation
demand perception delay	6	Month	To perceive changes in demand it takes time. This time is estimated in 6 months. It is an educated guess made by researchers based on the frequency of reports on the subject

desirability of not retrofitting	2	Dmnl	This variable represents how desirable is the option to not do nothing when people consider retrofit. The value has been chosen arbitrarily by researchers. It seems to match well the reference mode.
desired change in future workforce	projected change in demand[SC type,measures]/workforce productivity[SC type ,measures]+projected retiring[SC type,measures]	workers	Based on the projected demand divided by the workforce productivity (and taking into account the projected retiring rate) it is possible to calculate the desired future workforce needed for sustainable supply chain
desired hiring	MAX(0,desired change in future workforce[SC type,measures])	workers	If the desired change in future workforce is positive, it means that new workforce is desired to be hired
desired investment for quality improvement	perceived gap in quality[measures]*costs for senior training[measures]/training time*total WF[measures]	GBP/Month	Based on the quality gap perceived and on the costs for training the total workforce the desired investment for improving the workforce skills is calculated
desired lay-offs	MAX(0,-desired change in future workforce[SC type,measures])	workers	If the desired change in future workforce is negative, it means the supply chain wants to fire part of its workforce
desired payback time	70	Month	The time homeowners would like to repay back their investment. Source Mike Gentry from BEIS: from previous policy experience with Green Deal, 25 years is already a not desired payback time. However there is a knowledge gap in the organization on that. A good proxy might be the avg time homeowners stay in a house.
desired payback time for workforce investments	60	Month	How much time the supply chain investors would like to see repaid their investments. Educated guess made by researchers
difference in prices	prices of interventions[SC type,interventions]-perceived prices of interventions for consumers [SC type,interventions]	GBP/Interventions	This variable accounts for changes in interventions prices due to subsidies
ease of available credit options	0	GBP/Interventions	This is a variable representing the possibility for renovators willing to top up their amenity renovation to find easy credit to increase their investing capacity
easy estimation of energy consumption per hh	avg energy consumption for non-retrofitted households - energy savings per household from installed measures	kWh/Month/ households	Here to the average energy consumption for non-retrofitted households is subtracted the energy savings per households due to retrofit measure installed
ECO start	156	Month	The time in the simulation when the ECO subsidies start
ECO subsidies[glazing]	0	Dmnl	How much the ECO subsidies discount the final price for homeowners. These are estimation based on the information retrieved from Andrei Miller and Karl Haughton (BEIS experts)
ECO subsidies[boiler]	0.17	Dmnl	How much the ECO subsidies discount the final price for homeowners. These are estimation based on the information retrieved from Andrei Miller and Karl Haughton (BEIS experts)
ECO subsidies[loft]	0.2	Dmnl	How much the ECO subsidies discount the final price for homeowners. These are estimation based on the information retrieved from Andrei Miller and Karl Haughton (BEIS experts)

ECO subsidies[insulation]	(1-cavity wall scenario)*0.7+ cavity wall scenario*0.45	Dmnl	How much the ECO subsidies discount the final price for homeowners. These are estimation based on the information retrieved from Andrei Miller and Karl Haughton (BEIS experts)
economic cycles switch	0	Dmnl	Switch to activate the oscillations of economic cycles
economic cycles time	240	Month	The time the SIN function needs to complete an oscillation. Twenty years is in line with the information retrieved from workshop participants
EEC and CERT start	24	Month	The time in the simulation when EEC and CERT subsidies start
EEC and CERT subsidies[glazing]	0	Dmnl	How much the EEC and CERT subsidies discount the final price for homeowners. These are estimation based on the information retrieved from Andrei Miller and Karl Haughton (BEIS experts)
EEC and CERT subsidies[boiler]	0	Dmnl	How much the EEC and CERT subsidies discount the final price for homeowners. These are estimation based on the information retrieved from Andrei Miller and Karl Haughton (BEIS experts)
EEC and CERT subsidies[loft]	0.5	Dmnl	How much the EEC and CERT subsidies discount the final price for homeowners. These are estimation based on the information retrieved from Andrei Miller and Karl Haughton (BEIS experts)
EEC and CERT subsidies[insulation]	cavity wall scenario*0.5+ (1-cavity wall scenario)*0.1	Dmnl	How much the EEC and CERT subsidies discount the final price for homeowners. These are estimation based on the information retrieved from Andrei Miller and Karl Haughton (BEIS experts)
effect of market fragmentation on credibility[single]	impact of fragmentation on credibility*market fragmentation	Dmnl	Market fragmentation works in different way for the two supply chain. For the single supply chain market fragmentation can increase the credibility because single installers can create their niche of local market in which their are trusted by customers; while for the multi supply chain market fragmentation works in the opposite direction, since it tends to decrease the credibility of the industry (big companies offering multi services are not usually trusted in a fragmented environment). This distinction tries to incorporate different inputs discussed in the second workshop
effect of market fragmentation on credibility[multi]	-impact of fragmentation on credibility*market fragmentation	Dmnl	Market fragmentation works in different way for the two supply chain. For the single supply chain market fragmentation can increase the credibility because single installers can create their niche of local market in which their are trusted by customers; while for the multi supply chain market fragmentation works in the opposite direction, since it tends to decrease the credibility of the industry (big companies offering multi services are not usually trusted in a fragmented environment). This distinction tries to incorporate different inputs discussed in the second workshop
effort intensity in enforcing monitoring quality	0.8	Dmnl	This is the effort . The value is an educated guess made by researchers
effort intensity in training	MIN(1, ZIDZ(investments in training[measures], desired investment for quality improvement[measures]))	Dmnl	Here the desired investments are confronted with the actual investments in order to obtain the actual effort the industry put in improving workforce skills

elasticity for impact of quality on energy performance	0.3	Dmnl	This elasticity expresses how much a unitary variation in quality of a measure installed impacts the energy performance of that measure
elasticity for impact of technology on non-financial attractiveness	0.2	Dmnl	How much a unitary variation in technology impact the non-financial attractiveness of a measure
elasticity for temperature to energy curve	1	Dmnl	How much a unitary change in temperature impact the energy consumption
elasticity of economy of scale effect	0	Dmnl	How a change in the total workforce, with respect of the reference workforce after which the economy of scale effect is activate, impact the costs of material. According to BEIS experts at the moment this effect is not there at the moment
energy consumption adjustment	MIN(Time/120/TIME STEP,1)*energy fall*0.75	kWh/Month/ households	Hunter Danskin (BEIS) made a guess for which roughly 25% in the decrease of energy consumption per household depended on retrofitted measures, the rest has been due to other factors. From data we saw that the fall in energy consumption from 2000 to 2010 was around 200 kWh/Month so we assume a discount that increase over time until 2010 up to a maximum of 0.75*200
energy consumption by interventions	energy consumption by retrofit intervention for reference temperature[interventions]* temperature to energy curve[interventions]	kWh/Month/ households	The energy consumption by intervention. It is calculated based on a reference temperature and if the temperature varies the energy consumed changes. In the model runs shown in the dissertation this temperature is assumed to be constant
energy consumption by retrofit intervention for reference temperature	avg energy consumption for non-retrofitted households- SUM(expected energy savings by intervention[SC type!,interventions])/ELMCOUNT (SC type)*interventions energy efficiency performance[interventions]* interventions per households	kWh/Month/ households	Here to the reference energy consumption for non-retrofitted households are subtracted the energy savings generated by a retrofit intervention adjusted to the performance the intervention will have
energy fall	200	kWh/Month/ households	Decrease in energy consumption since 2000. Source: estimated from 'United Kingdom housing energy fact file 2013' (Figure 2a)
energy price	GET XLS DATA('energy.xlsx', 'Sheet1', 'A' , 'C2')	GBP/kWh	Data on the average energy consumption retrieved from Palmer & Cooper, 2013 Source: report released by DECC/BEIS: 'United Kingdom housing energy fact file 2013'
energy savings per household from installed measures	(weighted energy savings from alternative insulation+ weighted energy savings from simulated installed measures)*measures per household	kWh/Month/ households	Here all the energy savings due to measure installed are aggregated and translated in energy savings per household
EPC band improvement per energy saving	0.0044	band/(kWh/Month/ measures)	Rough estimation made by the researchers of energetic savings generated by an EPC improvement of one band

EPC mortgage policy starting time	216	Month	Green mortgage policy starting time when it is activate. Year 2018
estimated retrofit potential fraction by intervention[i]	potential fraction by measure[insulation] -estimated potential fraction by intervention[gi]-estimated potential fraction by intervention[bi]-estimated potential fraction by intervention[li]-estimated potential fraction by intervention[gli]-estimated potential fraction by intervention[bli]-estimated potential fraction by intervention[gbi]-estimated potential fraction by intervention[gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
estimated retrofit potential fraction by intervention[l]	potential fraction by measure[loft]-estimated potential fraction by intervention[gl]-estimated potential fraction by intervention[bl]-estimated potential fraction by intervention[li]-estimated potential fraction by intervention[gbl]- estimated potential fraction by intervention[gli]- estimated potential fraction by intervention[bli]-estimated potential fraction by intervention[gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
estimated retrofit potential fraction by intervention[g]	potential fraction by measure[glazing]-estimated potential fraction by intervention[gb]-estimated potential fraction by intervention[gl]-estimated potential fraction by intervention[gi]-estimated potential fraction by intervention[gbl]estimated potential fraction by intervention[gli]-estimated potential fraction by intervention[gbi]-estimated potential fraction by intervention[gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
estimated retrofit potential fraction by intervention[b]	potential fraction by measure[boiler] -estimated potential fraction by intervention[gb]-estimated potential fraction by intervention[bl]-estimated potential fraction by intervention[bi]-estimated potential fraction by intervention[gbl] -estimated potential fraction by intervention[bli]-estimated potential fraction by intervention[gbi]-estimated potential fraction by intervention[gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention

estimated retrofit potential fraction by intervention[gb]	potential fraction by measure[glazing]*potential fraction by measure[boiler] -estimated potential fraction by intervention[gbi]-estimated potential fraction by intervention[gbl]-estimated potential fraction by intervention[gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
estimated retrofit potential fraction by intervention[gl]	potential fraction by measure[glazing]*potential fraction by measure[loft] -estimated potential fraction by intervention[gli]-estimated potential fraction by intervention[gbl]-estimated potential fraction by intervention[gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
estimated retrofit potential fraction by intervention[gi]	potential fraction by measure[glazing]*potential fraction by measure[insulation]- estimated potential fraction by intervention[gli]-estimated potential fraction by intervention [gbi]-estimated potential fraction by intervention [gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
estimated retrofit potential fraction by intervention[bl]	potential fraction by measure[boiler]*potential fraction by measure[loft]- estimated potential fraction by intervention[bli]-estimated potential fraction by intervention[gbl]-estimated potential fraction by intervention[gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
estimated retrofit potential fraction by intervention[bi]	potential fraction by measure[boiler]*potential fraction by measure[insulation]- estimated potential fraction by intervention[bli]-estimated potential fraction by intervention [gbi]-estimated potential fraction by intervention[gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
estimated retrofit potential fraction by intervention[li]	potential fraction by measure[loft]*potential fraction by measure[insulation]- estimated potential fraction by intervention[gli]-estimated potential fraction by intervention [bli]-estimated potential fraction by intervention[gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
estimated retrofit potential fraction by intervention[gbli]	potential fraction by measure[glazing]*potential fraction by measure[loft]*potential fraction by measure	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention

	[boiler]*potential fraction by measure[insulation]		
estimated retrofit potential fraction by intervention[gbl]	potential fraction by measure[glazing]*potential fraction by measure[loft]*potential fraction by measure [boiler] -estimated potential fraction by intervention[gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
estimated retrofit potential fraction by intervention[gbi]	potential fraction by measure[glazing]*potential fraction by measure[boiler]* potential fraction by measure[insulation]- estimated potential fraction by intervention[gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
estimated retrofit potential fraction by intervention[gli]	potential fraction by measure[glazing]*potential fraction by measure[loft]*potential fraction by measure[insulation]- estimated potential fraction by intervention[gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
estimated retrofit potential fraction by intervention[bli]	potential fraction by measure[loft]*potential fraction by measure[boiler]* potential fraction by measure[insulation] -estimated potential fraction by intervention[gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
estimated retrofit potential fraction by intervention[n]	PROD(1-potential fraction by measure[measures!])	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
estimated property distribution per stamp duty band[up125]	0.229236	Dmnl	Estimated housing stock distribution per stamp duty band. Source: House Price Statistics for Small Areas in England and Wales: 1995 to 2014 https://www.ons.gov.uk/peoplepopulationandcommunity/housing/bulletins/housepricestatisticsforsmallareasinenglandandwales/2015-06-24
estimated property distribution per stamp duty band[up250]	0.516736	Dmnl	Estimated housing stock distribution per stamp duty band. Source: House Price Statistics for Small Areas in England and Wales: 1995 to 2014 https://www.ons.gov.uk/peoplepopulationandcommunity/housing/bulletins/housepricestatisticsforsmallareasinenglandandwales/2015-06-24
estimated property distribution per stamp duty band[up925]	0.247708	Dmnl	Estimated housing stock distribution per stamp duty band. Source: House Price Statistics for Small Areas in England and Wales: 1995 to 2014 https://www.ons.gov.uk/peoplepopulationandcommunity/housing/bulletins/housepricestatisticsforsmallareasinenglandandwales/2015-06-24
estimated property distribution per stamp duty band[up1500]	0.004375	Dmnl	Estimated housing stock distribution per stamp duty band. Source: House Price Statistics for Small Areas in England and Wales: 1995 to 2014 https://www.ons.gov.uk/peoplepopulationandcommunity/housing/bulletins/housepricestatisticsforsmallareasinenglandandwales/2015-06-24

estimated property distribution per stamp duty band[over1500]	0.00194444	Dmnl	Estimated housing stock distribution per stamp duty band. Source: House Price Statistics for Small Areas in England and Wales: 1995 to 2014 https://www.ons.gov.uk/peoplepopulationandcommunity/housing/bulletins/housepricestatisticsforsmallareasinenglandandwales/2015-06-24
estimated retrofitted fraction by intervention[i]	retrofitted fraction by measure[insulation] -estimated retrofitted fraction by intervention[gi] -estimated retrofitted fraction by intervention[bi] -estimated retrofitted fraction by intervention[li] -estimated retrofitted fraction by intervention[gli] -estimated retrofitted fraction by intervention[bli] -estimated retrofitted fraction by intervention[gbi] -estimated retrofitted fraction by intervention[gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
estimated retrofitted fraction by intervention[l]	retrofitted fraction by measure[loft] -estimated retrofitted fraction by intervention[gl] -estimated retrofitted fraction by intervention[bl] -estimated retrofitted fraction by intervention[li] -estimated retrofitted fraction by intervention[gbl] -estimated retrofitted fraction by intervention[gli] -estimated retrofitted fraction by intervention[bli] -estimated retrofitted fraction by intervention[gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
estimated retrofitted fraction by intervention[g]	retrofitted fraction by measure[glazing] -estimated retrofitted fraction by intervention[gb] -estimated retrofitted fraction by intervention[gl] -estimated retrofitted fraction by intervention[gi]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention

	-estimated retrofitted fraction by intervention[gbl] -estimated retrofitted fraction by intervention[gli] -estimated retrofitted fraction by intervention[gbi] -estimated retrofitted fraction by intervention[gbli]		
estimated retrofitted fraction by intervention[b]	retrofitted fraction by measure[boiler] -estimated retrofitted fraction by intervention[gb] -estimated retrofitted fraction by intervention[bl] -estimated retrofitted fraction by intervention[bi] -estimated retrofitted fraction by intervention[gbl] -estimated retrofitted fraction by intervention[bli] -estimated retrofitted fraction by intervention[gbi] -estimated retrofitted fraction by intervention[gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
estimated retrofitted fraction by intervention[gb]	retrofitted fraction by measure[glazing]*retrofitted fraction by measure[boiler]-estimated retrofitted fraction by intervention[gbi]-estimated retrofitted fraction by intervention[gbl]- estimated retrofitted fraction by intervention[gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
estimated retrofitted fraction by intervention[gl]	retrofitted fraction by measure[glazing]*retrofitted fraction by measure[loft]- estimated retrofitted fraction by intervention[gli]- estimated retrofitted fraction by intervention[gbl]- estimated retrofitted fraction by intervention[gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
estimated retrofitted fraction by intervention[gi]	retrofitted fraction by measure[glazing]*retrofitted fraction by measure[insulation]-estimated retrofitted fraction by intervention[gli]- estimated retrofitted fraction by intervention[gbi] - estimated retrofitted fraction by intervention[gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention

estimated retrofitted fraction by intervention[bl]	retrofitted fraction by measure[boiler]*retrofitted fraction by measure[loft]- estimated retrofitted fraction by intervention[bli]-estimated retrofitted fraction by intervention[gbl]- estimated retrofitted fraction by intervention[gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
estimated retrofitted fraction by intervention[bi]	retrofitted fraction by measure[boiler]*retrofitted fraction by measure[insulation]- estimated retrofitted fraction by intervention[bli]-estimated retrofitted fraction by intervention[gbi]- estimated retrofitted fraction by intervention[gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
estimated retrofitted fraction by intervention[li]	retrofitted fraction by measure[loft]*retrofitted fraction by measure[insulation]- estimated retrofitted fraction by intervention[gli]-estimated retrofitted fraction by intervention[bli]- estimated retrofitted fraction by intervention[gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
estimated retrofitted fraction by intervention[gbli]	retrofitted fraction by measure[glazing]*retrofitted fraction by measure[loft]*retrofitted fraction by measure[boiler]*retrofitted fraction by measure[insulation]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
estimated retrofitted fraction by intervention[gbl]	retrofitted fraction by measure[glazing]*retrofitted fraction by measure[loft]*retrofitted fraction by measure [boiler]- estimated retrofitted fraction by intervention[gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
estimated retrofitted fraction by intervention[gbi]	retrofitted fraction by measure[glazing]*retrofitted fraction by measure[boiler]*retrofitted fraction by measure [insulation]- estimated retrofitted fraction by intervention[gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
estimated retrofitted fraction by intervention[gli]	retrofitted fraction by measure[glazing]*retrofitted fraction by measure[loft]*retrofitted fraction by measure [insulation]- estimated retrofitted fraction by intervention[gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention

estimated retrofitted fraction by intervention[bli]	retrofitted fraction by measure[loft]*retrofitted fraction by measure[boiler]*retrofitted fraction by measure [insulation]- estimated retrofitted fraction by intervention[gbli]	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
estimated retrofitted fraction by intervention[n]	PROD(1-retrofitted fraction by measure[measures!])	Dmnl	Fraction of houses in which an intervention has not been done yet and, therefore, houses that are potentially available for that specific retrofit intervention
exogenous popularity of cavity	GET XLS DATA('energy.xlsx','Sheet1','A','K2')	Dmnl	The popularity of cavity wall is calculated externally and the used as input when it is time to run the model for solid wall scenario
exogenous popularity of solid wall	0	Dmnl	The popularity of solid wall is calculated externally and the used as input when it is time to run the model for solid wall scenario.
exogenous retrofitted fraction for cavity	GET XLS DATA('energy.xlsx','Sheet1','A','J2')	Dmnl	The retrofitted cavity wall fraction of the stock is calculated and then used here as an exogenous input when the model simulates for solid wall
exogenous retrofitted fraction for solid	0	Dmnl	The retrofitted solid wall fraction of the stock is calculated and then used here as an exogenous input when the model simulates for cavity wall. However it is close to be zero in reality
expected bill savings by intervention[interventions]	energy price*SUM(expected energy savings by intervention[SC type!,interventions])/ELMCOUNT (SC type)	GBP/Month/Interventions	Expected bill saving by households per intervention. These are the savings declared at the beginning when a measure is installed
expected energy savings by intervention[SC type,i]	expected energy savings by measure[SC type,insulation]* (1-measures savings discount by combination[SC type,one])/ interventions per measure	kWh/Month/Interventions	This variable calculates how much are the expected saving per each retrofit intervention
expected energy savings by intervention[SC type,l]	expected energy savings by measure[SC type,loft]*(1-measures savings discount by combination [SC type,one])/interventions per measure	kWh/Month/Interventions	This variable calculates how much are the expected saving per each retrofit intervention
expected energy savings by intervention[SC type,g]	expected energy savings by measure[SC type,glazing]*(1-measures savings discount by combination [SC type,one])/interventions per measure	kWh/Month/Interventions	This variable calculates how much are the expected saving per each retrofit intervention
expected energy savings by intervention[SC type,b]	expected energy savings by measure[SC type,boiler]*(1-measures savings discount by combination [SC type,one])/interventions per measure	kWh/Month/Interventions	This variable calculates how much are the expected saving per each retrofit intervention
expected energy savings by intervention[SC type,gb]	(expected energy savings by measure[SC type,glazing]+expected energy savings by measure [SC type,boiler])*(1-measures savings	kWh/Month/Interventions	This variable calculates how much are the expected saving per each retrofit intervention

	discount by combination[SC type,two])/interventions per measure		
expected energy savings by intervention[SC type,gl]	(expected energy savings by measure[SC type,glazing]+expected energy savings by measure [SC type,loft]) *(1-measures savings discount by combination[SC type,two])/interventions per measure	kWh/Month/Interventions	This variable calculates how much are the expected saving per each retrofit intervention
expected energy savings by intervention[SC type,gi]	(expected energy savings by measure[SC type,glazing]+expected energy savings by measure[SC type,insulation]) *(1-measures savings discount by combination[SC type,two])/interventions per measure	kWh/Month/Interventions	This variable calculates how much are the expected saving per each retrofit intervention
expected energy savings by intervention[SC type,bl]	(expected energy savings by measure[SC type,loft]+expected energy savings by measure[SC type,boiler]) *(1-measures savings discount by combination[SC type,two])/interventions per measure	kWh/Month/Interventions	This variable calculates how much are the expected saving per each retrofit intervention
expected energy savings by intervention[SC type,bi]	(expected energy savings by measure[SC type,insulation]+expected energy savings by measure[SC type,boiler]) *(1-measures savings discount by combination[SC type,two])/interventions per measure	kWh/Month/Interventions	This variable calculates how much are the expected saving per each retrofit intervention
expected energy savings by intervention[SC type,li]	(expected energy savings by measure[SC type,loft]+expected energy savings by measure [SC type,insulation])*(1-measures savings discount by combination[SC type,two])/interventions per measure	kWh/Month/Interventions	This variable calculates how much are the expected saving per each retrofit intervention
expected energy savings by intervention[SC type,gbli]	(expected energy savings by measure[SC type,glazing]+expected energy savings by measure [SC type,boiler]+expected energy savings by measure[SC type,loft]+expected energy savings by measure[SC type,insulation]) *(1-measures savings discount by combination[SC type,four])/interventions per measure	kWh/Month/Interventions	This variable calculates how much are the expected saving per each retrofit intervention
expected energy savings by intervention[SC type,gbl]	(expected energy savings by measure[SC type,glazing]+ expected energy savings by measure[SC type,boiler]+ expected energy savings by measure[SC type,loft]) *(1-measures savings discount by combination[SC type,three])/interventions per measure	kWh/Month/Interventions	This variable calculates how much are the expected saving per each retrofit intervention

expected energy savings by intervention[SC type,gbi]	(expected energy savings by measure[SC type,glazing]+ expected energy savings by measure[SC type,boiler]+ expected energy savings by measure[SC type,insulation]) *(1-measures savings discount by combination[SC type,three]) /interventions per measure	kWh/Month/Interventions	This variable calculates how much are the expected saving per each retrofit intervention
expected energy savings by intervention[SC type,gli]	(expected energy savings by measure[SC type,glazing]+ expected energy savings by measure[SC type,loft]+ expected energy savings by measure[SC type,insulation])*(1-measures savings discount by combination[SC type,three])/ interventions per measure	kWh/Month/Interventions	This variable calculates how much are the expected saving per each retrofit intervention
expected energy savings by intervention[SC type,bli]	(expected energy savings by measure[SC type,boiler]+ expected energy savings by measure[SC type,loft]+ expected energy savings by measure[SC type,insulation]) *(1-measures savings discount by combination[SC type,three])/interventions per measure	kWh/Month/Interventions	This variable calculates how much are the expected saving per each retrofit intervention
expected energy savings by intervention[SC type,n]	0* expected energy savings by measure[SC type,boiler]/interventions per measure	kWh/Month/Interventions	This variable calculates how much are the expected saving per each retrofit intervention
expected energy savings by measure	reference energy savings by measure[SC type,measures]* Retrofit technology[measures]^techno to energy savings elasticity	kWh/Month/measures	These are the expected energy savings by retrofit measure. These are based on an initial reference and they can increase over time if technological improvements take place
expected EPC improvement by intervention	SUM(expected energy savings by intervention[SC type!,interventions])/ELMCOUNT (SC type)* EPC band improvement per energy saving/ measures per intervention	band	Here it is calculated how much each retrofit intervention contributes to an improvement of EPC band. Please note that the SUM is divided by 2 (ELMCOUNT(SC type)) in order to not over-count the two supply chain (multi and single)
expected EPC improvement by measure	SUM(expected energy savings by measure[SC type!,measures])/ELMCOUNT(SC type) *EPC band improvement per energy saving	band	Here it is calculated how much each retrofit measure contributes to an improvement of EPC band. Please note that the SUM is divided by 2 (ELMCOUNT(SC type)) in order to not over count the two supply chain (multi and single)
expected mortgage premium by intervention	expected EPC improvement by intervention[interventions]*mortgage premium for EPC band *STEP(1,EPC mortgage policy starting time)	Dmnl	Here the mortgage premium due to the green mortgage policy is calculated for intervention
expected profits for manufacturers for investments horizon	possible future measures installed[measures]* profit per measure for manufacturer[measures]* trust of industry[measures]	GBP	Here the expected future profits for the manufacturers are calculated multiplying the profit for the potential. Then this is adjusted based on the trust the industry has on the sector

expenses for retrofit relative to renovations	market volume for retrofit/market volume for renovations	Dmnl	The percentage of money spent in retrofit is compare with the total amount of money for renovations in order to appreciate the importance retrofit has
extent distribution in interventions per month	ZIDZ(SUM(interventions per month by extent by SC[SC type!,extent]), SUM(interventions per month by extent by SC[SC type!,extent!]))	Dmnl	How the monthly intervention per extent are distributed with respect of the total amount of intervention
extents distribution in measures demand[SC type,one,glazing]	ZIDZ(demand for retrofit by interventions[SC type,g] ,retrofit demand by measures[SC type,glazing])*measures per intervention	Dmnl	This variable calculate how often measure are installed alone or in combination with one, two or three other measures. It is calculated for all the four measures (4 measures multiplied 4 extents, equal 16 equations)
extents distribution in measures demand[SC type,one,boiler]	ZIDZ(demand for retrofit by interventions[SC type,b], retrofit demand by measures[SC type,boiler])*measures per intervention	Dmnl	This variable calculate how often measure are installed alone or in combination with one, two or three other measures. It is calculated for all the four measures (4 measures multiplied 4 extents, equal 16 equations)
extents distribution in measures demand[SC type,one,loft]	ZIDZ(demand for retrofit by interventions[SC type,l], retrofit demand by measures[SC type,loft]) *measures per intervention	Dmnl	This variable calculate how often measure are installed alone or in combination with one, two or three other measures. It is calculated for all the four measures (4 measures multiplied 4 extents, equal 16 equations)
extents distribution in measures demand[SC type,one,insulation]	ZIDZ(demand for retrofit by interventions[SC type,i], retrofit demand by measures[SC type,insulation])*measures per intervention	Dmnl	This variable calculate how often measure are installed alone or in combination with one, two or three other measures. It is calculated for all the four measures (4 measures multiplied 4 extents, equal 16 equations)
extents distribution in measures demand[SC type,two,glazing]	ZIDZ((demand for retrofit by interventions[SC type,gb]+ demand for retrofit by interventions[SC type,gl]+ demand for retrofit by interventions[SC type,gi]), retrofit demand by measures[SC type,glazing])* measures per intervention	Dmnl	This variable calculate how often measure are installed alone or in combination with one, two or three other measures. It is calculated for all the four measures (4 measures multiplied 4 extents, equal 16 equations)
extents distribution in measures demand[SC type,three,glazing]	ZIDZ((demand for retrofit by interventions[SC type,gbl]+ demand for retrofit by interventions[SC type,gbi]+ demand for retrofit by interventions[SC type,gli]), retrofit demand by measures[SC type,glazing])* measures per intervention	Dmnl	This variable calculate how often measure are installed alone or in combination with one, two or three other measures. It is calculated for all the four measures (4 measures multiplied 4 extents, equal 16 equations)
extents distribution in measures demand[SC type,four,glazing]	ZIDZ(demand for retrofit by interventions[SC type,gbli], retrofit demand by measures[SC type,glazing])* measures per intervention	Dmnl	This variable calculate how often measure are installed alone or in combination with one, two or three other measures. It is calculated for all the four measures (4 measures multiplied 4 extents, equal 16 equations)
extents distribution in measures demand[SC type,two,boiler]	ZIDZ((demand for retrofit by interventions[SC type,gb]+ demand for retrofit by interventions[SC type,bl]+ demand for retrofit by interventions[SC type,bi]), retrofit demand	Dmnl	This variable calculate how often measure are installed alone or in combination with one, two or three other measures. It is calculated for all the four measures (4 measures multiplied 4 extents, equal 16 equations)

	by measures[SC type,boiler])* measures per intervention		
extents distribution in measures demand[SC type,three,boiler]	ZIDZ((demand for retrofit by interventions[SC type,gbl]+ demand for retrofit by interventions[SC type,gbi]+ demand for retrofit by interventions[SC type,bli]), retrofit demand by measures[SC type,boiler])* measures per intervention	Dmnl	This variable calculate how often measure are installed alone or in combination with one, two or three other measures. It is calculated for all the four measures (4 measures multiplied 4 extents, equal 16 equations)
extents distribution in measures demand[SC type,four,boiler]	ZIDZ(demand for retrofit by interventions[SC type,gbli], retrofit demand by measures[SC type,boiler])* measures per intervention	Dmnl	This variable calculate how often measure are installed alone or in combination with one, two or three other measures. It is calculated for all the four measures (4 measures multiplied 4 extents, equal 16 equations)
extents distribution in measures demand[SC type,two,loft]	ZIDZ((demand for retrofit by interventions[SC type,gl]+ demand for retrofit by interventions[SC type,gl]+ demand for retrofit by interventions[SC type,li]), retrofit demand by measures[SC type,loft])* measures per intervention	Dmnl	This variable calculate how often measure are installed alone or in combination with one, two or three other measures. It is calculated for all the four measures (4 measures multiplied 4 extents, equal 16 equations)
extents distribution in measures demand[SC type,three,loft]	ZIDZ((demand for retrofit by interventions[SC type,gbl]+ demand for retrofit by interventions[SC type,bli]+ demand for retrofit by interventions[SC type,gli]), retrofit demand by measures[SC type,loft])* measures per intervention	Dmnl	This variable calculate how often measure are installed alone or in combination with one, two or three other measures. It is calculated for all the four measures (4 measures multiplied 4 extents, equal 16 equations)
extents distribution in measures demand[SC type,four,loft]	ZIDZ(demand for retrofit by interventions[SC type,gbli], retrofit demand by measures[SC type,loft])* measures per intervention	Dmnl	This variable calculate how often measure are installed alone or in combination with one, two or three other measures. It is calculated for all the four measures (4 measures multiplied 4 extents, equal 16 equations)
extents distribution in measures demand[SC type,two,insulation]	ZIDZ((demand for retrofit by interventions[SC type,gi]+ demand for retrofit by interventions[SC type,li]+ demand for retrofit by interventions[SC type,bi]), retrofit demand by measures[SC type,insulation]) *measures per intervention	Dmnl	This variable calculate how often measure are installed alone or in combination with one, two or three other measures. It is calculated for all the four measures (4 measures multiplied 4 extents, equal 16 equations)
extents distribution in measures demand[SC type,three,insulation]	ZIDZ((demand for retrofit by interventions[SC type,bli]+ demand for retrofit by interventions[SC type,gbi]+ demand for retrofit by interventions[SC type,gli]), retrofit demand by measures[SC type,insulation])* measures per intervention	Dmnl	This variable calculate how often measure are installed alone or in combination with one, two or three other measures. It is calculated for all the four measures (4 measures multiplied 4 extents, equal 16 equations)

extents distribution in measures demand[SC type,four,insulation]	ZIDZ(demand for retrofit by interventions[SC type,gbli], retrofit demand by measures[SC type,insulation])*measures per intervention	Dmnl	This variable calculate how often measure are installed alone or in combination with one, two or three other measures. It is calculated for all the four measures (4 measures multiplied 4 extents, equal 16 equations)
extents distribution in measures demand[SC type,zero,measures]	0	Dmnl	This variable calculate how often measure are installed alone or in combination with one, two or three other measures. It is calculated for all the four measures (4 measures multiplied 4 extents, equal 16 equations)
Failed measures[measures]	INTEG (defection rate[measures]-fixing rate[measures], 0)	measures	Stock in which the measure that are defected accumulate
financial attractiveness	desired payback time/payback time[SC type,interventions]* impact of sense of opportunity non financial attractiveness[SC type,interventions]	Dmnl	Here the desired payback time is confronted with the actual payback time. Then the results are multiplied by the sense of opportunity generated by the subsidies that can prompt homeowner to perceive an higher financial attractiveness
firing aggressiveness	0.05	Dmnl	This parameter is represents the hypothetical aggressiveness with which workers are fired if needed
fixing rate[measures]	Failed measures[measures]/fixing time	measures/Month	Rate in which failed measure gets repaired
fixing time	3	Month	The time a defected measure need to be detected and repaired. Educated guess made by researchers
flexibility for extra investment	0.1	Dmnl	People are willing to spent the 10% more on their renovation to retrofit. Source: Energy Saving Trust Trigger Point Report 2011 (p.5) http://www.energysavingtrust.org.uk/sites/default/files/reports/EST_Trigger_Points_report.pdf
fraction of buyers among renovators	0.4	Dmnl	Percentage of buyers that also do renovation to their new property
fraction of buyers considering retrofit because of green mortgages but not stamp rebate	(1-stamp duty rebates switch)*fraction of buyers taking green mortgages + stamp duty rebates switch*fraction of buyers taking green mortgages*(percentage of buyers not paying stamp duty+stamp rebates eligible but not aware fraction)	Dmnl	Percentage of total house buyers considering retrofit because of green mortgages but not stamp rebate. It is important not to take into account people that gets aware due to the stamp duty rebate, otherwise there is the risk to over count the number of buyers getting aware. Therefore, in the case the stamp duty policy is activated, the variable sum the people that are not aware of the stamp duty rebate or do not pay the stamp duty and multiply them by the fraction of people that gets a green mortgage
fraction of buyers considering retrofit because of stamp rebate but not green mortgages	stamp rebates eligible and aware fraction*(1-fraction of buyers taking green mortgages)	Dmnl	Fraction of buyers considering retrofit because of stamp duty rebate and not because of green mortgages
fraction of buyers considering retroift because of both stamp rebates and green mortgages	fraction of buyers taking green mortgages*stamp rebates eligible and aware fraction	Dmnl	In the potential demand for retrofit from buyers, fraction of buyers considering retroift because of both stamp rebates and green mortgages

fraction of buyers desiring a mortgage	fraction of buyers taking mortgages	Dmnl	Percentage of people buying a house that desired a mortgage. It based on the actual number of households purchasing a property with a mortgage
fraction of buyers eligible for stamp duty rebates	STEP(stamp duty rebates switch,stamp rebate starting time)* (1-percentage of buyers not paying stamp duty)	Dmnl	The percentage of buyers that have to pay a stamp duty in case they buy a property
fraction of buyers taking a conditional mortgage	fraction of buyers with no access to mortgages due to low EPC level* fraction of lenders offering conditional lending for retrofit* willingness of mortgage borrowers to take a conditional mortgage* STEP(1,EPC mortgage policy starting time)	Dmnl	Percentage of home buyers purchasing a low EPC property, that do not access to credit, that are offered with a conditional mortgage and the are willing to accept this offer
fraction of buyers taking green mortgages	fraction of buyers taking a conditional mortgage+ fraction of buyers taking larger mortgages to retrofit	Dmnl	The total amount of borrowers getting a green mortgage. It is the result of the sum of the households getting a larger mortgage to retrofit and of the buyers purchasing a low EPC property that take a conditional mortgage to retrofit the new property
fraction of buyers taking larger mortgages to retrofit	fraction of buyers with access to mortgages* willingness of mortgage borrowers to take an additional mortgage* fraction of lenders offering additional lending for retrofit* STEP(1,EPC mortgage policy starting time)	Dmnl	Percentage of mortgage borrowers that can access to a mortgage, that are offered with additional cash on the initial mortgage to retrofit their new property and accept this offer
fraction of buyers taking mortgages	0.4603	Dmnl	Percentage of buyers taking a mortgage when buying a new property in UK. Sourece: p.7 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/595785/2015-16_EHS_Headline_Report.pdf . Knowing the proportion between outright buyers and mortgagors of current tenure we assume that the distribution for new property sales is the same
fraction of buyers with access to mortgages	(1-fraction of properties with no access to mortgages)* fraction of buyers desiring a mortgage	Dmnl	The number of buyers desiring a mortgage that access to it. In case lenders do not prioritize EPC when lending, and therefore do not lend to low EPC, all the buyers access to a mortgage. In case lenders prioritize, only part of the access to a mortgage
fraction of buyers with no access to mortgages due to low EPC level	fraction of properties with no access to mortgages* fraction of buyers desiring a mortgage	Dmnl	Fraction of buyers that at the same are asking for a mortgage, are buying a low EPC property and do not get a mortgage because lenders do not lend to low EPC property purchasing
fraction of exstension of habitable space	0.1*STEP(compulsory retrofit for extensions switch,216)	Dmnl	The real value is unknown so at the moment it is an educated guess to test the impact of the policy. However, in the model runs this policy has been switched off
fraction of lenders offering additional lending for retrofit	1	Dmnl	Percentage of lenders that offers additional cash for retrofit to buyers asking a mortgage
fraction of lenders offering conditional lending for retrofit	1	Dmnl	Percentage of lenders offering conditional lending when a buyer ask a mortgage to buy a low EPC property. This conditional lending consist in offering extra credit to the buyer for retrofitting the new property. In case the buyer refuses the offer, the mortgage is denied

fraction of lenders prioritizing EPC	0	Dmnl	Percentage of lenders prioritizing the mortgages issued based on the EPC level. If the EPC level of the house purchased is low, lenders do not lend money to the mortgagor
fraction of properties with no access to mortgages	STEP(fraction of lenders prioritizing EPC,EPC mortgage policy starting time)* percentage of buyers with low EPC levels	Dmnl	In case lenders do not lend money to low EPC, this variable represents the fraction of properties with no access to mortgages
fraction of renovations considering retrofit	MIN(1,MAX(0, avg popularity of retrofit*impact of awareness on fraction of retrofit renovations + increased awareness by energy suppliers selling retrofit))	Dmnl	Percentage of households doing amenity renovations that also consider to top up this renovation with retrofit
fraction of renovators offering retrofit	retrofit WF fraction* (max advise from renovators-market fragmentation)	Dmnl	Percentage of renovators offering retrofit to homeowners undertaking amenity renovations. It depends on the fraction of retrofit workforce over the total and on the number of advices the retrofit workforce give. However the positive effect is balanced by the market fragmented. The more the single supply chain dominates the multi the less they are prone to suggest to do retrofit
fraction of retrofit measures installed as amenity	Added value to property of measures[measures]/avg added value of renovations/ (1+competitive alternatives for amenity renovations)/ (1+reference hassle factor per measure[measures])	Dmnl	Units: Here the added value to a property by each measure is confronted with a reference average added value, with other competitive alternative and discounted by the hassle factor involved in the installation that makes the measure less attractive
fraction of retrofit over total renovations	total retrofit interventions per month/ (total retrofit interventions per month+renovations without retrofit)	Dmnl	Percentage of retrofit intervention over the total number of renovations (with and without retrofit)
fraction of retrofitting leading to failures	MAX(0, SUM(fractional retrofit rate by SC type[SC type!]* avg probability of measures failures[SC type!,measures]))	Dmnl	Fraction retrofit measure that are not properly installed and will become a failed installation. It depends on the average probability of measure failures and on the measure installed by supply chain
fractional amplitude of economic cycles	0.3	Dmnl	This is the maximum amplitude of the oscillation the economic cycles have
fractional retrofit rate by SC type	ZIDZ(SUM(retrofit rate by intervention[SC type,interventions!]), SUM(retrofit rate by intervention[SC type!,interventions!]))	Dmnl	Retrofit rate distributed per supply chain type
from EE added value to max added value multiplier	0.5	Dmnl	How much the measures' added value because of house price premium per EPC band translates in added to a property by a measure. Educated guess made by researchers
from single to multi SC flow	IF THEN ELSE(Workforce for retrofit[single,measures], (perceived prevalence of combined interventions*SUM(Workforce for retrofit [SC type!,measures])- Workforce for retrofit[multi,measures])* readiness to shift from single to multi, 0)	workers/Month	This flow represents the rate workers in the single supply chain move to the multi. In practice, single suppliers once they realize multi measures interventions are demanded they start to offer multi measures too, or if they can't to associate with other single installers

fulfilled interventions	MIN(demand for retrofit by interventions[SC type,interventions]+interventions backlog adjustment [SC type,interventions], SC capacity for interventions[SC type,interventions])	Interventions/ Month	All the demand for retrofit interventions (actual demand and eventually backlog) that is satisfy by supply chain
guarantees on retrofit performances	0	Dmnl	This was a possible policy suggested by workshop participants. It represents the percentage of guarantees on the energy performance of the intervention installed (sort of insurance mechanisms). They are supposed to increase the trust homeowners have in the industry
hh initiating amenity only renovations	Households planning amenity only renovations/avg time before deciding*(1-installers' advise impact)	households/Month	Households that initiate only amenity renovations
hh starting to consider retrofit after advise	Households planning amenity only renovations/avg time before deciding*installers' advise impact	households/Month	Flow of households starting to consider retrofit after installers advise
hh starting to plan amenity only renovations	avg renovation rate*(1-fraction of exstension of habitable space)*(1-fraction of renovations considering retrofit)	households/Month	Flow of households starting to plan only amenity renovations
hh starting to plan retrofit renovations[efficiency]	avg renovation rate*(1-fraction of exstension of habitable space)*fraction of renovations considering retrofit	households/Month	Flow of households directly starting to plan to top up an amenity renovation with a retrofit intervention
hh starting to plan retrofit renovations[extension]	avg renovation rate*fraction of exstension of habitable space	households/Month	Flow of households directly starting to plan to top up an amenity renovation with a retrofit intervention
house price premium per EPC band	INTEG (change in price premium per EPC band, 0)	1/band	How much the price of a house increase per an improvement of one EPC band
households behavioural compliance	reference behavioural compliance*impact of maintenance on behaviour[measures]	Dmnl	The ability of households to use in the correct way the measure installed is affected by the maintenance it requires. The more maintenance the less households will use over time the measure properly
households per interventions	1	households/ Interventions	One intervention per household
Households planning amenity only renovations	INTEG (hh starting to plan amenity only renovations-hh initiating amenity only renovations- hh starting to consider retrofit after advise, hh starting to plan amenity only renovations*avg time before deciding)	households	Stock of households planning amenity only renovations
Households planning renovation and retrofit[amenity]	INTEG (hh starting to consider retrofit after advise- potential demand from renovations[amenity], hh starting to consider retrofit after advise*avg time before deciding)	households	Stock of households planning renovation and retrofit. Here a script accounting for the different reasons for which they are in this stock is used

Households planning renovation and retrofit[efficiency]	INTEG (hh starting to plan retrofit renovations[efficiency]- potential demand from renovations[efficiency], hh starting to plan retrofit renovations[efficiency]*avg time before deciding)	households	Stock of households planning renovation and retrofit. Here a script accounting for the different reasons for which they are in this stock is used
Households planning renovation and retrofit[extension]	INTEG (hh starting to plan retrofit renovations[extension]- potential demand from renovations[extension], hh starting to plan retrofit renovations[extension]*avg time before deciding)	households	Stock of households planning renovation and retrofit. Here a script accounting for the different reasons for which they are in this stock is used
households sustainability concerns	0.05	Dmnl	Households propensity to positively considerate retrofit because of sustainability concerns. Based on workshop inputs
housing market reactiveness in price change	fraction of lenders prioritizing EPC* reference reactiveness of house prices* mortgagors appreciation of green mortgages	1/Month	This is the speed to which the housing market adapt to green mortgage policy changes. The usual speed of market adaptation is dampened since the policy targets only some buyers. Therefore, the fraction of buyers taking green mortgages over the total number of buyers taking a mortgage can give an idea on how green mortgage are appreciated. The less green mortgages are appreciated by the market the slower will be the housing price to change because of the new policy
housing stock composition by retrofit extent[four]	retrofitted fraction by measure[insulation]*retrofitted fraction by measure [glazing]*retrofitted fraction by measure[loft]*retrofitted fraction by measure[boiler]	Dmnl	This variable differentiate the housing stock based on how many measures have been installed (extent of retrofit)
housing stock composition by retrofit extent[three]	retrofitted fraction by measure[insulation]*retrofitted fraction by measure[glazing]* retrofitted fraction by measure[loft]+ retrofitted fraction by measure[glazing]*retrofitted fraction by measure[loft]*retrofitted fraction by measure[boiler]+ retrofitted fraction by measure[insulation]*retrofitted fraction by measure[glazing]*retrofitted fraction by measure[boiler]+ retrofitted fraction by measure[insulation]*retrofitted fraction by measure[loft]*retrofitted fraction by measure[boiler]- 4*housing stock composition by retrofit extent[four]	Dmnl	This variable differentiate the housing stock based on how many measures have been installed (extent of retrofit)
housing stock composition by retrofit extent[two]	retrofitted fraction by measure[insulation]*retrofitted fraction by measure [glazing]+ retrofitted fraction by measure[insulation]*retrofitted fraction by measure[loft]+ retrofitted fraction by	Dmnl	This variable differentiate the housing stock based on how many measures have been installed (extent of retrofit)

	measure[insulation]*retrofitted fraction by measure [boiler]+ retrofitted fraction by measure[glazing]*retrofitted fraction by measure[loft]+ retrofitted fraction by measure[glazing]*retrofitted fraction by measure[boiler]+ retrofitted fraction by measure[loft]*retrofitted fraction by measure[boiler]- 3*housing stock composition by retrofit extent[three]- 6*housing stock composition by retrofit extent[four]		
housing stock composition by retrofit extent[one]	1-housing stock composition by retrofit extent[zero]- housing stock composition by retrofit extent[two]- housing stock composition by retrofit extent[three]- housing stock composition by retrofit extent[four]	Dmnl	This variable differentiate the housing stock based on how many measures have been installed (extent of retrofit)
housing stock composition by retrofit extent[zero]	(1-retrofitted fraction by measure[insulation])* (1-retrofitted fraction by measure [glazing])* (1-retrofitted fraction by measure[loft])* (1-retrofitted fraction by measure[boiler])	Dmnl	This variable differentiate the housing stock based on how many measures have been installed (extent of retrofit)
ideal percentage of controls	0.2	Dmnl	It has been estimate that the ideal percentage of installation quality controls should be the 20%. Source: Hunter Danskin (BEIS)
impact of awareness on fraction of retrofit renovations	0.6	Dmnl	How effective is retrofit awareness in making the homeowners renovating to consider retrofit
impact of behavioural compliance on measures energy performance	households behavioural compliance[measures]^(1/automatization in use)*(1-tailored advise and smart metering[SC type])+ tailored advise and smart metering[SC type]	Dmnl	Here the effect households behavioural compliance has on the measure energy performance is calculated. The households behavioural compliance is slightly affected by the automatization in use and strongly affected by the tailored advise from the adviser and the use of smart metering
impact of economic cycles on renovation fraction	risk taking attitude by economic cycles	Dmnl	This variable represents the impact economic cycles can have on the renovation fraction
impact of economy of scale on costs of materials	MIN(1, (total WF[measures]/workforce reference for economy of scale[measures]) ^elasticity of economy of scale effect)	Dmnl	Here the impact of economy of scale on the material costs is calculated based on a elasticity
impact of fragmentation on credibility	0.5	Dmnl	This variable reports the impact that market fragmentation has on credibility. It is an educated guess done by researchers
impact of interventions technology on non-	1	Dmnl	To calculate the impact of technology on intervention non-financial attractiveness a geometric mean has been used. Geometric mean because we need to mean impacts among the measures of the intervention and these impacts will be used as factors in a

financial attractiveness[n]			multiplication (not as terms as sum, in which case an arithmetic mean would have been more appropriate)
impact of interventions technology on non-financial attractiveness [g]	impact of measures technology on non-financial attractiveness [glazing]	Dmnl	To calculate the impact of technology on intervention non-financial attractiveness a geometric mean has been used. Geometric mean because we need to mean impacts among the measures of the intervention and these impacts will be used as factors in a multiplication (not as terms as sum, in which case an arithmetic mean would have been more appropriate)
impact of interventions technology on non-financial attractiveness [b]	impact of measures technology on non-financial attractiveness [boiler]	Dmnl	To calculate the impact of technology on intervention non-financial attractiveness a geometric mean has been used. Geometric mean because we need to mean impacts among the measures of the intervention and these impacts will be used as factors in a multiplication (not as terms as sum, in which case an arithmetic mean would have been more appropriate)
impact of interventions technology on non-financial attractiveness [l]	impact of measures technology on non-financial attractiveness [loft]	Dmnl	To calculate the impact of technology on intervention non-financial attractiveness a geometric mean has been used. Geometric mean because we need to mean impacts among the measures of the intervention and these impacts will be used as factors in a multiplication (not as terms as sum, in which case an arithmetic mean would have been more appropriate)
impact of interventions technology on non-financial attractiveness [i]	impact of measures technology on non-financial attractiveness [insulation]	Dmnl	To calculate the impact of technology on intervention non-financial attractiveness a geometric mean has been used. Geometric mean because we need to mean impacts among the measures of the intervention and these impacts will be used as factors in a multiplication (not as terms as sum, in which case an arithmetic mean would have been more appropriate)
impact of interventions technology on non-financial attractiveness [gb]	(impact of measures technology on non-financial attractiveness [boiler]*impact of measures technology on non-financial attractiveness [glazing])^0.5	Dmnl	To calculate the impact of technology on intervention non-financial attractiveness a geometric mean has been used. Geometric mean because we need to mean impacts among the measures of the intervention and these impacts will be used as factors in a multiplication (not as terms as sum, in which case an arithmetic mean would have been more appropriate)
impact of interventions technology on non-financial attractiveness [gl]	(impact of measures technology on non-financial attractiveness [glazing]* impact of measures technology on non-financial attractiveness [loft])^0.5	Dmnl	To calculate the impact of technology on intervention non-financial attractiveness a geometric mean has been used. Geometric mean because we need to mean impacts among the measures of the intervention and these impacts will be used as factors in a multiplication (not as terms as sum, in which case an arithmetic mean would have been more appropriate)
impact of interventions technology on non-financial attractiveness [gi]	(impact of measures technology on non-financial attractiveness [glazing] * impact of measures technology on non-financial attractiveness [insulation])^0.5	Dmnl	To calculate the impact of technology on intervention non-financial attractiveness a geometric mean has been used. Geometric mean because we need to mean impacts among the measures of the intervention and these impacts will be used as factors in a multiplication (not as terms as sum, in which case an arithmetic mean would have been more appropriate)
impact of interventions technology on non-financial attractiveness [bl]	(impact of measures technology on non-financial attractiveness [boiler] * impact of measures technology on non-financial attractiveness [loft])^0.5	Dmnl	To calculate the impact of technology on intervention non-financial attractiveness a geometric mean has been used. Geometric mean because we need to mean impacts among the measures of the intervention and these impacts will be used as factors in a

			multiplication (not as terms as sum, in which case an arithmetic mean would have been more appropriate)
impact of interventions technology on non-financial attractiveness [bi]	(impact of measures technology on non-financial attractiveness [boiler]* impact of measures technology on non-financial attractiveness [insulation])^0.5	Dmnl	To calculate the impact of technology on intervention non-financial attractiveness a geometric mean has been used. Geometric mean because we need to mean impacts among the measures of the intervention and these impacts will be used as factors in a multiplication (not as terms as sum, in which case an arithmetic mean would have been more appropriate)
impact of interventions technology on non-financial attractiveness [li]	(impact of measures technology on non-financial attractiveness [insulation]* impact of measures technology on non-financial attractiveness [loft])^0.5	Dmnl	To calculate the impact of technology on intervention non-financial attractiveness a geometric mean has been used. Geometric mean because we need to mean impacts among the measures of the intervention and these impacts will be used as factors in a multiplication (not as terms as sum, in which case an arithmetic mean would have been more appropriate)
impact of interventions technology on non-financial attractiveness [gbl]	(impact of measures technology on non-financial attractiveness [glazing]* impact of measures technology on non-financial attractiveness [boiler]* impact of measures technology on non-financial attractiveness [loft])^(1/3)	Dmnl	To calculate the impact of technology on intervention non-financial attractiveness a geometric mean has been used. Geometric mean because we need to mean impacts among the measures of the intervention and these impacts will be used as factors in a multiplication (not as terms as sum, in which case an arithmetic mean would have been more appropriate)
impact of interventions technology on non-financial attractiveness [gbi]	(impact of measures technology on non-financial attractiveness [glazing]* impact of measures technology on non-financial attractiveness [boiler]* impact of measures technology on non-financial attractiveness [insulation])^(1/3)	Dmnl	To calculate the impact of technology on intervention non-financial attractiveness a geometric mean has been used. Geometric mean because we need to mean impacts among the measures of the intervention and these impacts will be used as factors in a multiplication (not as terms as sum, in which case an arithmetic mean would have been more appropriate)
impact of interventions technology on non-financial attractiveness [gli]	(impact of measures technology on non-financial attractiveness [glazing]* impact of measures technology on non-financial attractiveness [insulation]* impact of measures technology on non-financial attractiveness [loft])^(1/3)	Dmnl	To calculate the impact of technology on intervention non-financial attractiveness a geometric mean has been used. Geometric mean because we need to mean impacts among the measures of the intervention and these impacts will be used as factors in a multiplication (not as terms as sum, in which case an arithmetic mean would have been more appropriate)
impact of interventions technology on non-financial attractiveness [bli]	(impact of measures technology on non-financial attractiveness [insulation]* impact of measures technology on non-financial attractiveness [boiler]* impact of measures technology on non-financial attractiveness [loft])^(1/3)	Dmnl	To calculate the impact of technology on intervention non-financial attractiveness a geometric mean has been used. Geometric mean because we need to mean impacts among the measures of the intervention and these impacts will be used as factors in a multiplication (not as terms as sum, in which case an arithmetic mean would have been more appropriate)
impact of interventions technology on non-financial attractiveness [gbli]	(impact of measures technology on non-financial attractiveness [glazing]* impact of measures technology on non-financial attractiveness [boiler]* impact of measures technology on non-financial attractiveness	Dmnl	To calculate the impact of technology on intervention non-financial attractiveness a geometric mean has been used. Geometric mean because we need to mean impacts among the measures of the intervention and these impacts will be used as factors in a multiplication (not as terms as sum, in which case an arithmetic mean would have been more appropriate)

	[loft]* impact of measures technology on non-financial attractiveness [insulation])^0.25		
impact of learning curve on labour costs	EXP(-Installed measures[measures]/(installed measures to halve the price/LN(2)))	Dmnl	The ratio between the installed measures and the reference number of measure after which the price is halved provide the comparison needed to know whether this learning curve is active. The Exponential of this ratio in a negative form, divided by the logarithm of two gives an exponential decrease, gives 0.5 when the installed measure are equal to the installed measure to halve the price
impact of maintenance on behaviour	MIN(1,maintenance frequency acceptable for consumer/maintenance frequency for measures proper work[measures])	Dmnl	This variable represents how the measure frequency can impact households behaviours and habits
impact of measures technology on non-financial attractiveness	Retrofit technology[measures]^ elasticity for impact of technology on non-financial attractiveness	Dmnl	The impact of technological improvements on the reference non-financial attractiveness is calculated based on the relative elasticity
impact of quality on energy performance	avg quality of installed measures[measures]^elasticity for impact of quality on energy performance	Dmnl	Here the impact of changes in quality on the energy performance of the measure installed is calculated based on a elasticity
impact of sense of opportunity non financial attractiveness	(MAX(0,sense of opportunity[SC type,interventions]))^sense of opportunity to financial attractiveness elasticity	Dmnl	The impact of the sense of opportunity generated by the presence of subsidies is calculated based on the respective elasticity
impact of tax reductions on renovation fraction	(1+perceived tax reduction on renovations)^tax reduction to renovation fraction elasticity	Dmnl	This variable calculates the impact a tax reduction has on the fraction of homeowners doing renovations
impact of technology on materials costs	MIN(1, Retrofit technology[measures]^technology to cost elasticity)	Dmnl	Here the impact of technological improvements on material costs is calculated based on an elasticity
impact of unintended consequences on opinions formation	10	Dmnl	How much unintended consequences (failed measures) impact the opinion formation (popularity) of households. Educated guess made by researchers. Failed measures make more 'noise' than measures installed properly
incentive to invest	IF THEN ELSE(projected return from investing[SC type,measures]>=return from not investing [SC type,measures], 1, 0)	Dmnl	If investing in the expansion of supply chain workforce is more profitable than not investing, it will be invested the necessary amount of money needed to cover any future workforce gap
increased awareness by energy suppliers selling retrofit	0	Dmnl	Test variable to introduce in the model the possibility for an increase in awareness due to energy suppliers
indoor temperature by intervention[n]	indoor temperature by retrofit extent[zero]	°	The indoor temperature is calculated per intervention, starting from extent (the number of measures installed)
indoor temperature by intervention[g]	indoor temperature by retrofit extent[one]	°	The indoor temperature is calculated per intervention, starting from extent (the number of measures installed)
indoor temperature by intervention[b]	indoor temperature by retrofit extent[one]	°	The indoor temperature is calculated per intervention, starting from extent (the number of measures installed)

indoor temperature by intervention[l]	indoor temperature by retrofit extent[one]	°	The indoor temperature is calculated per intervention, starting from extent (the number of measures installed)
indoor temperature by intervention[i]	indoor temperature by retrofit extent[one]	°	The indoor temperature is calculated per intervention, starting from extent (the number of measures installed)
indoor temperature by intervention[gb]	indoor temperature by retrofit extent[two]	°	The indoor temperature is calculated per intervention, starting from extent (the number of measures installed)
indoor temperature by intervention[gl]	indoor temperature by retrofit extent[two]	°	The indoor temperature is calculated per intervention, starting from extent (the number of measures installed)
indoor temperature by intervention[gi]	indoor temperature by retrofit extent[two]	°	The indoor temperature is calculated per intervention, starting from extent (the number of measures installed)
indoor temperature by intervention[bl]	indoor temperature by retrofit extent[two]	°	The indoor temperature is calculated per intervention, starting from extent (the number of measures installed)
indoor temperature by intervention[bi]	indoor temperature by retrofit extent[two]	°	The indoor temperature is calculated per intervention, starting from extent (the number of measures installed)
indoor temperature by intervention[li]	indoor temperature by retrofit extent[two]	°	The indoor temperature is calculated per intervention, starting from extent (the number of measures installed)
indoor temperature by intervention[gbl]	indoor temperature by retrofit extent[three]	°	The indoor temperature is calculated per intervention, starting from extent (the number of measures installed)
indoor temperature by intervention[gbi]	indoor temperature by retrofit extent[three]	°	The indoor temperature is calculated per intervention, starting from extent (the number of measures installed)
indoor temperature by intervention[gli]	indoor temperature by retrofit extent[three]	°	The indoor temperature is calculated per intervention, starting from extent (the number of measures installed)
indoor temperature by intervention[bli]	indoor temperature by retrofit extent[three]	°	The indoor temperature is calculated per intervention, starting from extent (the number of measures installed)
indoor temperature by intervention[gbli]	indoor temperature by retrofit extent[four]	°	The indoor temperature is calculated per intervention, starting from extent (the number of measures installed)
indoor temperature by retrofit extent[zero]	reference indoor temperature	°	Indoor temperature by retrofit extent. If there is no rebound effect all the temperature are equal
indoor temperature by retrofit extent[one]	indoor temperature by retrofit extent[zero]+ rebound effect*temperature increase per extent level	°	Indoor temperature by retrofit extent. If there is no rebound effect all the temperature are equal
indoor temperature by retrofit extent[two]	indoor temperature by retrofit extent[one]+ rebound effect*temperature increase per extent level	°	Indoor temperature by retrofit extent. If there is no rebound effect all the temperature are equal
indoor temperature by retrofit extent[three]	indoor temperature by retrofit extent[two]+ rebound effect*temperature increase per extent level	°	Indoor temperature by retrofit extent. If there is no rebound effect all the temperature are equal
indoor temperature by retrofit extent[four]	indoor temperature by retrofit extent[three]+ rebound effect*temperature increase per extent level	°	Indoor temperature by retrofit extent. If there is no rebound effect all the temperature are equal

industry trust building time	12	Month	The time industry needs change its trust. It is an educated guess made by researchers
INIT installed fraction[glazing]	0.477	Dmnl	Fraction of the retrofit measure already installed in the housing stock by year 2000. Estimation based on two report released by DECC/BEIS: 'United Kingdom housing energy fact file 2013' and 'Households energy efficiency national statistics. Detailed report 2016'. Integrated with I. Hamilton (2014) 'Uptake of energy efficiency interventions in English dwellings'. We assumed the number of homeowners (and so of the potential measures to install) to be constant (around 18 millions) and that a constant fraction (around 70%) of the reported uptake rate is from the homeowners.
INIT installed fraction[loft]	0.35	Dmnl	Fraction of the retrofit measure already installed in the housing stock by year 2000. Estimation based on two report released by DECC/BEIS: 'United Kingdom housing energy fact file 2013' and 'Households energy efficiency national statistics. Detailed report 2016'. Integrated with I. Hamilton (2014) 'Uptake of energy efficiency interventions in English dwellings'. We assumed the number of homeowners (and so of the potential measures to install) to be constant (around 18 millions) and that a constant fraction (around 70%) of the reported uptake rate is from the homeowners.
INIT installed fraction[boiler]	0.0169	Dmnl	Fraction of the retrofit measure already installed in the housing stock by year 2000. Estimation based on two report released by DECC/BEIS: 'United Kingdom housing energy fact file 2013' and 'Households energy efficiency national statistics. Detailed report 2016'. Integrated with I. Hamilton (2014) 'Uptake of energy efficiency interventions in English dwellings'. We assumed the number of homeowners (and so of the potential measures to install) to be constant (around 18 millions) and that a constant fraction (around 70%) of the reported uptake rate is from the homeowners.
INIT installed fraction[insulation]	0.004*(1-cavity wall scenario)+ 0.314*cavity wall scenario	Dmnl	Fraction of the retrofit measure already installed in the housing stock by year 2000. Estimation based on two report released by DECC/BEIS: 'United Kingdom housing energy fact file 2013' and 'Households energy efficiency national statistics. Detailed report 2016'. Integrated with I. Hamilton (2014) 'Uptake of energy efficiency interventions in English dwellings'. We assumed the number of homeowners (and so of the potential measures to install) to be constant (around 18 millions) and that a constant fraction (around 70%) of the reported uptake rate is from the homeowners.
INIT measures distribution[glazing]	1	Dmnl	Fraction of the houses in which a measure was already or could be installed (by year 2000). Estimation based on two report released by DECC/BEIS: 'United Kingdom housing energy fact file 2013' and 'Households energy efficiency national statistics. Detailed report 2016'. Integrated with I. Hamilton (2014) 'Uptake of energy efficiency interventions in English dwellings'. We assumed the number of homeowners (and so of the potential measures to install) to be constant (around 18 millions) and that a constant fraction (around 70%) of the reported uptake rate is from the homeowners.
INIT measures distribution[loft]	0.863	Dmnl	Fraction of the houses in which a measure was already or could be installed (by year 2000). Estimation based on two report released by DECC/BEIS: 'United Kingdom housing energy fact file 2013' and 'Households energy efficiency national statistics. Detailed report 2016'. Integrated with I. Hamilton (2014) 'Uptake of energy efficiency interventions in English dwellings'. We assumed the number of homeowners (and so of the potential measures to

			install) to be constant (around 18 millions) and that a constant fraction (around 70%) of the reported uptake rate is from the homeowners.
INIT measures distribution[insulation]	solid INIT distribution*(1-cavity wall scenario)+ cavity INIT distribution*cavity wall scenario	Dmnl	Fraction of the houses in which a measure was already or could be installed (by year 2000). Estimation based on two report released by DECC/BEIS: 'United Kingdom housing energy fact file 2013' and 'Households energy efficiency national statistics. Detailed report 2016'. Integrated with I. Hamilton (2014) 'Uptake of energy efficiency interventions in English dwellings'. We assumed the number of homeowners (and so of the potential measures to install) to be constant (around 18 millions) and that a constant fraction (around 70%) of the reported uptake rate is from the homeowners.
INIT measures distribution[boiler]	1	Dmnl	Fraction of the houses in which a measure was already or could be installed (by year 2000). Estimation based on two report released by DECC/BEIS: 'United Kingdom housing energy fact file 2013' and 'Households energy efficiency national statistics. Detailed report 2016'. Integrated with I. Hamilton (2014) 'Uptake of energy efficiency interventions in English dwellings'. We assumed the number of homeowners (and so of the potential measures to install) to be constant (around 18 millions) and that a constant fraction (around 70%) of the reported uptake rate is from the homeowners.
INIT stock	1.8e+007	measures	Number of UK homeowners. Source: http://visual.ons.gov.uk/uk-perspectives-2016-housing-and-home-ownership-in-the-uk/
initial market fragmentation	0.9	Dmnl	Initial market fragmentation. Based on the inputs of the workshops
initial total WF	135000	workers	Number of total workers employed in retrofit industry. Source grey literature: pag. 16 http://carbon.coop/sites/default/files/attachments/2016-09-12/2016%20URBED%20Tyndall%20The%20Retrofit%20factfile%20-%20facts%20and%20publications.pdf
Installed measures	INTEG (aggregate measures uptake rate[measures]+fixing rate[measures]-defection rate [measures],INIT stock*INIT measures distribution[measures]*INIT installed fraction[measures])	measures	Cumulative stock of the measure installed
installed measures to halve the price	5e+008	measures	The number of installed measures that lead to halve the labour costs because of learning effect in the industry (so it is able to optimize at the best all the components). Educated guess made by researchers
Installed measures weighted by quality	INTEG (measures installation rate weighted by quality[measures], Installed measures[measures]*workforce skills[measures])	measures	The installed measures are weighted by quality (namely the workforce skills level with which they are installed). If the number is equal to the number of the stock installed measures it means the measures have been installed with the maximum quality. Otherwise, they have been installed with a lower one
installers' advise impact	fraction of renovators offering retrofit	Dmnl	Percentage of households considering only amenity renovation that starts to consider to top it up with retrofit because of installer advice

intervention performances in bill savings	ZIDZ(actual bill savings by intervention[interventions], expected bill savings by intervention[interventions])	Dmnl	The actual the expected bills' savings are compared in order to assess intervention performance
interventions backlog accumulation	MAX(0, demand for retrofit by interventions[SC type,interventions]-fulfilled interventions [SC type,interventions])	Interventions/ Month	If there is a gap between the demand for retrofit and the capability of the supply chain to satisfy the demand this flow is bigger than zero and lead to a backlog accumulation
interventions backlog adjustment	Backlog of interventions[SC type,interventions]/backlog adjustment time	Interventions/ Month	The backlog that the supply chain detect and realize it needs to be fulfilled
interventions backlog depletion	MAX(0, fulfilled interventions[SC type,interventions]-demand for retrofit by interventions [SC type,interventions])	Interventions/ Month	Rate of backlogged interventions that are fulfilled by the supply chain in addition to the actual demand
interventions energy efficiency performance[n]	1	Dmnl	Here the energy performance is calculated per intervention averaging the sum of the single measure energy performance
interventions energy efficiency performance[g]	measures energy efficiency performance[glazing]	Dmnl	Here the energy performance is calculated per intervention averaging the sum of the single measure energy performance
interventions energy efficiency performance[b]	measures energy efficiency performance[boiler]	Dmnl	Here the energy performance is calculated per intervention averaging the sum of the single measure energy performance
interventions energy efficiency performance[l]	measures energy efficiency performance[loft]	Dmnl	Here the energy performance is calculated per intervention averaging the sum of the single measure energy performance
interventions energy efficiency performance[i]	measures energy efficiency performance[insulation]	Dmnl	Here the energy performance is calculated per intervention averaging the sum of the single measure energy performance
interventions energy efficiency performance[gb]	(measures energy efficiency performance[boiler]+ measures energy efficiency performance[glazing])/2	Dmnl	Here the energy performance is calculated per intervention averaging the sum of the single measure energy performance
interventions energy efficiency performance[gl]	(measures energy efficiency performance[glazing]+ measures energy efficiency performance[loft])/2	Dmnl	Here the energy performance is calculated per intervention averaging the sum of the single measure energy performance
interventions energy efficiency performance[gi]	(measures energy efficiency performance[glazing]+ measures energy efficiency performance[insulation])/2	Dmnl	Here the energy performance is calculated per intervention averaging the sum of the single measure energy performance
interventions energy efficiency performance[bl]	(measures energy efficiency performance[boiler]+ measures energy efficiency performance[loft])/2	Dmnl	Here the energy performance is calculated per intervention averaging the sum of the single measure energy performance

interventions energy efficiency performance[bi]	(measures energy efficiency performance[boiler]+ measures energy efficiency performance[insulation])/2	Dmnl	Here the energy performance is calculated per intervention averaging the sum of the single measure energy performance
interventions energy efficiency performance[li]	(measures energy efficiency performance[insulation]+ measures energy efficiency performance[loft])/2	Dmnl	Here the energy performance is calculated per intervention averaging the sum of the single measure energy performance
interventions energy efficiency performance[gbl]	(measures energy efficiency performance[glazing]+ measures energy efficiency performance[boiler]+ measures energy efficiency performance[loft])/3	Dmnl	Here the energy performance is calculated per intervention averaging the sum of the single measure energy performance
interventions energy efficiency performance[gbi]	(measures energy efficiency performance[glazing]+ measures energy efficiency performance[boiler]+ measures energy efficiency performance[insulation])/3	Dmnl	Here the energy performance is calculated per intervention averaging the sum of the single measure energy performance
interventions energy efficiency performance[gli]	(measures energy efficiency performance[glazing]+ measures energy efficiency performance[insulation]+ measures energy efficiency performance[loft])/3	Dmnl	Here the energy performance is calculated per intervention averaging the sum of the single measure energy performance
interventions energy efficiency performance[bli]	(measures energy efficiency performance[insulation]+ measures energy efficiency performance[boiler]+ measures energy efficiency performance[loft])/3	Dmnl	Here the energy performance is calculated per intervention averaging the sum of the single measure energy performance
interventions energy efficiency performance[gbli]	(measures energy efficiency performance[glazing]+ measures energy efficiency performance[boiler]+ measures energy efficiency performance[loft]+ measures energy efficiency performance[insulation])/4	Dmnl	Here the energy performance is calculated per intervention averaging the sum of the single measure energy performance
interventions per household	1	Interventions/ households	Number of retrofit intervention done per households every installation
interventions per households	1	Interventions/ households	One households can undertake only one intervention each time
interventions per measure	1	Interventions/ measures	Only one measure per type can be done in an intervention
interventions per month by extent by SC[SC type,one]	retrofit rate by intervention[SC type,g]+ retrofit rate by intervention[SC type,b]+ retrofit rate by intervention[SC type,l]+ retrofit rate by intervention[SC type,i]	Interventions/ Month	Intervention grouped by extent. An intervention with one measure installed has extent one, an intervention with two measures installed has extent two and so on
interventions per month by extent by SC[SC type,two]	retrofit rate by intervention[SC type,gb]+ retrofit rate by intervention[SC type,gl]+ retrofit rate by intervention[SC type,gi]+	Interventions/ Month	Intervention grouped by extent. An intervention with one measure installed has extent one, an intervention with two measures installed has extent two and so on

	retrofit rate by intervention[SC type,bl]+ retrofit rate by intervention[SC type,li]+ retrofit rate by intervention[SC type,bi]		
interventions per month by extent by SC[SC type,three]	retrofit rate by intervention[SC type,gbl]+ retrofit rate by intervention[SC type,gli]+ retrofit rate by intervention[SC type,gbi]+ retrofit rate by intervention[SC type,bli]	Interventions/ Month	Intervention grouped by extent. An intervention with one measure installed has extent one, an intervention with two measures installed has extent two and so on
interventions per month by extent by SC[SC type,four]	retrofit rate by intervention[SC type,gbli]	Interventions/ Month	Intervention grouped by extent. An intervention with one measure installed has extent one, an intervention with two measures installed has extent two and so on
interventions per month by extent by SC[SC type,zero]	0	Interventions/ Month	Intervention grouped by extent. An intervention with one measure installed has extent one, an intervention with two measures installed has extent two and so on
interventions popularity[i]	Popularity of measures[insulation]	Dmnl	Here the popularity is translated from measure to intervention with a geometric mean
interventions popularity[l]	Popularity of measures[loft]	Dmnl	Here the popularity is translated from measure to intervention with a geometric mean
interventions popularity[g]	Popularity of measures[glazing]	Dmnl	Here the popularity is translated from measure to intervention with a geometric mean
interventions popularity[b]	Popularity of measures[boiler]	Dmnl	Here the popularity is translated from measure to intervention with a geometric mean
interventions popularity[gb]	(Popularity of measures[glazing]*Popularity of measures[boiler])^(1/2)	Dmnl	Here the popularity is translated from measure to intervention with a geometric mean
interventions popularity[gl]	(Popularity of measures[glazing]*Popularity of measures[loft])^(1/2)	Dmnl	Here the popularity is translated from measure to intervention with a geometric mean
interventions popularity[gi]	(Popularity of measures[glazing]*Popularity of measures[insulation])^(1/2)	Dmnl	Here the popularity is translated from measure to intervention with a geometric mean
interventions popularity[bl]	(Popularity of measures[boiler]*Popularity of measures[loft])^(1/2)	Dmnl	Here the popularity is translated from measure to intervention with a geometric mean
interventions popularity[bi]	(Popularity of measures[boiler]*Popularity of measures[insulation])^(1/2)	Dmnl	Here the popularity is translated from measure to intervention with a geometric mean
interventions popularity[li]	(Popularity of measures[loft]*Popularity of measures[insulation])^(1/2)	Dmnl	Here the popularity is translated from measure to intervention with a geometric mean
interventions popularity[gbli]	(Popularity of measures[glazing]*Popularity of measures[loft]*Popularity of measures[boiler]*Popularity of measures[insulation])^(1/3)	Dmnl	Here the popularity is translated from measure to intervention with a geometric mean
interventions popularity[gbl]	(Popularity of measures[glazing]*Popularity of measures[boiler]*Popularity of measures[loft])^(1/3)	Dmnl	Here the popularity is translated from measure to intervention with a geometric mean

interventions popularity[gbi]	(Popularity of measures[glazing]*Popularity of measures[boiler]*Popularity of measures[insulation])^(1/3)	Dmnl	Here the popularity is translated from measure to intervention with a geometric mean
interventions popularity[gli]	(Popularity of measures[glazing]*Popularity of measures[loft]*Popularity of measures[insulation])^(1/3)	Dmnl	Here the popularity is translated from measure to intervention with a geometric mean
interventions popularity[bli]	(Popularity of measures[boiler]*Popularity of measures[insulation]*Popularity of measures[loft])^(1/3)	Dmnl	Here the popularity is translated from measure to intervention with a geometric mean
interventions popularity[n]	1	Dmnl	Here the popularity is translated from measure to intervention with a geometric mean
investment effort in workforce	incentive to invest[SC type,measures]	Dmnl	All the necessary amount of money to hire new workforce are invested
investments horizon	120	Month	Time needed by investors to considerate the profitability of a sector. Educated guess made by researchers
investments in technology	budget percentage for technological investment*budget for upcoming month[measures]	GBP/Month	Here the budget invested in technology is calculated. It is obtained multiplying the budget for investments for the upcoming month by the percentage of technological investment
investments in training	actual budget percentage for training*budget for upcoming month[measures]	GBP/Month	The amount of money monthly invested in training
labour contribution to costs	MIN(1, labour costs fraction over total*impact of learning curve on labour costs[measures])	Dmnl	Here the fractional labour costs are dampened by the impact of the learning curve. Learning curve is between zero and one
labour costs fraction over total	0.8	Dmnl	Percentage of labour costs in a measure installed (the remaining is material contribution cost). Source: Niel Witney (BEIS)
latency	60	Month	The time frame in which someone that has done a renovation wait before to do another one
learning by experience	MAX(0, (maximum skills from experience*total WF[measures]-Workforce weighted by skills[measures]) /reference time for skills acquisition)	workers/Month	This flow represents workers gaining experience and improving their skills and therefore the quality of the job they do
lenders restrictions on additional mortgage	avg mortgage size*expected mortgage premium by intervention[interventions]	GBP/Interventions	How much additional money lenders give to buyers to retrofit their new property
maintenance costs	cost of a maintenance intervention[SC type]*maintenance frequency[SC type,interventions]	GBP/Interventions/ Month	Here the maintenance costs for an intervention are multiplied by the frequency of the maintenance in order to obtain the total maintenance costs
maintenance frequency[SC type,n]	0	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need to call a different installed. Instead, for the interventions done by multi supply chain, the frequency is given by the measure that the needs to be checked more often: this because

			there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others
maintenance frequency[SC type,g]	maintenance frequency for measures proper work[glazing]	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need to call a different installed. Instead, for the interventions done by multi supply chain, the frequency is given by the measure that the needs to be checked more often: this because there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others
maintenance frequency[SC type,b]	maintenance frequency for measures proper work[boiler]	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need to call a different installed. Instead, for the interventions done by multi supply chain, the frequency is given by the measure that the needs to be checked more often: this because there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others
maintenance frequency[SC type,l]	maintenance frequency for measures proper work[loft]	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need to call a different installed. Instead, for the interventions done by multi supply chain, the frequency is given by the measure that the needs to be checked more often: this because there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others
maintenance frequency[SC type,i]	maintenance frequency for measures proper work[insulation]	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need to call a different installed. Instead, for the interventions done by multi supply chain, the frequency is given by the measure that the needs to be checked more often: this because there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others
maintenance frequency[single,gb]	maintenance frequency for measures proper work[glazing]+ maintenance frequency for measures proper work[boiler]	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need to call a different installed. Instead, for the interventions done by multi supply chain, the frequency is given by the measure that the needs to be checked more often: this because there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others
maintenance frequency[single,gl]	maintenance frequency for measures proper work[glazing]+ maintenance frequency for measures proper work[loft]	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need to call a different installed. Instead, for the interventions done by multi supply chain, the frequency is given by the measure that the needs to be checked more often: this because there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others
maintenance frequency[single,gi]	maintenance frequency for measures proper work[glazing]+ maintenance frequency for measures proper work[insulation]	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need to call a different installed. Instead, for the interventions done by multi supply chain, the

			frequency is given by the measure that the needs to be checked more often: this because there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others
maintenance frequency[single,bl]	maintenance frequency for measures proper work[loft]+ maintenance frequency for measures proper work[boiler]	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need to call a different installed. Instead, for the interventions done by multi supply chain, the frequency is given by the measure that the needs to be checked more often: this because there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others
maintenance frequency[single,bi]	maintenance frequency for measures proper work[boiler]+ maintenance frequency for measures proper work[insulation]	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need to call a different installed. Instead, for the interventions done by multi supply chain, the frequency is given by the measure that the needs to be checked more often: this because there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others
maintenance frequency[single,li]	maintenance frequency for measures proper work[loft]+ maintenance frequency for measures proper work[insulation]	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need to call a different installed. Instead, for the interventions done by multi supply chain, the frequency is given by the measure that the needs to be checked more often: this because there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others
maintenance frequency[single,gbl]	maintenance frequency for measures proper work[glazing]+ maintenance frequency for measures proper work[loft]+ maintenance frequency for measures proper work[boiler]	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need to call a different installed. Instead, for the interventions done by multi supply chain, the frequency is given by the measure that the needs to be checked more often: this because there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others
maintenance frequency[single,gbi]	maintenance frequency for measures proper work[glazing]+ maintenance frequency for measures proper work[boiler]+ maintenance frequency for measures proper work[insulation]	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need to call a different installed. Instead, for the interventions done by multi supply chain, the frequency is given by the measure that the needs to be checked more often: this because there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others
maintenance frequency[single,gli]	maintenance frequency for measures proper work[glazing]+ maintenance frequency for measures proper work[loft]+ maintenance frequency for measures proper work[insulation]	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need to call a different installed. Instead, for the interventions done by multi supply chain, the frequency is given by the measure that the needs to be checked more often: this because there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others
maintenance frequency[single,bli]	maintenance frequency for measures proper work[loft]+ maintenance frequency for	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need

	measures proper work[boiler]+ maintenance frequency for measures proper work[insulation]		to call a different installed. Instead, for the interventions done by multi supply chain, the frequency is given by the measure that the needs to be checked more often: this because there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others
maintenance frequency[single,gbli]	maintenance frequency for measures proper work[glazing]+ maintenance frequency for measures proper work[loft]+ maintenance frequency for measures proper work[boiler]+ maintenance frequency for measures proper work[insulation]	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need to call a different installed. Instead, for the interventions done by multi supply chain, the frequency is given by the measure that the needs to be checked more often: this because there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others
maintenance frequency[multi,gb]	MAX(maintenance frequency for measures proper work[glazing], maintenance frequency for measures proper work[boiler])	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need to call a different installed. Instead, for the interventions done by multi supply chain, the frequency is given by the measure that the needs to be checked more often: this because there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others
maintenance frequency[multi,gl]	MAX(maintenance frequency for measures proper work[glazing], maintenance frequency for measures proper work[loft])	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need to call a different installed. Instead, for the interventions done by multi supply chain, the frequency is given by the measure that the needs to be checked more often: this because there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others
maintenance frequency[multi,gi]	MAX(maintenance frequency for measures proper work[glazing], maintenance frequency for measures proper work[insulation])	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need to call a different installed. Instead, for the interventions done by multi supply chain, the frequency is given by the measure that the needs to be checked more often: this because there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others
maintenance frequency[multi,bl]	MAX(maintenance frequency for measures proper work[loft], maintenance frequency for measures proper work[boiler])	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need to call a different installed. Instead, for the interventions done by multi supply chain, the frequency is given by the measure that the needs to be checked more often: this because there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others
maintenance frequency[multi,bi]	MAX(maintenance frequency for measures proper work[boiler], maintenance frequency for measures proper work[insulation])	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need to call a different installed. Instead, for the interventions done by multi supply chain, the frequency is given by the measure that the needs to be checked more often: this because there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others

maintenance frequency[multi,li]	MAX(maintenance frequency for measures proper work[loft], maintenance frequency for measures proper work[insulation])	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need to call a different installed. Instead, for the interventions done by multi supply chain, the frequency is given by the measure that the needs to be checked more often: this because there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others
maintenance frequency[multi,gbl]	MAX(maintenance frequency for measures proper work[glazing], MAX(maintenance frequency for measures proper work[loft], maintenance frequency for measures proper work[boiler]))	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need to call a different installed. Instead, for the interventions done by multi supply chain, the frequency is given by the measure that the needs to be checked more often: this because there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others
maintenance frequency[multi,gbi]	MAX(maintenance frequency for measures proper work[glazing], MAX(maintenance frequency for measures proper work[boiler], maintenance frequency for measures proper work[insulation]))	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need to call a different installed. Instead, for the interventions done by multi supply chain, the frequency is given by the measure that the needs to be checked more often: this because there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others
maintenance frequency[multi,gli]	MAX(maintenance frequency for measures proper work[glazing], MAX(maintenance frequency for measures proper work[loft], maintenance frequency for measures proper work[insulation]))	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need to call a different installed. Instead, for the interventions done by multi supply chain, the frequency is given by the measure that the needs to be checked more often: this because there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others
maintenance frequency[multi,bli]	MAX(maintenance frequency for measures proper work[loft], MAX(maintenance frequency for measures proper work[boiler], maintenance frequency for measures proper work[insulation]))	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need to call a different installed. Instead, for the interventions done by multi supply chain, the frequency is given by the measure that the needs to be checked more often: this because there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others
maintenance frequency[multi,gbli]	MAX(maintenance frequency for measures proper work[glazing], MAX(maintenance frequency for measures proper work[boiler], MAX(maintenance frequency for measures proper work[insulation], maintenance frequency for measures proper work[loft])))	1/Month	This is the maintenance frequency for intervention. For the interventions done by single supply chain it is the sum of the different frequency, since all the time the customer need to call a different installed. Instead, for the interventions done by multi supply chain, the frequency is given by the measure that the needs to be checked more often: this because there is one the installer for all the measures and therefore once he comes for checking a measure he can also check the others
maintenance frequency acceptable for consumer	0.3	1/Month	This is what is believed to be an adequate and acceptable maintenance frequency that a household can take care of. Educated guess made by researchers based on the inputs provided during the workshops

maintenance frequency for measures proper work[glazing]	1/120	1/Month	These are educated guesses on how often a measure needs maintenance to properly work over time
maintenance frequency for measures proper work[boiler]	1/36	1/Month	These are educated guesses on how often a measure needs maintenance to properly work over time
maintenance frequency for measures proper work[loft]	1/60	1/Month	These are educated guesses on how often a measure needs maintenance to properly work over time
maintenance frequency for measures proper work[insulation]	IF THEN ELSE(cavity wall scenario>0.5, 1/60, 1/240)	1/Month	These are educated guesses on how often a measure needs maintenance to properly work over time
market fragmentation	MAX(0, ZIDZ(SUM(Workforce for retrofit[single,measures!]), SUM(Workforce for retrofit[SC type!,measures!])))	Dmnl	This variable represents the fragmentation of the retrofit market. This aspect is represented dividing installers able to install only one measure by the installer that are able install more
market volume for renovations	renovations*reference expenditures for renovations[renovation type]	GBP/Month	Here the market volume of all the renovations is calculated
market volume for retrofit	SUM(market volume for retrofit by measure[SC type!,measures!])	GBP/Month	The total volume of the business per month related to retrofit
market volume for retrofit by measure	reference prices for individual measure[measures]* retrofit demand by measures[SC type,measures]	GBP/Month	The monthly volume of business involved in retrofit installations is here calculated
marketing	max impact of marketing on popularity change[measures]*potential fraction by measure[measures]	1/Month	Here the impact of marketing is discount by the potential still available in the housing stock
marketing pressure	total WF[measures]/workforce threshold for marketing	Dmnl	This variable assess whether the workforce exceed the threshold for marketing
materials contribution to costs	(1-labour costs fraction over total)* impact of economy of scale on costs of materials[SC type,measures]* impact of technology on materials costs[measures]	Dmnl	Here the fractional material costs are dampened by the economy of scale and technological improvements. Economy of scale and technological improvements assumes both a value between zero and one
max added value	reference max added value+ measures added value for energy efficiency improvement[measures]*from EE added value to max added value multiplier	Dmnl	The maximum added value (non-financial reasons) is summed with the added value for measure mortgage premium (financial reasons)
max advise from renovators	2	Dmnl	Number of maximum advices to do retrofit by worker. Estimation done by researchers
max fractional popularity change due to marketing	0.005	1/Month	This represents the maximum change that marketing can do to popularity per unit of time

max impact of marketing on popularity change[measures]	max fractional popularity change due to marketing* (1+ (marketing pressure[measures]-1)/(1+ABS(marketing pressure[measures]-1)))/2	1/Month	This is a S-shaped function that when the marketing pressure is bigger than 1 we reach the 'max fractional popularity change due to marketing'
max unintended consequences probability	0.05	Dmnl	Realistic estimation of the maximal probability of unintended consequences when a retrofit measure is installed (this is the case in which it is installed by low skilled workers). Based on inputs with UCL experts
maximum rebate from stamp duty usable to retrofit	STEP(stamp duty rebates switch,stamp rebate starting time)* avg stamp duty* stamp duty rebate maximum fraction/ interventions per household	GBP/Interventions	The amount of money a buyer can invest per retrofit intervention because of a stamp duty rebate
maximum skills from experience	1	Dmnl	One represents the maximum skill that can be gained by a worker
measures added value for energy efficiency improvement	house price premium per EPC band*expected EPC improvement by measure[measures]	Dmnl	How much a retrofit measure adds value to the property because of increase in house valued due to EPC improvements
measures capacity gap accumulation	MAX(0, retrofit demand by measures[SC type,measures]-SC capacity for measures[SC type,measures])	measures/Month	This flow account for the monthly capacity gap that there could be between demand and supply
measures capacity gap reduction[SC type,glazing]	measures per intervention*(backlog interventions drop out[SC type,g]+ backlog interventions drop out[SC type,gb]+ backlog interventions drop out[SC type,gl]+ backlog interventions drop out[SC type,gi]+ backlog interventions drop out[SC type,gbl]+ backlog interventions drop out[SC type,gbi]+ backlog interventions drop out[SC type,gli]+ backlog interventions drop out[SC type,gbli]+ interventions backlog depletion[SC type,g]+ interventions backlog depletion[SC type,gb]+ interventions backlog depletion[SC type,gl]+ interventions backlog depletion[SC type,gi]+ interventions backlog depletion[SC type,gbi]+ interventions backlog depletion[SC type,gli]+ interventions backlog depletion[SC type,gbl]+ interventions backlog depletion[SC type,gbli])	measures/Month	The more the demand backlog is monthly solved the more the capacity gap accumulated decreases. It is calculated per measure, summing all the intervention that include that measure
measures capacity gap reduction[SC type, boiler]	measures per intervention*(backlog interventions drop out[SC type,b]+ backlog interventions drop out[SC type,gb]+ backlog interventions drop out[SC type,bl]+ backlog interventions drop out[SC type,bi]+ backlog	measures/Month	The more the demand backlog is monthly solved the more the capacity gap accumulated decreases. It is calculated per measure, summing all the intervention that include that measure

	interventions drop out[SC type,gbl]+ backlog interventions drop out[SC type,gbi]+ backlog interventions drop out[SC type,bli]+ backlog interventions drop out[SC type,gbli]+ interventions backlog depletion[SC type,b]+ interventions backlog depletion[SC type,bi]+ interventions backlog depletion[SC type,bi]+ interventions backlog depletion[SC type,gb]+ interventions backlog depletion[SC type,gbi]+ interventions backlog depletion[SC type,gbl]+ interventions backlog depletion[SC type,bli]+ interventions backlog depletion[SC type,gbli])		
measures capacity gap reduction[SC type, loft]	measures per intervention*(backlog interventions drop out[SC type,l]+ backlog interventions drop out[SC type,gl]+ backlog interventions drop out[SC type,bl]+ backlog interventions drop out[SC type,li]+ backlog interventions drop out[SC type,gbl]+ backlog interventions drop out[SC type,gli]+ backlog interventions drop out[SC type,bli]+ backlog interventions drop out[SC type,gbli]+ interventions backlog depletion[SC type,l]+ interventions backlog depletion[SC type,bl]+ interventions backlog depletion[SC type,li]+ interventions backlog depletion[SC type,gl]+ interventions backlog depletion[SC type,gbl]+ interventions backlog depletion[SC type,gli]+ interventions backlog depletion[SC type,bli]+ interventions backlog depletion[SC type,gbli])	measures/Month	The more the demand backlog is monthly solved the more the capacity gap accumulated decreases. It is calculated per measure, summing all the intervention that include that measure
measures capacity gap reduction[SC type, insulation]	measures per intervention*(backlog interventions drop out[SC type,i]+ backlog interventions drop out[SC type,bi]+ backlog interventions drop out[SC type,li]+ backlog interventions drop out[SC type,gi]+ backlog interventions drop out[SC type,gbi]+ backlog interventions drop out[SC type,gli]+ backlog interventions drop out[SC type,bli]+ backlog interventions drop out[SC type,gbli]+ interventions backlog depletion[SC type,i]+ interventions backlog depletion[SC type,bi]+ interventions backlog depletion[SC type,li]+ interventions backlog depletion[SC type,gi]+	measures/Month	The more the demand backlog is monthly solved the more the capacity gap accumulated decreases. It is calculated per measure, summing all the intervention that include that measure

	interventions backlog depletion[SC type,gbi]+ interventions backlog depletion[SC type,gli]+ interventions backlog depletion[SC type,bli]+ interventions backlog depletion[SC type,gbli])		
measures discount by combination[single, extent]	0	Dmnl	If more measures are installed together by just one installer in an intervention it is possible they cost less than installing them one by one in different interventions. This effect activates when 3 or more measure are installed together. Otherwise, multi supply chain is more expensive to in install one or two measure (because multi supply chain needs to mobilize more resource to do an installation than single supply chain)
measures discount by combination[multi,one]	-0.2	Dmnl	If more measures are installed together by just one installer in an intervention it is possible they cost less than installing them one by one in different interventions. This effect activates when 3 or more measure are installed together. Otherwise, multi supply chain is more expensive to in install one or two measure (because multi supply chain needs to mobilize more resource to do an installation than single supply chain)
measures discount by combination[multi,two]	-0.1	Dmnl	If more measures are installed together by just one installer in an intervention it is possible they cost less than installing them one by one in different interventions. This effect activates when 3 or more measure are installed together. Otherwise, multi supply chain is more expensive to in install one or two measure (because multi supply chain needs to mobilize more resource to do an installation than single supply chain)
measures discount by combination[multi,three]	0.1	Dmnl	If more measures are installed together by just one installer in an intervention it is possible they cost less than installing them one by one in different interventions. This effect activates when 3 or more measure are installed together. Otherwise, multi supply chain is more expensive to in install one or two measure (because multi supply chain needs to mobilize more resource to do an installation than single supply chain)
measures discount by combination[multi,four]	0.2	Dmnl	If more measures are installed together by just one installer in an intervention it is possible they cost less than installing them one by one in different interventions. This effect activates when 3 or more measure are installed together. Otherwise, multi supply chain is more expensive to in install one or two measure (because multi supply chain needs to mobilize more resource to do an installation than single supply chain)
measures discount by combination[multi,zero]	0	Dmnl	If more measures are installed together by just one installer in an intervention it is possible they cost less than installing them one by one in different interventions. This effect activates when 3 or more measure are installed together. Otherwise, multi supply chain is more expensive to in install one or two measure (because multi supply chain needs to mobilize more resource to do an installation than single supply chain)
measures energy efficiency performance	SUM(impact of behavioural compliance on measures energy performance[SC type!,measures])/ ELMCOUNT(SC type)* impact of quality on energy performance[measures]	Dmnl	Here the two aspects that affect the retrofit measure performance are aggregated (the households behavioural compliance and the quality of the measure installation). Since there are two different supply chain, an average of the both is done

measures installation rate weighted by quality	aggregate measures uptake rate[measures]*workforce skills[measures]	measures/Month	Flow of measure installed weighted by the workforce skills
measures opinion formation	awareness spreading by word of mouth[measures]* perceived measures benefits[measures]-negative wom from unintended consequences[measures]	1/Month	Here all the factors influencing the households' opinion are aggregated. The positive word of mouth is multiplied by the perceived benefits and then subtracted by the negative word of mouth
measures per extent[zero]	0	measures	Number of measure installed per retrofit extent
measures per extent[one]	1	measures	Number of measure installed per retrofit extent
measures per extent[two]	2	measures	Number of measure installed per retrofit extent
measures per extent[three]	3	measures	Number of measure installed per retrofit extent
measures per extent[four]	4	measures	Number of measure installed per retrofit extent
measures per household	1	measures/ households	Each type of measure per household
measures per intervention	1	measures/ Interventions	Only measures are installed per intervention. The sense of this variable is to be a unit converter
measures performance on bill savings[glazing]	XIDZ(intervention performances in bill savings[g]*estimated retrofitted fraction by intervention[g]+ intervention performances in bill savings[gb]*estimated retrofitted fraction by intervention [gb]+ intervention performances in bill savings[gl]*estimated retrofitted fraction by intervention[gl]+ intervention performances in bill savings[gi]*estimated retrofitted fraction by intervention[gi]+ intervention performances in bill savings[gbl]*estimated retrofitted fraction by intervention[gbl]+ intervention performances in bill savings[gbi]*estimated retrofitted fraction by intervention[gbi]+ intervention performances in bill savings[gli]*estimated retrofitted fraction by intervention[gli]+ intervention performances in bill savings[gbli]*estimated retrofitted fraction by intervention[gbli], estimated retrofitted fraction by intervention[g]+ estimated	Dmnl	The actual and the expected bills' savings are compared in order to assess measure performance. This is calculated starting from the intervention performance on bill savings

	retrofitted fraction by intervention[gb]+ estimated retrofitted fraction by intervention[gl]+ estimated retrofitted fraction by intervention[gi]+ estimated retrofitted fraction by intervention[gbl]+ estimated retrofitted fraction by intervention[gbi]+ estimated retrofitted fraction by intervention[gli]+ estimated retrofitted fraction by intervention[gbli],1)		
measures performance on bill savings[boiler]	XIDZ(intervention performances in bill savings[b]*estimated retrofitted fraction by intervention[b]+ intervention performances in bill savings[gb]*estimated retrofitted fraction by intervention[gb]+ intervention performances in bill savings[bl]*estimated retrofitted fraction by intervention[bl]+ intervention performances in bill savings[bi]*estimated retrofitted fraction by intervention[bi]+ intervention performances in bill savings[gbl]*estimated retrofitted fraction by intervention[gbl]+ intervention performances in bill savings[gbi]*estimated retrofitted fraction by intervention[gbi]+ intervention performances in bill savings[bli]*estimated retrofitted fraction by intervention[bli]+ intervention performances in bill savings[gbli]*estimated retrofitted fraction by intervention[gbli], estimated retrofitted fraction by intervention[b]+ estimated retrofitted fraction by intervention[gb]+ estimated retrofitted fraction by intervention[bl]+ estimated retrofitted fraction by intervention[bi]+ estimated retrofitted fraction by intervention[gbl]+ estimated retrofitted fraction by intervention[gbi]+ estimated retrofitted fraction by intervention[bli]+ estimated retrofitted fraction by intervention[gbli], 1)	Dmnl	The actual and the expected bills' savings are compared in order to assess measure performance. This is calculated starting from the intervention performance on bill savings
measures performance on bill savings[insulation]	XIDZ(intervention performances in bill savings[i]*estimated retrofitted fraction by intervention[i]+ intervention performances in bill savings[bi]*estimated retrofitted fraction	Dmnl	The actual and the expected bills' savings are compared in order to assess measure performance. This is calculated starting from the intervention performance on bill savings

	by intervention[bi]+ intervention performances in bill savings[li]*estimated retrofitted fraction by intervention[li]+ intervention performances in bill savings[gi]*estimated retrofitted fraction by intervention[gi]+ intervention performances in bill savings[bli]*estimated retrofitted fraction by intervention[bli]+ intervention performances in bill savings[gbi]*estimated retrofitted fraction by intervention[gbi]+ intervention performances in bill savings[gli]*estimated retrofitted fraction by intervention[gli]+ intervention performances in bill savings[gbli]*estimated retrofitted fraction by intervention[gbli], estimated retrofitted fraction by intervention[i]+ estimated retrofitted fraction by intervention[bi]+ estimated retrofitted fraction by intervention[li]+ estimated retrofitted fraction by intervention[gi]+ estimated retrofitted fraction by intervention[bli]+ estimated retrofitted fraction by intervention[gbi]+ estimated retrofitted fraction by intervention[gli]+ estimated retrofitted fraction by intervention[gbli],1)		
measures performance on bill savings[loft]	XIDZ(intervention performances in bill savings[l]*estimated retrofitted fraction by intervention[l]+ intervention performances in bill savings[bl]*estimated retrofitted fraction by intervention[bl]+ intervention performances in bill savings[gl]*estimated retrofitted fraction by intervention[gl]+ intervention performances in bill savings[li]*estimated retrofitted fraction by intervention[li]+ intervention performances in bill savings[gbl]*estimated retrofitted fraction by intervention[gbl]+ intervention performances in bill savings[bli]*estimated retrofitted fraction by intervention[bli]+ intervention performances in bill savings[gli]*estimated retrofitted fraction by intervention[gli]+ intervention performances in bill savings[gbli]*estimated retrofitted fraction by intervention[gbli], estimated retrofitted	Dmnl	The actual and the expected bills' savings are compared in order to assess measure performance. This is calculated starting from the intervention performance on bill savings and averaging the different performance

	fraction by intervention[l]+estimated retrofitted fraction by intervention[bl]+estimated retrofitted fraction by intervention[gl]+estimated retrofitted fraction by intervention[li]+estimated retrofitted fraction by intervention[gbl]+ estimated retrofitted fraction by intervention[bli]+estimated retrofitted fraction by intervention[gli]+ estimated retrofitted fraction by intervention[gbli],1)		
measures savings discount by combination[SC type, extent]	0	Dmnl	According to the data showed in 'NATIONAL ENERGY EFFICIENCY DATA-FRAMEWORK Summary of analysis using the National Energy Efficiency Data-Framework (NEED), June 2016' pag 34, there seems to be no univocal energy savings 'discount' in cumulative instalments
min unintended consequences probability	0.01	Dmnl	Realistic estimation of the minimum probability of unintended consequences when a retrofit measure is installed (this is the case in which it is installed by high skilled workers).
monitoring effectiveness	MIN(1,percentage of controls by regulation/ideal percentage of controls)* certification bodies quality* market fragmentation	Dmnl	The monitor effectiveness is calculated comparing the percentage of control done because of regulation (the actual controls performed) with the ideal percentage of controls. This is multiplied by the certification bodies quality (in case certification bodies have use low quality in their job, the monitoring effectiveness decreases). Moreover market fragmentation make more difficult to perform monitoring
mortgage premium for EPC band	0.05	1/band	If policies are in place, how much more extra money lenders are willing to give for an improvement of a EPC band. Data retrieved from confidential information in BEIS
mortgagors appreciation of green mortgages	ZIDZ (fraction of buyers taking green mortgages,fraction of buyers taking mortgages)	Dmnl	This division represents the fraction of buyers getting a green mortgage over the total number of buyer taking a mortgage. From this number it is possible to assess how much the green mortgage option has been adopted and appreciated by mortgagors
natural technological improvement rate	0.001	1/Month	Technology is assumed to improve by itself, independently on investments, by a certain rate. This rate is an educated guess made by researchers since no data were available
negative wom from unintended consequences	impact of unintended consequences on opinions formation* retrofit failing fractional rate[measures]*contact rate	1/Month	Negative word of mouth obtained, as traditional way in SD, multiplying the contact rate by the fractional rate of failed measures and weighted by the importance households give to these failed measure
new non-susceptible homeowners' houses	0	households/Month	This flow represents the flow of new houses built that 'creates' new homeowners that have recently done a renovation. Since the housing stock is assumed to be static this inflow is null
new potential measures to install	new susceptible homeowners' houses*measures per household	measures/Month	Inflow of new potential available due to the construction of new houses
new susceptible homeowners' houses	0	households/Month	This flow represents the flow of new houses built that 'creates' new homeowners that have not recently done a renovation. Since the housing stock is assumed to be static this inflow is null

no restrictions on additional mortgages	0	Dmnl	If lenders not support the installation of the whole intervention. In this case lenders support with additional cash on the mortgage the whole intervention
non-financial attractiveness per intervention [n]	0	Dmnl	Here the non-financial attractiveness is calculated per intervention starting from the measures' non-financial attractiveness
non-financial attractiveness per intervention [g]	non-financial attractiveness per measure [glazing]	Dmnl	Here the non-financial attractiveness is calculated per intervention starting from the measures' non-financial attractiveness
non-financial attractiveness per intervention [b]	non-financial attractiveness per measure [boiler]	Dmnl	Here the non-financial attractiveness is calculated per intervention starting from the measures' non-financial attractiveness
non-financial attractiveness per intervention [l]	non-financial attractiveness per measure [loft]	Dmnl	Here the non-financial attractiveness is calculated per intervention starting from the measures' non-financial attractiveness
non-financial attractiveness per intervention [i]	non-financial attractiveness per measure [insulation]	Dmnl	Here the non-financial attractiveness is calculated per intervention starting from the measures' non-financial attractiveness
non-financial attractiveness per intervention [gb]	non-financial attractiveness per measure [glazing]+ non-financial attractiveness per measure [boiler]	Dmnl	Here the non-financial attractiveness is calculated per intervention starting from the measures' non-financial attractiveness
non-financial attractiveness per intervention [gl]	non-financial attractiveness per measure [glazing]+ non-financial attractiveness per measure [loft]	Dmnl	Here the non-financial attractiveness is calculated per intervention starting from the measures' non-financial attractiveness
non-financial attractiveness per intervention [gi]	non-financial attractiveness per measure [glazing]+ non-financial attractiveness per measure [insulation]	Dmnl	Here the non-financial attractiveness is calculated per intervention starting from the measures' non-financial attractiveness
non-financial attractiveness per intervention [bl]	non-financial attractiveness per measure [boiler]+ non-financial attractiveness per measure [loft]	Dmnl	Here the non-financial attractiveness is calculated per intervention starting from the measures' non-financial attractiveness
non-financial attractiveness per intervention [bi]	non-financial attractiveness per measure [boiler]+ non-financial attractiveness per measure [insulation]	Dmnl	Here the non-financial attractiveness is calculated per intervention starting from the measures' non-financial attractiveness
non-financial attractiveness per intervention [li]	non-financial attractiveness per measure [loft]+ non-financial attractiveness per measure [insulation]	Dmnl	Here the non-financial attractiveness is calculated per intervention starting from the measures' non-financial attractiveness
non-financial attractiveness per intervention [gbl]	non-financial attractiveness per measure [glazing]+ non-financial attractiveness per measure [boiler]+ non-financial attractiveness per measure [loft]	Dmnl	Here the non-financial attractiveness is calculated per intervention starting from the measures' non-financial attractiveness

non-financial attractiveness per intervention [gbi]	non-financial attractiveness per measure [glazing]+ non-financial attractiveness per measure [boiler]+ non-financial attractiveness per measure [insulation]	Dmnl	Here the non-financial attractiveness is calculated per intervention starting from the measures' non-financial attractiveness
non-financial attractiveness per intervention [gli]	non-financial attractiveness per measure [glazing]+ non-financial attractiveness per measure [loft]+ non-financial attractiveness per measure [insulation]	Dmnl	Here the non-financial attractiveness is calculated per intervention starting from the measures' non-financial attractiveness
non-financial attractiveness per intervention [bli]	non-financial attractiveness per measure [boiler]+ non-financial attractiveness per measure [loft]+ non-financial attractiveness per measure [insulation]	Dmnl	Here the non-financial attractiveness is calculated per intervention starting from the measures' non-financial attractiveness
non-financial attractiveness per intervention [gbli]	non-financial attractiveness per measure [glazing]+ non-financial attractiveness per measure [boiler]+ non-financial attractiveness per measure [loft]+ non-financial attractiveness per measure [insulation]	Dmnl	Here the non-financial attractiveness is calculated per intervention starting from the measures' non-financial attractiveness
non-financial attractiveness per measure	(reference non-financial attractiveness per measure [measures]* impact of measures technology on non-financial attractiveness [measures]+ households sustainability concerns)* (1+Added value to property of measures[measures])	Dmnl	It collects all the non-financial features of a measure (aesthetics, thermal comfort, etc.) that make the measure attractive to homeowners. In detail, it integrates a reference non-financial attractiveness per measure (that can change over time due to technological improvements), with households propensity to retrofit because of sustainability concerns and with the added value that a measure can give to property
non-susceptible stock	INTEG (new non-susceptible homeowners' houses +renovations- re-getting susceptible, INIT stock/measures per household-susceptible for renovations stock)	households	Stock of houses that recently undertook a renovations and that therefore are very unlikely to be susceptible to another renovation in a short period
number of measures per intervention	SUM(extent distribution in interventions per month[extent!]*measures per extent[extent!])	measures	Variable counting the average number of measures installed per intervention
old boilers replacement	STEP(1,60)*Potential for retrofit measures to install[boiler]/avg boiler duration	measures/Month	From 2005 (month 60) it became compulsory to install a condensing boiler in case of boiler replacement. This calculate the old boilers that broke down and need to be replaced
past prices retention time	36	Month	How much time people need to perceive variation in retrofit prices. It has been set to this value by researchers. The reason to set it to three year is that it is believe that households do not update themselves about retrofit prices and subsidies very often
payback time	MIN(1200, XIDZ(upfront cost for consumer[SC type,interventions],believed monthly savings [SC type,interventions]))	Month	Here the upfront costs are confronted with the believed monthly savings in order to obtain the actual payback time. 1200 represents the fact the maximum payback time considered is 100 years
perceived demand[SC type,measures]	SMOOTH(retrofit demand by measures[SC type,measures],demand perception delay)	measures/Month	The perceived demand is an informational delay of the actual demand
perceived gap in quality	(quality standards for installations-workforce skills[measures])*monitoring effectiveness	Dmnl	The quality of actual installation is equal to the workforce skills. This is confronted with the quality standards and the eventual gap generated is multiplied by the monitoring

			effectiveness: if monitoring effectiveness is lower the one not the entire gap is perceived but only part of it
perceived hassle factor	reference hassle factor per interventions[SC type,interventions]*(1+LN(1+market fragmentation))	Dmnl	The hassle factor can be amplified if the market fragmentation is very high (>1) or dampened if low (<1)
perceived market volume	INTEG (change in perceived market volume[SC type,measures], market volume for retrofit by measure[SC type,measures])	GBP/Month	This is the perceived market volume by the actors in the sector
perceived measures benefits	SMOOTH(consumers experience of measures benefits[measures], performance acknowledgement time)	Dmnl	Information delay. It represents the time homeowners need to perceived the experience of an installed measure
perceived prevalence of combined interventions	DELAY1(prevalence of combined interventions,perception delay for prevalence of combined interventions)	Dmnl	Perception delay. The supply chain needs time to perceived any prevalence of multi measure intervention over single
perceived prices of interventions for consumers	INTEG(change in perceived interventions prices[SC type,interventions],prices of interventions[SC type,interventions])	GBP/Interventions	The stock accounts for the perceived retrofit prices by households
perceived tax reduction on renovations	SMOOTHI(STEP(tax reduction on renovations,tax reduction starting time), renovations tax reduction perception delay, 0)	Dmnl	Delay function representing the perception of a tax reduction by homeowners
percentage of buyers not paying stamp duty	estimated property distribution per stamp duty band[up125]	Dmnl	Buyers purchasing a property cheaper than 125000 GBP do not pay stamp duty
percentage of buyers with low EPC levels	current EPC distribution[epcE]+ current EPC distribution[epcF]+ current EPC distribution[epcG]	Dmnl	Percentage of buyers purchasing an inefficient property. E, F and G are considered as inefficient EPC bands
percentage of controls by regulation	0.03	Dmnl	The percentage of controls that need to be done on the industry according to the law. Source: Hunter Danskin (BEIS)
perception delay for prevalence of combined interventions	12	Month	The time the supply chain needs to realize there is a prevalence of multi interventions over single intervention
perception time for perceived market volume	6	Month	Time actors in the retrofit system need to perceived changes in the market volume. Educated guess made by researchers
performance acknowledgement time	2	Month	Time homeowners need to perceived a change due to a retrofit measure installation
policy coherence	0.5	Dmnl	This parameter is assumed to range between zero and one. Zero is when policy coherence is very low, one is the opposite. Policy coherence is refers to the stability and harmony policies in the sector have. If these factors are present investors perceive the retrofit environment as stable and are more willing to invest. For example, if laws and schemes continuously change the policy coherence is very low because the sector is very unstable

popularity change	popularity saturation effect[measures]*(measures opinion formation[measures]+ marketing[measures])	1/Month	Here the flow of popularity change is calculated. It can be positive and thus increasing the popularity of a measure. But it also can be negative and therefore it decreases the popularity of the measure. The popularity saturation effect makes sure the popularity do not increase more than 1
Popularity of measures	INTEG (popularity change[measures], INIT installed fraction[measures])	Dmnl	Popularity is the natural step beyond awareness. Popularity merges the concept of awareness with the one of a positive of negative opinion. Therefore, homeowners aware of retrofit may have a good or bad opinion about it. In case they are aware and have a good opinion, we ca say that the measure is popular. It is initialized with the fractional distribution of the measures among the housing stock. It has been believed it was a good anchor starting value for popularity
popularity saturation effect	(1-Popularity of measures[measures])*Popularity of measures[measures]	Dmnl	This variable makes sure the popularity do not overcome the value of one
possible future measures installed	MIN(SUM(retrofit demand by measures[SC type!,measures])*investments horizon, Potential for retrofit measures to install[measures])	measures	Here the potential for retrofit is confronted with future demand. This variable makes sure the retrofit demand calculated over the investment horizon don't exceed the actual potential
potential demand from buyers	Buyers planning retrofit/avg time before deciding	households/Month	Buyers that are deciding whether retrofit or not
potential demand from buyers for potential fraction	estimated potential fraction by intervention[interventions]*potential demand from buyers* buyers distribution[buyers type]	households/Month	Here the potential demand from buyers (buyers considering whether to retrofit or not) are distributed based on they reason why they are considering retrofit (stamp duty or green mortgage or both) and then discounted by the intervention potential remaining
potential demand from renovation for potential fraction	estimated potential fraction by intervention[interventions]*potential demand from renovations [renovation type]	households/Month	Here the potential demand from renovators willing to top up with retrofit is adjusted for the actual potential available for intervention
potential demand from renovations	MAX(0, Households planning renovation and retrofit[renovation type]/avg time before deciding)	households/Month	Households deciding whether top up their amenity renovation with retrofit or not
potential for measures increase in added value	(max added value[measures]-Added value to property of measures[measures])	Dmnl	This variable represents the different between what could be the maximum added value to a property of a measure installation and the actual added value by a measure. In the difference between the two the potential lies
Potential for retrofit measures to install	INTEG (new potential measures to install[measures]-aggregate measures uptake rate [measures], INIT stock*INIT measures distribution[measures]*(1-INIT installed fraction[measures]))	measures	Stock accounting for the potential available for each measure (houses not retrofitted with that specific measure)

potential fraction by measure	MIN(Potential for retrofit measures to install[measures]/total measures[measures],1)	Dmnl	Fraction of houses in which a measure has not been installed yet and therefore are potential for retrofit
potential measures	INIT stock*INIT measures distribution[measures]	measures	The initial stock is multiplied by the measure distribution in order to obtain the actual number of potential measures
potential savings	MAX(0, expected bill savings by intervention[interventions]-maintenance costs[SC type ,interventions])	GBP/Interventions/ Month	These potential bill savings that homeowners take into account when they evaluate whether or retrofit or no. They do not just consider the expected savings but they subtract the maintenance costs
pressure to increase measures added value	non-financial attractiveness per measure [measures]* Popularity of measures[measures]	Dmnl	This variable aggregates measures' non-financial attractiveness and popularity in order to accounts for all the 'positive' features that make a measure to be perceived as an added value
prevalence of combined interventions	ZIDZ(extent distribution in interventions per month[four]+ extent distribution in interventions per month[three]+ extent distribution in interventions per month[two], SUM(extent distribution in interventions per month[extent!]))	Dmnl	This variable is a counter to calculate the percentage combine interventions (more than one measure installed per intervention, namely extent two, three and four) with respect of the total
prices for individual measures	(1+profit margin)* (1- subsidies / consumer tax credit [measures]*(1-STEP(stop of subsidies,subsidies stop time)))* suppliers costs for individual measuress[SC type,measures]* (1-contribution from other actors)	GBP/measures	The final prices are calculated adding to the costs for installers the profit the want to have, discounted by the subsidies (here a step function is used to modulate the introduction of different subsidies and to stop them when needed). Moreover it is reported the possibility of other externa actors (e.g. energy suppliers) support the uptake of retrofit measures, thus decreasing the price for homeowners
prices of interventions[SC type,i]	prices for individual measures[SC type,insulation]*(1-measures discount by combination[SC type,one])/ interventions per measure	GBP/Interventions	Here the price for the interventions are calculated. More measures installed in an intervention are cheaper than installing them in separate interventions. This effect works only for more at least 3 measures or more installed by multi supply chain
prices of interventions[SC type,l]	prices for individual measures[SC type,loft]*(1-measures discount by combination[SC type,one])/ interventions per measure	GBP/Interventions	Here the price for the interventions are calculated. More measures installed in an intervention are cheaper than installing them in separate interventions. This effect works only for more at least 3 measures or more installed by multi supply chain
prices of interventions[SC type,g]	prices for individual measures[SC type,glazing]*(1-measures discount by combination[SC type,one])/ interventions per measure	GBP/Interventions	Here the price for the interventions are calculated. More measures installed in an intervention are cheaper than installing them in separate interventions. This effect works only for more at least 3 measures or more installed by multi supply chain
prices of interventions[SC type,b]	prices for individual measures[SC type,boiler]*(1-measures discount by combination[SC type,one])/ interventions per measure	GBP/Interventions	Here the price for the interventions are calculated. More measures installed in an intervention are cheaper than installing them in separate interventions. This effect works only for more at least 3 measures or more installed by multi supply chain

prices of interventions[SC type,gb]	(prices for individual measures[SC type,glazing]+prices for individual measures[SC type,boiler])* (1-measures discount by combination[SC type,two])/interventions per measure	GBP/Interventions	Here the price for the interventions are calculated. More measures installed in an intervention are cheaper than installing them in separate interventions. This effect works only for more at least 3 measures or more installed by multi supply chain
prices of interventions[SC type,gl]	(prices for individual measures[SC type,glazing]+prices for individual measures[SC type,loft])* (1-measures discount by combination[SC type,two])/interventions per measure	GBP/Interventions	Here the price for the interventions are calculated. More measures installed in an intervention are cheaper than installing them in separate interventions. This effect works only for more at least 3 measures or more installed by multi supply chain
prices of interventions[SC type,gi]	(prices for individual measures[SC type,glazing]+prices for individual measures[SC type,insulation])* (1-measures discount by combination[SC type,two])/interventions per measure	GBP/Interventions	Here the price for the interventions are calculated. More measures installed in an intervention are cheaper than installing them in separate interventions. This effect works only for more at least 3 measures or more installed by multi supply chain
prices of interventions[SC type,bl]	(prices for individual measures[SC type,loft]+prices for individual measures[SC type,boiler])* (1-measures discount by combination[SC type,two])/interventions per measure	GBP/Interventions	Here the price for the interventions are calculated. More measures installed in an intervention are cheaper than installing them in separate interventions. This effect works only for more at least 3 measures or more installed by multi supply chain
prices of interventions[SC type,bi]	(prices for individual measures[SC type,insulation]+prices for individual measures[SC type,boiler])* (1-measures discount by combination[SC type,two])/interventions per measure	GBP/Interventions	Here the price for the interventions are calculated. More measures installed in an intervention are cheaper than installing them in separate interventions. This effect works only for more at least 3 measures or more installed by multi supply chain
prices of interventions[SC type,li]	(prices for individual measures[SC type,loft]+prices for individual measures[SC type,insulation])* (1-measures discount by combination[SC type,two])/interventions per measure	GBP/Interventions	Here the price for the interventions are calculated. More measures installed in an intervention are cheaper than installing them in separate interventions. This effect works only for more at least 3 measures or more installed by multi supply chain
prices of interventions[SC type,gbli]	(prices for individual measures[SC type,glazing]+prices for individual measures[SC type,boiler]+ prices for individual measures[SC type,loft]+prices for individual measures [SC type,insulation])* (1-measures discount by combination[SC type,four])/interventions per measure	GBP/Interventions	Here the price for the interventions are calculated. More measures installed in an intervention are cheaper than installing them in separate interventions. This effect works only for more at least 3 measures or more installed by multi supply chain
prices of interventions[SC type,gbl]	(prices for individual measures[SC type,glazing]+ prices for individual measures[SC type,boiler]+ prices for individual measures[SC type,loft])* (1-measures discount	GBP/Interventions	Here the price for the interventions are calculated. More measures installed in an intervention are cheaper than installing them in separate interventions. This effect works only for more at least 3 measures or more installed by multi supply chain

	by combination[SC type,three])/interventions per measure		
prices of interventions[SC type,gbi]	(prices for individual measures[SC type,glazing]+ prices for individual measures[SC type,boiler]+ prices for individual measures[SC type,insulation])* (1-measures discount by combination[SC type,three])/interventions per measure	GBP/Interventions	Here the price for the interventions are calculated. More measures installed in an intervention are cheaper than installing them in separate interventions. This effect works only for more at least 3 measures or more installed by multi supply chain
prices of interventions[SC type,gli]	(prices for individual measures[SC type,glazing]+ prices for individual measures[SC type,loft]+ prices for individual measures[SC type,insulation])* (1-measures discount by combination[SC type,three])/interventions per measure	GBP/Interventions	Here the price for the interventions are calculated. More measures installed in an intervention are cheaper than installing them in separate interventions. This effect works only for more at least 3 measures or more installed by multi supply chain
prices of interventions[SC type,bli]	(prices for individual measures[SC type,boiler]+ prices for individual measures[SC type,loft]+ prices for individual measures[SC type,insulation])* (1-measures discount by combination[SC type,three])/interventions per measure	GBP/Interventions	Here the price for the interventions are calculated. More measures installed in an intervention are cheaper than installing them in separate interventions. This effect works only for more at least 3 measures or more installed by multi supply chain
prices of interventions[SC type,n]	0*prices for individual measures[SC type,boiler]/interventions per measure	GBP/Interventions	Here the price for the interventions are calculated. More measures installed in an intervention are cheaper than installing them in separate interventions. This effect works only for more at least 3 measures or more installed by multi supply chain
profit by measures	SUM(extents distribution in measures demand[SC type,extent!,measures]* (1-measures discount by combination[SC type,extent!])* avg profit per measure installed[measures])	GBP/measures	The profit can be different if more measures are installed in only one intervention (they may cost less). This variable take this effect into account. Therefore sum all the profits that are done by measure also if installed in combination with other measures
profit margin	0.2	Dmnl	On the cost of a measure this is the profit margin that installers apply
profit per measure for manufacturer	avg profit per measure installed[measures]	GBP/measures	This variable is just to show that to the average profit per measure installed correspond a profit for the manufacturers that produce the retrofit measures. Considering the manufacturers is important since they are the one who make investments in technology and offer training courses
projected change in demand	(projected demand[SC type,measures]-retrofit demand by measures[SC type,measures])	measures/Month	The projected demand is compared with the actual demand in order to assess if future demand will be higher or lower than the actual
projected demand	FORECAST(perceived demand[SC type,measures], avg time for WF adjustment forecasts, workforce adjustment horizon)	measures/Month	Then with the function FORECAST the perceived demand is projected in the future in order to see what is likely to be the demand value in in a future time horizon
projected profit rate from change in demand	projected change in demand[SC type,measures]*profit by measures[SC type,measures]	GBP/Month	Here the profit by measure is multiplied by the future projected demand in order to estimate the future projected profit due to variation in demand (therefore gains or losses)

projected retiring	retirement rate[SC type,measures]*workforce adjustment horizon	workers	Here the retirement rate is multiplied by the workforce adjustment horizon in order to obtain a sort of prediction of the future amount of workers retiring in the time span of the adjustment horizon
projected return from investing	MAX(0,projected profit rate from change in demand[SC type,measures])* desired payback time for workforce investments* trust of industry[measures]	GBP	Here the projected profit returns are calculated based on the desired payback time and adjusted to the trust of industry
projected wage costs	avg worker wage*workforce adjustment horizon	GBP/workers	Here the projected wage cost for the considered time horizon are calculated
quality standards for installations	1	Dmnl	This is the quality of intervention the system aims for. One is the maximum quality possible
re-getting susceptible	non-susceptible stock /latency	households/Month	Flow of households that have done a renovation and that get back to be susceptible to do another renovation
readiness to shift from single to multi	0.1	1/Month	This variable represents the speed to which installers in the single supply chain move to the multi one. It is an educated guess made by researchers
rebound effect	0	Dmnl	Switch to activate the rebound effect
REF avg energy consumption per household	GET XLS DATA('energy.xlsx', 'Sheet1' , 'A' , 'D2')	kWh/ (Month* households)	Data on the average energy consumption retrieved from Palmer & Cooper, 2013 [Source: report released by DECC/BEIS: 'United Kingdom housing energy fact file 2013']
REF cavity insulations	GET XLS DATA('energy.xlsx', 'Sheet1' , 'A' , 'E2')	measures	The data obtained for cavity wall insulation have been integrated in the model, so when the cavity wall scenario runs they can be taken into account when it is needed
REF installed measures[glazing]	GET XLS DATA('energy.xlsx', 'Sheet1' , 'A' , F2')	measures	These are the real numbers of the retrofit uptake rate. These estimations are based on two report released by DECC/BEIS: 'United Kingdom housing energy fact file 2013' and 'Households energy efficiency national statistics. Detailed report 2016'. Integrated with I. Hamilton (2014) 'Uptake of energy efficiency interventions in English dwellings'
REF installed measures[loft]	GET XLS DATA('energy.xlsx', 'Sheet1' , 'A' , 'G10')	measures	These are the real numbers of the retrofit uptake rate. These estimations are based on two report released by DECC/BEIS: 'United Kingdom housing energy fact file 2013' and 'Households energy efficiency national statistics. Detailed report 2016'. Integrated with I. Hamilton (2014) 'Uptake of energy efficiency interventions in English dwellings'
REF installed measures[insulation]	IF THEN ELSE(cavity wall scenario<0.5, REF solid insulation, REF cavity insulations)	measures	These are the real numbers of the retrofit uptake rate. These estimations are based on two report released by DECC/BEIS: 'United Kingdom housing energy fact file 2013' and 'Households energy efficiency national statistics. Detailed report 2016'. Integrated with I. Hamilton (2014) 'Uptake of energy efficiency interventions in English dwellings'
REF installed measures[boiler]	GET XLS DATA('energy.xlsx', 'Sheet1' , 'A' , 'H2')	measures	These are the real numbers of the retrofit uptake rate. These estimations are based on two report released by DECC/BEIS: 'United Kingdom housing energy fact file 2013' and 'Households energy efficiency national statistics. Detailed report 2016'. Integrated with I. Hamilton (2014) 'Uptake of energy efficiency interventions in English dwellings'
REF solid insulation	GET XLS DATA('energy.xlsx', 'Sheet1' , 'A' , 'I10')	measures	The data obtained for solid wall insulation have been integrated in the model, so when the cavity wall scenario runs they can be taken into account when it is needed

reference accumulated measures for credibility	5e+007	measures	After this a reference number of retrofit measures installed is passed, credibility is positively affected. Otherwise credibility is lower since this positive size effect is not activated yet
reference avg homeowners property sales	674812/12	households/Month	Monthly number of property sales to homeowners per month. Source: House Price Statistics for Small Areas in England and Wales: 1995 to 2014 https://www.ons.gov.uk/peoplepopulationandcommunity/housing/bulletins/housepricestatisticsforsmallareasinenglandandwales/2015-06-24
reference behavioural compliance	0.9	Dmnl	Reference ability of households to use the retrofit measures installed in the correct way. Educated guess made by researchers
reference consumption for non-retrofitted households 2000	1800	kWh/Month/ households	We get this value for reference energy consumption of non-retrofitted houses by imposing that the energy consumption estimated on the base of installed measures in 2000 is equal to that reported in: 'United Kingdom housing energy fact file 2013'
reference costs for individual measures	reference prices for individual measure[measures]*(1-profit margin)	GBP/measures	The real costs for suppliers are unknown. Since only the final prices for homeowners are known, these have been multiplied by (1-profit margin), in which the profit margin is the profit that installers apply to their costs, in order to estimate the costs for installers through a reasonable backwards process
reference energy savings by measure[SC type,loft]	300/12	kWh/Month/ measures	Reference energy savings by measure per month. Source: DECC/BEIS report: 'NATIONAL ENERGY EFFICIENCY DATA-FRAMEWORK Summary of analysis using the National Energy Efficiency Data-Framework (NEED)' June 2016
reference energy savings by measure[SC type,insulation]	cavity wall scenario*cavity wall savings+ (1-cavity wall scenario)*solid wall savings	kWh/Month/ measures	Reference energy savings by measure per month. Source: DECC/BEIS report: 'NATIONAL ENERGY EFFICIENCY DATA-FRAMEWORK Summary of analysis using the National Energy Efficiency Data-Framework (NEED)' June 2016
reference energy savings by measure[SC type,boiler]	1200/12	kWh/Month/ measures	Reference energy savings by measure per month. Source: DECC/BEIS report: 'NATIONAL ENERGY EFFICIENCY DATA-FRAMEWORK Summary of analysis using the National Energy Efficiency Data-Framework (NEED)' June 2016
reference energy savings by measure[SC type,glazing]	600/12	kWh/Month/ measures	Reference energy savings by measure per month. Source: DECC/BEIS report: 'NATIONAL ENERGY EFFICIENCY DATA-FRAMEWORK Summary of analysis using the National Energy Efficiency Data-Framework (NEED)' June 2016
reference expenditures for renovations	42000	GBP/Interventions	Data retrieved from the grey literature. Source: UK Houzz & Home 2016 (p.6) http://info.houzz.com/rs/804-JLJ-529/images/UK_%20Houzz%20%26%20Home.pdf This is in line with another source in the grey literature: http://www.homeadvisor.com/cost/additions-and-remodels/remodel-multiple-rooms/ However, there are different data from EST Trigger Point Report (2015): upper bound 10'000 GBP
reference hassle factor per interventions[SC type,n]	0	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)

reference hassle factor per interventions[SC type,g]	reference hassle factor per measure[glazing]	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)
reference hassle factor per interventions[SC type,b]	reference hassle factor per measure[boiler]	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)
reference hassle factor per interventions[SC type,l]	reference hassle factor per measure[loft]	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)
reference hassle factor per interventions[SC type,i]	reference hassle factor per measure[insulation]	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)
reference hassle factor per interventions[single,gb]	reference hassle factor per measure[glazing]+ reference hassle factor per measure[boiler]	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)
reference hassle factor per interventions[single,gl]	reference hassle factor per measure[glazing]+ reference hassle factor per measure[loft]	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)
reference hassle factor per interventions[single,gi]	reference hassle factor per measure[glazing]+ reference hassle factor per measure[insulation]	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)

reference hassle factor per interventions[single,bl]	reference hassle factor per measure[boiler]+ reference hassle factor per measure[loft]	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)
reference hassle factor per interventions[single,bi]	reference hassle factor per measure[boiler]+ reference hassle factor per measure[insulation]	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)
reference hassle factor per interventions[single,li]	reference hassle factor per measure[loft]+ reference hassle factor per measure[insulation]	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)
reference hassle factor per interventions[single,gbl]	reference hassle factor per measure[glazing]+ reference hassle factor per measure[boiler]+reference hassle factor per measure[loft]	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)
reference hassle factor per interventions[single,gbi]	reference hassle factor per measure[glazing]+ reference hassle factor per measure[boiler]+ reference hassle factor per measure[insulation]	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)
reference hassle factor per interventions[single,gli]	reference hassle factor per measure[glazing]+ reference hassle factor per measure[loft]+ reference hassle factor per measure[insulation]	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)
reference hassle factor per interventions[single,bli]	reference hassle factor per measure[boiler]+ reference hassle factor per measure[loft]+ reference hassle factor per measure[insulation]	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)

reference hassle factor per interventions[single,gbli]	reference hassle factor per measure[glazing]+ reference hassle factor per measure[boiler]+ reference hassle factor per measure[loft]+ reference hassle factor per measure[insulation]	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)
reference hassle factor per interventions[multi,gb]	MAX(reference hassle factor per measure[glazing], reference hassle factor per measure[boiler])	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)
reference hassle factor per interventions[multi,gl]	MAX(reference hassle factor per measure[glazing],reference hassle factor per measure[loft])	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)
reference hassle factor per interventions[multi,gi]	MAX(reference hassle factor per measure[glazing], reference hassle factor per measure[insulation])	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)
reference hassle factor per interventions[multi,bl]	MAX(reference hassle factor per measure[boiler], reference hassle factor per measure[loft])	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)
reference hassle factor per interventions[multi,bi]	MAX(reference hassle factor per measure[boiler], reference hassle factor per measure[insulation])	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)
reference hassle factor per interventions[multi,li]	MAX(reference hassle factor per measure[loft], reference hassle factor per measure[insulation])	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)

reference hassle factor per interventions[multi,gbl]	MAX(reference hassle factor per measure[glazing], MAX(reference hassle factor per measure[boiler], reference hassle factor per measure[loft]))	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)
reference hassle factor per interventions[multi,gbi]	MAX(reference hassle factor per measure[glazing], MAX(reference hassle factor per measure[boiler], reference hassle factor per measure[insulation]))	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)
reference hassle factor per interventions[multi,gli]	MAX(reference hassle factor per measure[glazing], MAX(reference hassle factor per measure[boiler], reference hassle factor per measure[loft]))	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)
reference hassle factor per interventions[multi,bli]	MAX(reference hassle factor per measure[boiler], MAX(reference hassle factor per measure[loft], reference hassle factor per measure[insulation]))	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)
reference hassle factor per interventions[multi,gbli]	MAX(reference hassle factor per measure[glazing], MAX(reference hassle factor per measure[boiler], MAX(reference hassle factor per measure[loft], reference hassle factor per measure[insulation])))	Dmnl	The hassle factor calculated per intervention and supply chain type. In single supply chain the hassle factor is the sum of the hassle factors related to the measure installed, while in multi it is the higher hassle factor among the measure installed. This because in single there are different installer for different measures (with each relative hassle factor related), while in multi there is only one installer for all the measures (everything is done at the same moment, lowering the hassle)
reference hassle factor per measure[glazing]	0.3	Dmnl	From a conversation with Mike Gentry: solid wall is the measure that creates way most hassle, cavity wall is generally easy to do (except for flats, that might be difficult), double glazing has a relative significant amount of hassle (although it is sold as a no hassle measure), boilers' low hassle and loft insulation is slightly more than cavity wall
reference hassle factor per measure[boiler]	0.3	Dmnl	From a conversation with Mike Gentry: solid wall is the measure that creates way most hassle, cavity wall is generally easy to do (except for flats, that might be difficult), double glazing has a relative significant amount of hassle (although it is sold as a no hassle measure), boilers' low hassle and loft insulation is slightly more than cavity wall
reference hassle factor per measure[insulation]	5*(1-cavity wall scenario)+ 0.3*cavity wall scenario	Dmnl	From a conversation with Mike Gentry: solid wall is the measure that creates way most hassle, cavity wall is generally easy to do (except for flats, that might be difficult), double

			glazing has a relative significant amount of hassle (although it is sold as a no hassle measure), boilers' low hassle and loft insulation is slightly more than cavity wall
reference hassle factor per measure[loft]	0.4	Dmnl	From a conversation with Mike Gentry: solid wall is the measure that creates way most hassle, cavity wall is generally easy to do (except for flats, that might be difficult), double glazing has a relative significant amount of hassle (although it is sold as a no hassle measure), boilers' low hassle and loft insulation is slightly more than cavity wall
reference indoor temperature	20	°	The average reference temperature in the UK houses. Educated guess made by researchers
reference max added value	0.03	Dmnl	The maximum possible added value to a property a measure can have for non-financial reasons. Educated guess made by researchers
reference non-financial attractiveness per measure [glazing]	15		To each measure a reference non-financial attractiveness has been given. This value aggregate aesthetics and thermal comfort. It is a dimensionless value because what is important for the model is the relative value compared to other measure. The values are given based on a interview with Mike Gentry from BEIS
reference non-financial attractiveness per measure [boiler]	2		To each measure a reference non-financial attractiveness has been given. This value aggregate aesthetics and thermal comfort. It is a dimensionless value because what is important for the model is the relative value compared to other measure. The values are given based on a interview with Mike Gentry from BEIS
reference non-financial attractiveness per measure [insulation]	cavity wall scenario+ (1+STEP(step in solid non-financial attractiveness ,240))*(1-cavity wall scenario)		To each measure a reference non-financial attractiveness has been given. This value aggregate aesthetics and thermal comfort. It is a dimensionless value because what is important for the model is the relative value compared to other measure. The values are given based on a interview with Mike Gentry from BEIS
reference non-financial attractiveness per measure [loft]	1	Dmnl	To each measure a reference non-financial attractiveness has been given. This value aggregate aesthetics and thermal comfort. It is a dimensionless value because what is important for the model is the relative value compared to other measure. The values are given based on a interview with Mike Gentry from BEIS
reference prices for individual measure[insulation]	IF THEN ELSE(cavity wall scenario>0.5, 500, 12000)	GBP/measures	Reference average prices retrieve from online suppliers. In line with what has been said during the workshops
reference prices for individual measure[glazing]	4000	GBP/measures	Reference average prices retrieve from online suppliers. In line with what has been said during the workshops
reference prices for individual measure[boiler]	2300	GBP/measures	Reference average prices retrieve from online suppliers. In line with what has been said during the workshops
reference prices for individual measure[loft]	400	GBP/measures	Reference average prices retrieve from online suppliers. In line with what has been said during the workshops
reference reactiveness of house prices	0.05	1/Month	This value represents the speed the housing prices adapt to changes in the market. Data were not available. It is an educated guess made by facilitators

reference renovation fraction	0.03125*0.69	1/Month	UK Houzz & Home (2015) says that 75% of houses made renovations between 2014 and 2015. If we assume this as the normal fraction we have 37.5% per year and 3.125% per month. Then we multiply by the share of the stock which is owner occupied (0.69)
reference skills of new workers	0.4	Dmnl	This value represents the skills of the new workforce hired. It is lower than the maximum since they are assumed to have no experience. Educated guess made by researchers
reference thermal comfort	1	Dmnl	The initial and reference thermal comfort is assumed to be high (1) since most homeowners are able to afford to warm adequately their house
reference time for skills acquisition	120	Month	It has been estimated by researchers that it takes 10 year to a worker to get perfectly skilled
reference workforce in the SC for renovation maintenance and improvements	330000	workers	Total workforce working in the renovation maintenance and improvements sector. Source: p.16 http://carbon.coop/sites/default/files/attachments/2016-09-12/2016%20URBED%20Tyndall%20The%20Retrofit%20factfile%20-%20facts%20and%20publications.pdf
relative importance of financial benefits	0.6	Dmnl	This weight is used to give different to financial and non-financial benefits in homeowners decision. This value is based on a conversation with Mike Gentry from BEIS
relative importance of popularity on desirability	0.4	Dmnl	How much is evaluated popularity compared to measure benefits when estimating the measure desirability (this value is close to the 'middle' since there are not many information available)
relative intervention desirability[SC type,interventions]	retrofit desirability[SC type,interventions]/SUM(retrofit desirability[SC type!,interventions!])	Dmnl	This variable calculates the relative desirability of each measure with respect of the total desirability. It is a sort of desirability distribution
reliability of EPC	0.5	Dmnl	Reliability of Energy Performance Certificate is a factor that can give more confidence on the credibility of the retrofit industry to the homeowners
renovation fraction	reference renovation fraction* impact of economic cycles on renovation fraction* impact of tax reductions on renovation fraction	1/Month	This variable is the amenity renovation fraction and accounts for all the effects
renovations	renovations without retrofit+ total retrofit interventions per month	households/Month	Flow of total renovations that are done per month
renovations tax reduction perception delay	12	Month	How much time households need to perceive a tax reduction
renovations without retrofit	demand from renovation drop out[amenity]+ hh initiating amenity only renovations-SUM(retrofit measures installed as amenity[measures!])/measures per household	households/Month	The number of amenity renovations that take place without being combined retrofit
renovators investing capacity	reference expenditures for renovations[renovation type]*flexibility for extra investment+ ease of available credit options[renovation type]	GBP/Interventions	This is the actual investing capacity for renovators willing to top up their renovation with retrofit

residential stock emissions	avg energy consumption per household*CO2 emissions per kWh*total housing stock	Kg/Month	Flow of CO2 emissions from the housing stock obtained multiplying the number of houses (housing stock) per its average energy consumption (average energy consumption per household) times the CO2 emitted per kWh. It is assumed one household per house
retirement rate	Workforce for retrofit[SC type,measures]/avg installers working time	workers/Month	The ratio between the actual workforce and the time the workers stay at work gives the retirement rate
retrofit affordability for buyers	MIN(1, XIDZ(buyers' investing capacity[SC type,interventions,buyers type], upfront cost for consumer[SC type,interventions],100))^ affordability steepness	Dmnl	The affordability function gives the fraction of the households that can afford the specific intervention in the specific type of buyers. If the buyers capacity is higher than the upfront cost, everybody can afford and the MIN function impose affordability equal to 1. If the capacity is lower than the upfront cost, the affordability is lower than one. A high affordability steepness means that even a small excess of the cost over the capacity, reduces drastically the demand and vice versa. Thanks to the XIDZ function, if the cost is zero, like in the intervention 'n', the affordability is 1, so nobody drop out
retrofit affordability for renovations[SC type,interventions,renovation type] :EXCEPT: [SC type,interventions,extension]	(1/2)* (1+TANH(affordability steepness* (1-upfront cost for consumer[SC type,interventions]/renovators investing capacity[renovation type])))	Dmnl	This tangent function is inclined by the affordability steepness and represents how much the investing capacity for retrofit of the households doing renovation is distributed among the population
retrofit affordability for renovations[SC type,interventions,extension]	1	Dmnl	This tangent function is inclined by the affordability steepness and represents how much the investing capacity for retrofit of the households doing renovation is distributed among the population
retrofit as amenity	SUM(retrofit measures installed as amenity[measures!])/measures per household	households/Month	Total retrofit measures installed for amenity reasons per households
retrofit credibility[SC type,interventions] :EXCEPT: [SC type,n]	MAX(0, MIN(1, (size effect on credibility*interventions popularity[interventions]+ effect of market fragmentation on credibility[SC type]+guarantees on retrofit performances) *reliability of EPC))	Dmnl	The credibility of the retrofit industry depends on many factors: the popularity of the intervention, on how many installation the industry has done (size effect on credibility), on the market fragmentation (the more fragmented the less credible), on guarantees on retrofit performances (insurances) and on the reliability of the Energy Performance Certificate (EPC)
retrofit credibility[SC type,n]	1	Dmnl	The credibility of the retrofit industry depends on many factors: the popularity of the intervention, on how many installation the industry has done (size effect on credibility), on the market fragmentation (the more fragmented the less credible), on guarantees on retrofit performances (insurances) and on the reliability of the Energy Performance Certificate (EPC)
retrofit demand by measures[SC type,insulation]	measures per intervention*(demand for retrofit by interventions[SC type,i]+ demand for retrofit by interventions[SC type,li]+ demand for retrofit by interventions[SC type,gi]+ demand for retrofit by	measures/Month	Total retrofit demand calculated by measure. All the intervention containing that specific measure are summed

	interventions[SC type,bi]+ demand for retrofit by interventions[SC type,gbi]+ demand for retrofit by interventions[SC type,gli]+ demand for retrofit by interventions[SC type,bli]+ demand for retrofit by interventions[SC type,gbli])		
retrofit demand by measures[SC type,loft]	measures per intervention*(demand for retrofit by interventions[SC type,l]+ demand for retrofit by interventions[SC type,li]+ demand for retrofit by interventions[SC type,gl]+ demand for retrofit by interventions[SC type,bl]+ demand for retrofit by interventions[SC type,gbl]+ demand for retrofit by interventions[SC type,gli]+ demand for retrofit by interventions[SC type,bli]+ demand for retrofit by interventions[SC type,gbli])	measures/Month	Total retrofit demand calculated by measure. All the intervention containing that specific measure are summed
retrofit demand by measures[SC type,boiler]	measures per intervention*(demand for retrofit by interventions[SC type,b]+ demand for retrofit by interventions[SC type,bl]+ demand for retrofit by interventions[SC type,gb]+ demand for retrofit by interventions[SC type,bi]+ demand for retrofit by interventions[SC type,gbl]+ demand for retrofit by interventions[SC type,gbi]+ demand for retrofit by interventions[SC type,bli]+ demand for retrofit by interventions[SC type,gbli])	measures/Month	Total retrofit demand calculated by measure. All the intervention containing that specific measure are summed
retrofit demand by measures[SC type, glazing]	measures per intervention*(demand for retrofit by interventions[SC type,g]+ demand for retrofit by interventions[SC type,gb]+ demand for retrofit by interventions[SC type,gl]+ demand for retrofit by interventions[SC type,gi]+ demand for retrofit by interventions[SC type,gbl]+ demand for retrofit by interventions[SC type,gli]+ demand for retrofit by interventions[SC type,gbi]+ demand for retrofit by interventions[SC type,gbli])	measures/Month	Total retrofit demand calculated by measure. All the intervention containing that specific measure are summed
retrofit desirability[single,interv	MAX(0, (benefits attractiveness[single,interventions]*(1-relative importance of popularity on desirability)+	Dmnl	Here all the feature of a retrofit intervention influencing its desirability are aggregated (benefits attractiveness, popularity, hassle factors, market fragmentation). The importance of popularity is weighted. The output is a number between zero and one

entions] :EXCEPT: [single,n]	interventions popularity[interventions]*relative importance of popularity on desirability)/ (1+perceived hassle factor[single,interventions])* market fragmentation)		
retrofit desirability[SC type,n]	desirability of not retrofitting	Dmnl	Here all the feature of a retrofit intervention influencing its desirability are aggregated (benefits attractiveness, popularity, hassle factors, market fragmentation). The importance of popularity is weighted. The output is a number between zero and one
retrofit desirability[multi,interventions] :EXCEPT: [multi,n]	MAX(0, (benefits attractiveness[multi,interventions]*(1-relative importance of popularity on desirability)+ interventions popularity[interventions]*relative importance of popularity on desirability)/ (1+perceived hassle factor[multi,interventions])* (1-market fragmentation))	Dmnl	Here all the feature of a retrofit intervention influencing its desirability are aggregated (benefits attractiveness, popularity, hassle factors, market fragmentation). The importance of popularity is weighted. The output is a number between zero and one
retrofit failing fractional rate	XIDZ(Failed measures[measures],total measures[measures],1)	Dmnl	Percentage of the defected measures installed and not yet fixed
retrofit measures installed as amenity	measures per household*fraction of retrofit measures installed as amenity[measures]* (hh initiating amenity only renovations+ demand from renovation drop out[amenity]+ demand from renovation drop out[efficiency])* potential fraction by measure[measures]	measures/Month	Number of measures installed per month for amenity reasons. It is calculated multiplying the fraction of retrofit measures installed as amenity by the potential for that measure still available in the housing stock and by the sum of all the possible demand for amenity renovation (households starting directly amenity renovation, households that consider to top up their amenity with retrofit but drop out the retrofit and households starting directly to do retrofit for energy efficiency reasons but drop out and therefore may consider to do an amenity renovation)
retrofit rate by intervention	MAX(0, fulfilled interventions[SC type,interventions])	Interventions/ Month	Rate of the total retrofit intervention per month
retrofit rate by measures[SC type,insulation]	(fulfilled interventions[SC type,i]+ fulfilled interventions[SC type,li]+ fulfilled interventions[SC type,gi]+ fulfilled interventions[SC type,bi]+ fulfilled interventions[SC type,gbi]+ fulfilled interventions[SC type,gli]+ fulfilled interventions[SC type,bli]+ fulfilled interventions[SC type,gbli])* measures per intervention	measures/Month	Actual retrofit installation by measure type. All the interventions containing the that specific measure are summed
retrofit rate by measures[SC type,loft]	(fulfilled interventions[SC type,l]+ fulfilled interventions[SC type,li]+ fulfilled interventions[SC type,gl]+ fulfilled interventions[SC type,bl]+ fulfilled interventions[SC type,gbl]+ fulfilled	measures/Month	Actual retrofit installation by measure type. All the interventions containing the that specific measure are summed

	interventions[SC type,gli]+fulfilled interventions[SC type,bli]+ fulfilled interventions[SC type,gbli])* measures per intervention		
retrofit rate by measures[SC type,boiler]	(fulfilled interventions[SC type,b]+ fulfilled interventions[SC type,bl]+ fulfilled interventions[SC type,gb]+ fulfilled interventions[SC type,bi]+ fulfilled interventions[SC type,gbl]+ fulfilled interventions[SC type,gbi]+ fulfilled interventions[SC type,bli]+ fulfilled interventions[SC type,gbli])* measures per intervention	measures/Month	Actual retrofit installation by measure type. All the interventions containing the that specific measure are summed
retrofit rate by measures[SC type,glazing]	(fulfilled interventions[SC type,g]+ fulfilled interventions[SC type,gb]+ fulfilled interventions[SC type,gl]+ fulfilled interventions[SC type,gi]+ fulfilled interventions[SC type,gbl]+ fulfilled interventions[SC type,gli]+ fulfilled interventions[SC type,gbi]+ fulfilled interventions[SC type,gbli])* measures per intervention	measures/Month	Actual retrofit installation by measure type. All the interventions containing the that specific measure are summed
Retrofit technology	INTEG (technology improvements[measures], 1)	Dmnl	Level of technological development. The stock is initialized with value one (it represents the actual level of technology) and it slowly increases over time
retrofit visibility[glazing]	5	Dmnl	After conversation with Mike Gentry (BEIS): glazing and boiler are two very visible and popular measure ('that's what people look at when they see a new house [...] because they interact with them), then they maybe look for loft insulation while cavity wall and solid wall are not even on the people's radar
retrofit visibility[insulation]	cavity wall scenario*0.2+ (1-cavity wall scenario)*0.8	Dmnl	After conversation with Mike Gentry (BEIS): glazing and boiler are two very visible and popular measure ('that's what people look at when they see a new house [...] because they interact with them), then they maybe look for loft insulation while cavity wall and solid wall are not even on the people's radar
retrofit visibility[boiler]	3	Dmnl	After conversation with Mike Gentry (BEIS): glazing and boiler are two very visible and popular measure ('that's what people look at when they see a new house [...] because they interact with them), then they maybe look for loft insulation while cavity wall and solid wall are not even on the people's radar
retrofit visibility[loft]	0.5	Dmnl	After conversation with Mike Gentry (BEIS): glazing and boiler are two very visible and popular measure ('that's what people look at when they see a new house [...] because they interact with them), then they maybe look for loft insulation while cavity wall and solid wall are not even on the people's radar

retrofit WF fraction	SUM(Workforce for retrofit[SC type!,measures!])/reference workforce in the SC for renovation maintenance and improvements	Dmnl	Percentage of workforce in the renovation maintenance and improvements sector that does retrofit
retrofitted fraction by measure	MIN(Installed measures[measures]/total measures[measures],1)	Dmnl	Stock fraction by measure type installed
return from not investing	MAX(0, cost of hiring[SC type,measures]* (1+(bank interest rate*TIME STEP))^ (desired payback time for workforce investments/TIME STEP))	GBP	Here the return from not investing an equivalent amount of money to the hiring costs for the considered time horizon are calculated
risk taking attitude by economic cycles	1+ economic cycles switch* fractional amplitude of economic cycles* SIN(6.28/economic cycles time*Time)	Dmnl	The economic cycles are represented as a SIN function, since it is believe that the housing market relatively regularly oscillates
SC capacity for interventions[SC type,i]	SC capacity for measures[SC type,insulation]/measures per intervention	Interventions/ Month	Supply chain capacity calculated per intervention. It is calculated based on the lower capacity available among the measures installed in the intervention. For 'n', namely doing nothing, the number is on purposely very high in order not to have no limitations for people that do not want to do anything
SC capacity for interventions[SC type,l]	SC capacity for measures[SC type,loft]/measures per intervention	Interventions/ Month	Supply chain capacity calculated per intervention. It is calculated based on the lower capacity available among the measures installed in the intervention. For 'n', namely doing nothing, the number is on purposely very high in order not to have no limitations for people that do not want to do anything
SC capacity for interventions[SC type,g]	SC capacity for measures[SC type,glazing]/measures per intervention	Interventions/ Month	Supply chain capacity calculated per intervention. It is calculated based on the lower capacity available among the measures installed in the intervention. For 'n', namely doing nothing, the number is on purposely very high in order not to have no limitations for people that do not want to do anything
SC capacity for interventions[SC type,b]	SC capacity for measures[SC type,boiler]/measures per intervention	Interventions/ Month	Supply chain capacity calculated per intervention. It is calculated based on the lower capacity available among the measures installed in the intervention. For 'n', namely doing nothing, the number is on purposely very high in order not to have no limitations for people that do not want to do anything
SC capacity for interventions[SC type,gb]	MIN(SC capacity for measures[SC type,glazing],SC capacity for measures[SC type, boiler])/ measures per intervention	Interventions/ Month	Supply chain capacity calculated per intervention. It is calculated based on the lower capacity available among the measures installed in the intervention. For 'n', namely doing nothing, the number is on purposely very high in order not to have no limitations for people that do not want to do anything
SC capacity for interventions[SC type,gl]	MIN(SC capacity for measures[SC type,glazing],SC capacity for measures[SC type,loft])/ measures per intervention	Interventions/ Month	Supply chain capacity calculated per intervention. It is calculated based on the lower capacity available among the measures installed in the intervention. For 'n', namely doing nothing, the number is on purposely very high in order not to have no limitations for people that do not want to do anything
SC capacity for interventions[SC type,gi]	MIN(SC capacity for measures[SC type,glazing],SC capacity for measures[SC type, insulation])/ measures per intervention	Interventions/ Month	Supply chain capacity calculated per intervention. It is calculated based on the lower capacity available among the measures installed in the intervention. For 'n', namely doing nothing, the number is on purposely very high in order not to have no limitations for people that do not want to do anything

SC capacity for interventions[SC type,bl]	MIN(SC capacity for measures[SC type,boiler],SC capacity for measures[SC type,loft])/ measures per intervention	Interventions/ Month	Supply chain capacity calculated per intervention. It is calculated based on the lower capacity available among the measures installed in the intervention. For 'n', namely doing nothing, the number is on purposely very high in order not to have no limitations for people that do not want to do anything
SC capacity for interventions[SC type,bi]	MIN(SC capacity for measures[SC type,boiler],SC capacity for measures[SC type,insulation])/ measures per intervention	Interventions/ Month	Supply chain capacity calculated per intervention. It is calculated based on the lower capacity available among the measures installed in the intervention. For 'n', namely doing nothing, the number is on purposely very high in order not to have no limitations for people that do not want to do anything
SC capacity for interventions[SC type,li]	MIN(SC capacity for measures[SC type,loft],SC capacity for measures[SC type,insulation])/ measures per intervention	Interventions/ Month	Supply chain capacity calculated per intervention. It is calculated based on the lower capacity available among the measures installed in the intervention. For 'n', namely doing nothing, the number is on purposely very high in order not to have no limitations for people that do not want to do anything
SC capacity for interventions[SC type,gbli]	MIN(SC capacity for measures[SC type,insulation], MIN(SC capacity for measures[SC type,loft], MIN(SC capacity for measures[SC type,boiler],SC capacity for measures[SC type,glazing])))/ measures per intervention	Interventions/ Month	Supply chain capacity calculated per intervention. It is calculated based on the lower capacity available among the measures installed in the intervention. For 'n', namely doing nothing, the number is on purposely very high in order not to have no limitations for people that do not want to do anything
SC capacity for interventions[SC type,gbl]	MIN(SC capacity for measures[SC type,glazing], MIN(SC capacity for measures[SC type,loft],SC capacity for measures[SC type,boiler]))/ measures per intervention	Interventions/ Month	Supply chain capacity calculated per intervention. It is calculated based on the lower capacity available among the measures installed in the intervention. For 'n', namely doing nothing, the number is on purposely very high in order not to have no limitations for people that do not want to do anything
SC capacity for interventions[SC type,gbi]	MIN(SC capacity for measures[SC type,insulation], MIN(SC capacity for measures[SC type,glazing],SC capacity for measures[SC type,boiler]))/ measures per intervention	Interventions/ Month	Supply chain capacity calculated per intervention. It is calculated based on the lower capacity available among the measures installed in the intervention. For 'n', namely doing nothing, the number is on purposely very high in order not to have no limitations for people that do not want to do anything
SC capacity for interventions[SC type,gli]	MIN(SC capacity for measures[SC type,insulation], MIN(SC capacity for measures[SC type,loft],SC capacity for measures[SC type,glazing]))/ measures per intervention	Interventions/ Month	Supply chain capacity calculated per intervention. It is calculated based on the lower capacity available among the measures installed in the intervention. For 'n', namely doing nothing, the number is on purposely very high in order not to have no limitations for people that do not want to do anything
SC capacity for interventions[SC type,bli]	MIN(SC capacity for measures[SC type,insulation], MIN(SC capacity for measures[SC type,loft],SC capacity for measures[SC type,boiler]))/ measures per intervention	Interventions/ Month	Supply chain capacity calculated per intervention. It is calculated based on the lower capacity available among the measures installed in the intervention. For 'n', namely doing nothing, the number is on purposely very high in order not to have no limitations for people that do not want to do anything
SC capacity for interventions[SC type,n]	(SUM(SC capacity for measures[SC type,measures!])+1e+018)/ measures per intervention	Interventions/ Month	Supply chain capacity calculated per intervention. It is calculated based on the lower capacity available among the measures installed in the intervention. For 'n', namely doing nothing, the number is on purposely very high in order not to have no limitations for people that do not want to do anything

SC capacity for measures	Workforce for retrofit[SC type,measures]*workforce productivity[SC type,measures]	measures/Month	The productivity of the two supply chain is obtained multiplying the workforce by its productivity
sense of opportunity	1-(ZIDZ(difference in prices[SC type,interventions],perceived prices of interventions for consumers [SC type,interventions]))	Dmnl	This variable accounts for homeowners appreciating a measure becoming cheaper because a change in the perceived price. This is calculated with the ZIDZ function. This ratio is subtracted to one in order to have a value between zero and one representing how this sense of opportunity is perceived
sense of opportunity to financial attractiveness elasticity	7.5	Dmnl	How much an unitary variation in sense of opportunity impact the non-financial attractiveness
size effect on credibility	accumulated measures/reference accumulated measures for credibility	Dmnl	All the measures installed are confronted with the reference accumulated number of retrofit measures installed to see if the a positive size effect on credibility is activated
skills decay	MAX(0, SUM(workforce decay[SC type!,measures])*workforce skills[measures])	workers/Month	Here the workers that retires or are fired 'bring' with them their skills. This means that there is an outflow of workers equal to the workforce decay and weighted for the skills they have (workforce skills)
solid exogenous installed measures	0	measures	Here the solid wall measures installed are calculated separately and then, when the cavity wall scenario is running, exogenously introduced in the model
solid INIT distribution	0.307	Dmnl	Fraction of houses with a solid wall. Estimation based on two report released by DECC/BEIS: 'United Kingdom housing energy fact file 2013' and 'Households energy efficiency national statistics. Detailed report 2016'. Integrated with I. Hamilton (2014) 'Uptake of energy efficiency interventions in English dwellings'
solid wall savings	2000/12	kWh/Month/ measures	Solid wall energy savings per month. Source: DECC/BEIS report: 'NATIONAL ENERGY EFFICIENCY DATA-FRAMEWORK Summary of analysis using the National Energy Efficiency Data-Framework (NEED)' June 2016
stamp duty rebate maximum fraction	1	Dmnl	This fraction represent how 'strong' the rebate is. In this case it is 100% of the stamp duty
stamp duty rebates switch	0	Dmnl	Switch to turn off and on the stamp duty rebate policy
stamp rebate starting time	216	Month	The time in the simulation in which the stamp duty rebate starts. It is set to start in 2018
stamp rebates eligible and aware fraction	buyers awareness of stamp duty rebates*fraction of buyers eligible for stamp duty rebates	Dmnl	Percentage of buyers that are eligible for a stamp duty and that are aware of the possibility to retrofit their new property with this amount of money coming from the rebate
stamp rebates eligible but not aware fraction	fraction of buyers eligible for stamp duty rebates* (1-buyers awareness of stamp duty rebates)	Dmnl	This variable represents the buyers that are eligible of a stamp duty but are not aware of the policy. It is assumed to be null since everybody is supposed to be aware of the policy
step in solid non-financial attractiveness	0	Dmnl	This variable is used to test what happen if there are remarkable changes in the measure non-financial attractiveness
stop of subsidies	0	Dmnl	This is a switch to activate or stop the subsidies

subsidies / consumer tax credit	(ECO subsidies[measures]-EEC and CERT subsidies[measures])*STEP(1,ECO start)+ EEC and CERT subsidies[measures]*STEP(1,EEC and CERT start)	Dmnl	This variable aggregates and differentiate in time all the subsidies discount to upfront costs for homeowners
subsidies stop time	216	Month	In case the stop of subsidies switch is on, this time represents the moment in which they will be stopped
summed desirability	SUM(relative intervention desirability[SC type!,interventions!])	Dmnl	Control variable so assess if the sum of all the desirability gives one
suppliers costs for individual measuress[SC type,measures]	(materials contribution to costs[SC type,measures]+labour contribution to costs [measures])* (1-VAT reductions)*reference costs for individual measures[measures]	GBP/measures	Here the fractional costs (if there is not effect in place, their sum is equal to one) are multiplied by the reference costs for individual measure in order to obtain the suppliers actual costs. A VAT reduction option is included
susceptible for renovations stock	INTEG (new susceptible homeowners' houses+ re-getting susceptible -renovations, MAX(Potential for retrofit measures to install[loft], MAX(Potential for retrofit measures to install[insulation], MAX(Potential for retrofit measures to install[boiler], Potential for retrofit measures to install[glazing])))/ measures per household)	households	Households that haven't undertake a renovation recently and that are susceptible to do a renovation
tax reduction on renovations	0	Dmnl	It has been mentioned in a workshop that a possible policy is to allow for a tax reduction on general renovation. This variable is here to test this scenario
tax reduction starting time	216	Month	This variable represents the time in which an hypothetical tax reduction on renovation starts
tax reduction to renovation fraction elasticity	0.5	Dmnl	This elasticity represents how much a tax reduction prompt homeowners to renovate more
tailored advise and smart metering[single]	0	Dmnl	Tailored installers advice and smart metering can improve the households behaviour and impact their behaviour compliance
tailored advise and smart metering[multi]	1	Dmnl	Tailored installers advice and smart metering can improve the households behaviour and impact their behaviour compliance
techno to energy savings elasticity	0.1	Dmnl	How a unitary change in technology impacts the energy savings delivered by a retrofit measure
technological improvement per investment unit	1e-008	1/GBP	This value is an educated guess made by researchers based on
technology improvements	(1-market fragmentation)* investments in technology[measures]* technological improvement per investment unit+ natural technological improvement rate	1/Month	Rate of technological improvement: it depends on the investments and on the natural technological improvement

technology to cost elasticity	0	Dmnl	How a unitary variation in technology change the material costs of a measure. Now it is assumed to be close to zero based on the inputs of Hunter Danskin (BEIS)
temperature increase per extent level	1	°	If there is a rebound effect, this variable reports the value of how much higher households will keep their indoor temperature per each additional retrofit extent installed
temperature to comfort elasticity	0.2	Dmnl	How much a unitary variation of temperature can change the comfort households perceive
temperature to energy curve	(indoor temperature by intervention[interventions]/reference indoor temperature)^ elasticity for temperature to energy curve	Dmnl	Here the variation in temperature due to the rebound effect is compared with the reference indoor temperature and then it is used to assess how much this variation impact the energy consumption
thermal comfort by intervention	reference thermal comfort* (indoor temperature by intervention[interventions]/ reference indoor temperature)^ temperature to comfort elasticity	Dmnl	Here the thermal comfort by intervention is calculated. It is obtained multiplying the reference thermal comfort by the ratio between the actual indoor temperature after an intervention and the reference indoor temperature. This ratio is elevated to the elasticity measuring changes in comfort after a unit variation in temperature
thermal comfort by measure[glazing]	XIDZ(thermal comfort by intervention[g]*estimated retrofitted fraction by intervention[g]+ thermal comfort by intervention[gb]*estimated retrofitted fraction by intervention[gb]+ thermal comfort by intervention[gl]*estimated retrofitted fraction by intervention[gl]+ thermal comfort by intervention[gi]*estimated retrofitted fraction by intervention[gi]+ thermal comfort by intervention[gbl]*estimated retrofitted fraction by intervention[gbl]+ thermal comfort by intervention[gbi]*estimated retrofitted fraction by intervention[gbi]+thermal comfort by intervention[gli]*estimated retrofitted fraction by intervention[gli]+ thermal comfort by intervention[gbli]*estimated retrofitted fraction by intervention[gbli],estimated retrofitted fraction by intervention[g]+ estimated retrofitted fraction by intervention[gb]+estimated retrofitted fraction by intervention[gl]+estimated retrofitted fraction by intervention[gi]+ estimated retrofitted fraction by intervention[gbl]+ estimated retrofitted fraction by intervention[gbi]+estimated retrofitted fraction by intervention[gli]+ estimated retrofitted fraction by intervention[gbli], reference thermal comfort)	Dmnl	Here the thermal comfort is calculated per measure starting from intervention thermal comfort, averaging all the comforts for each measure

thermal comfort by measure[boiler]	XIDZ(thermal comfort by intervention[b]*estimated retrofitted fraction by intervention[b]+ thermal comfort by intervention[gb]*estimated retrofitted fraction by intervention[gb]+ thermal comfort by intervention[bl]*estimated retrofitted fraction by intervention[bl]+ thermal comfort by intervention[bi]*estimated retrofitted fraction by intervention[bi]+ thermal comfort by intervention[gbl]*estimated retrofitted fraction by intervention[gbl]+ thermal comfort by intervention[gbi]*estimated retrofitted fraction by intervention[gbi]+ thermal comfort by intervention[bli]*estimated retrofitted fraction by intervention[bli]+ thermal comfort by intervention[gbli]*estimated retrofitted fraction by intervention[gbli], estimated retrofitted fraction by intervention[b]+ estimated retrofitted fraction by intervention[gb]+ estimated retrofitted fraction by intervention[bl]+ estimated retrofitted fraction by intervention[bi]+ estimated retrofitted fraction by intervention[gbl]+ estimated retrofitted fraction by intervention[gbi]+ estimated retrofitted fraction by intervention[bli]+ estimated retrofitted fraction by intervention[gbli], reference thermal comfort)	Dmnl	Here the thermal comfort is calculated per measure starting from intervention thermal comfort, averaging all the comforts for each measure
thermal comfort by measure[insulation]	XIDZ(thermal comfort by intervention[i]*estimated retrofitted fraction by intervention[i]+ thermal comfort by intervention[bi]*estimated retrofitted fraction by intervention[bi]+ thermal comfort by intervention[li]*estimated retrofitted fraction by intervention[li]+ thermal comfort by intervention[gi]*estimated retrofitted fraction by intervention[gi]+ thermal comfort by intervention[bli]*estimated retrofitted fraction by intervention[bli]+ thermal comfort by intervention[gbi]*estimated retrofitted fraction by intervention[gbi]+ thermal comfort by intervention[gli]*estimated retrofitted	Dmnl	Here the thermal comfort is calculated per measure starting from intervention thermal comfort, averaging all the comforts for each measure

	fraction by intervention[gli]+ thermal comfort by intervention[gbli]*estimated retrofitted fraction by intervention[gbli], estimated retrofitted fraction by intervention[i]+ estimated retrofitted fraction by intervention[bi]+ estimated retrofitted fraction by intervention[li]+ estimated retrofitted fraction by intervention[gi]+ estimated retrofitted fraction by intervention[bli]+ estimated retrofitted fraction by intervention[gbi]+ estimated retrofitted fraction by intervention[gli]+ estimated retrofitted fraction by intervention[gbli], reference thermal comfort)		
thermal comfort by measure[loft]	XIDZ(thermal comfort by intervention[l]*estimated retrofitted fraction by intervention[l]+ thermal comfort by intervention[bl]*estimated retrofitted fraction by intervention[bl]+thermal comfort by intervention[gl]* estimated retrofitted fraction by intervention[gl]+ thermal comfort by intervention[li]*estimated retrofitted fraction by intervention[li]+ thermal comfort by intervention[gbl]*estimated retrofitted fraction by intervention[gbl]+ thermal comfort by intervention[bli]*estimated retrofitted fraction by intervention[bli]+ thermal comfort by intervention[gli]*estimated retrofitted fraction by intervention[gli]+ thermal comfort by intervention[gbli]*estimated retrofitted fraction by intervention[gbli], estimated retrofitted fraction by intervention[l]+ estimated retrofitted fraction by intervention[bl]+ estimated retrofitted fraction by intervention[gl]+estimated retrofitted fraction by intervention[li]+ estimated retrofitted fraction by intervention[gbl]+ estimated retrofitted fraction by intervention[bli]+ estimated retrofitted fraction by intervention[gli]+ estimated retrofitted fraction by intervention[gbli], reference thermal comfort)	Dmnl	Here the thermal comfort is calculated per measure starting from intervention thermal comfort, averaging all the comforts for each measure

TIME STEP	0.5	Month	The time step for the simulation
total demand	demand from buyers+ demand from renovations+ demand from boiler replacements+ retrofit as amenity	households/Month	Total retrofit demand from households per month (not divided by measure or intervention type)
total housing stock	susceptible for renovations stock+ non-susceptible stock	households	It counts the total housing stock. In the model, it is static
total measures	Potential for retrofit measures to install[measures]+Installed measures[measures]+Failed measures[measures]	measures	Total measure that are installed, possible to installed or failed
total potential demand from renovation	SUM(potential demand from renovations[renovation type!])	households/Month	Total demand arising from the of all the type households willing to top up their renovation with energy efficiency
total retrofit interventions per month	(SUM(retrofit rate by intervention[SC type!,interventions!])-SUM(retrofit rate by intervention[SC type!,n]))*households per interventions	households/Month	Total number of retrofit intervention undertaken per month
total WF	SUM(Workforce for retrofit[SC type!,measures])	workers	Sum of the multi and single supply chain per measure
training costs for junior	2000	GBP/workers	Educated guess made by researchers on the cost of training new hired workforce
training time	6	Month	Educated guess on how much time is needed to train workforce
trust of industry	MAX(0,MIN(1, SMOOTH(Popularity of measures[measures],industry trust building time)* risk taking attitude by economic cycles*policy coherence))	Dmnl	This value between one and zero represents the level of trust the industry have on the potential of the sector. This trust depend on the popularity of retrofit and it is perceived as an informational delay. However, this potential is dampened by the policy coherence: if investors perceive there is no coherence in the policies applied to the retrofit sector, they see the sector as unstable (e.g. first there are subsidies and then they are erased). Economic cycles can have an impact on investors
upfront cost for consumer	prices of interventions[SC type,interventions]	GBP/Interventions	These are the actual costs that homeowners face when they have to decide whether retrofit or not
VAT reductions	0	Dmnl	This is a possible police discussed in the workshop. It consists on decreasing the VAT taxation on retrofit measure in order to ultimately decrease the upfront cost for homeowners
weighted energy savings from alternative insulation	alternative insulation retrofitted fraction* alternative insulation INIT distribution* alternative insulation energy savings	kWh/Month/ measures	If the model simulates the cavity wall scenario, then this variable reports the energy savings over time for solid wall in order to include them in the energy savings calculation. On the contrary ,if the model simulates the solid wall scenario
weighted energy savings from simulated installed measures	SUM(INIT measures distribution[measures!]* expected energy savings by measure[SC type!,measures!]* retrofitted fraction by measure[measures!]* measures energy efficiency performance[measures!])/ELMCOUNT(SC type)	kWh/Month/ measures	Here the energy savings due to the measure installed in the stock are calculated

willingness of mortgage borrowers to take a conditional mortgage	1	Dmnl	Percentage of mortgage borrowers that are willing to accept the lenders offer of a conditional mortgage to retrofit the low EPC property they are buying
willingness of mortgage borrowers to take an additional mortgage	1	Dmnl	Percentage of mortgage borrowers that are willing to accept the lenders offer of additional cash on the initial mortgage to retrofit their new property
workforce adjustment for backlog	MAX(0,Accumulated capacity gap for measures[SC type,measures]/workforce productivity[SC type,measures]/ adjustment time for backlog)	workers	The ratio between the accumulated capacity gap and the workforce productivity gives the amount of workforce needed to close the capacity gap. This is divided by the time the supply chain need to hire this 'missing' workforce
workforce adjustment horizon	12	Month	The reference time the supply chain use as horizon to estimate what size the future workforce should be. It is equivalent to the time supply chain needs to adjust the workforce in excess. Educated guess made by researchers
workforce adjustment time	6	Month	The time the industry needs to adjust the workforce to the projections and needs of the market. The value is an educated guess made by researchers since no data were available. It has been estimated to be six months
workforce decay	IF THEN ELSE(Workforce for retrofit[SC type,measures]>0, retirement rate[SC type,measures]+ firing aggressiveness* desired lay-offs [SC type,measures]/ workforce adjustment horizon, 0)	workers/Month	The workforce decay comprehend the retirement rate and the people that are fired because in future they seem not to be needed (this firing process depends on the firing aggressiveness of the supply chain and on the time horizon supply chain use to estimate workforce adjustments)
Workforce for retrofit[single,measures]	INTEG (-from single to multi SC flow[measures]+workforce growth[single,measures]- workforce decay[single,measures], initial market fragmentation*INIT installed fraction[measures]*initial total WF)	workers	Total retrofit workforce by type (single or multi installers)
Workforce for retrofit[multi,measures]	INTEG (from single to multi SC flow[measures]+workforce growth[multi,measures]-workforce decay[multi,measures], (1-initial market fragmentation)*INIT installed fraction[measures]*initial total WF)	workers	Total retrofit workforce by type (single or multi installers)
workforce growth	(investment effort in workforce[SC type,measures]* desired hiring[SC type,measures]/workforce adjustment time+ workforce adjustment for backlog[SC type,measures]/workforce adjustment time)	workers/Month	This flow represents the increase in the retrofit workforce for both single and multi supply chain. It depends on the investments done in the supply chain multiplied by the desired hiring (this is a workforce expansion due to future projected profits). To this it is summed the workforce needed to cover any eventual backlog
workforce productivity	10	measures/workers/ Month	The value is an educated guess made by researchers since no data were available

workforce reference for economy of scale	INITIAL(total WF[measures])	workers	Workforce is a proxy for accounting the supply chain size. This value is a reference value after which the economy of scale starts to play a role
workforce skills	MIN(1, Workforce weighted by skills[measures]/total WF[measures])	Dmnl	Here the workforce weighted by skill is divided by the total workforce available, in order to calculate the average total workforce skills
workforce threshold for marketing	30000	workers	Once the workforce employed for a specific measure exceed this number, the different actors in the supply chain start to compete and to initiate marketing initiatives. Educated guess made by researchers based on the inputs of BEIS experts
workforce training	MAX(0, effort intensity in training[measures]*total WF[measures]* perceived gap in quality[measures]/training time)	workers/Month	This inflow represents the increase workforce skills: this inflow of workers trained to close the quality gap goes into the stock and increases the workforce weighted by skills
Workforce weighted by skills	INTEG (contribution to skills of newly hired[measures]+learning by experience[measures]+workforce training[measures]-skills decay[measures], reference skills of new workers*SUM(Workforce for retrofit[SC type!,measures]))	workers	Here the total workforce is weighted by the skills they have. If the workforce has maximum skills (namely one) this number is equal to the total workforce, otherwise it is lower

External .xlsx file

An external Microsoft Excel (.xlsx format) file named ‘energy’ was used to support with external data the model. Below are reported all the data in the file, necessary to replicate the simulations. Important is to remember to place this data in a sheet named ‘Sheet1’

Time step	Year	GBP/kWh	Avg energy consumption	Cavity homeowners	Glazing homeowners	Loft homeowners	Boiler homeowners	Solid homeowners	Retrofitted fraction by measure	Popularity of measures	Installed measures
0	2000	0,04	1740,586271	3919200	8583600		305522,693		0,31400001	0,31400001	3916835,75
12	2001	0,0353	1789,891832	3919200	9232200		412189,4067		0,349683374	0,31465286	4361950
24	2002	0,0356	1763,599137	4112400	9887700		613412,5831		0,390242457	0,316252232	4867884
36	2003	0,0346	1794,152994	4422900	10534332,79		1061722,381		0,430651426	0,318367183	5371945,5
48	2004	0,0407	1832,782362	4830000	11224549,45		1210719,916		0,469188511	0,32087639	5852657
60	2005	0,0423	1775,998257	4954200	11788165,1		2067383,933		0,505629182	0,323698282	6307218
72	2006	0,0503	1730,282753	5506200	12784816,63		3627136,616		0,538158238	0,32676065	6712985
84	2007	0,0521	1669,247022	6023700	13408428,31		5175016,791		0,567193627	0,329393278	7075173
96	2008	0,0628	1686,666667	7113900	14593500	7196700	5422861,371	46230	0,593389392	0,333338767	7401940
108	2009	0,0634	1597,222222	7631400	15048900	7748700	7917565,602	52440	0,617305219	0,33675009	7700266
120	2010	0,0614	1801,666667	8155800	15400800	7748700	10425765,26	66930	0,639278233	0,340191752	7974356,5
132	2011	0,0646	1443,888889	8576700	15642300	8838900	12513956,48	72450	0,65963161	0,343634278	8228245
144	2012	0,0646	1603,200135	8431800				93840	0,678509116	0,347056627	8463723
156	2013	0,0646		8286900		10252710		145590	0,695413888	0,350445688	8674592
168	2014	0,0646		8558070		10413480		411930	0,710848927	0,353796601	8867129
180	2015	0,0646		8841660		10642560		446430	0,725559652	0,357097387	9050630
192	2016	0,0646		9039690		10786080		479550	0,739589989	0,360336214	9225644
204	2017	0,0646		9214950		10924770		500250	0,752749681	0,36350733	9389797
216	2018	0,0646							0,765136063	0,36660701	9544305
228	2019	0,0646							0,776827812	0,369632244	9690148
240	2020	0,0646							0,7881037	0,372579455	9830804
252	2021	0,0646							0,798924148	0,375443667	9965779
264	2022	0,0646							0,80915755	0,378223509	10093431
276	2023	0,0646							0,818910658	0,380918473	10215093
288	2024	0,0646							0,828229189	0,383526921	10331332
300	2025	0,0646							0,837067783	0,386048555	10441584
312	2026	0,0646							0,845449686	0,388484001	10546140
324	2027	0,0646							0,853400171	0,390833735	10645314
336	2028	0,0646							0,860942662	0,393098772	10739399
348	2029	0,0646							0,867482662	0,395283699	10820978
360	2030	0,0646							0,873610854	0,397396624	10897422
372	2031	0,0646							0,879471064	0,399438053	10970521
384	2032	0,0646							0,885076165	0,401408583	11040439
396	2033	0,0646							0,890437543	0,403309226	11107317
408	2034	0,0646							0,895564795	0,405141115	11171274
420	2035	0,0646							0,900466979	0,406905413	11232425
432	2036	0,0646							0,905152977	0,408603311	11290879
444	2037	0,0646							0,909631014	0,41023615	11346739
456	2038	0,0646							0,913909197	0,411805511	11400104
468	2039	0,0646							0,917995393	0,413312912	11451076
480	2040	0,0646							0,921897233	0,414759394	11499749
492	2041	0,0646							0,925622165	0,416148514	11546213
504	2042	0,0646							0,929177344	0,417480171	11590560
516	2043	0,0646							0,932569742	0,418756664	11632877
528	2044	0,0646							0,935806096	0,419979781	11673248
540	2045	0,0646							0,93889302	0,42115128	11711754
552	2046	0,0646							0,941836715	0,422272921	11748475
564	2047	0,0646							0,944643259	0,42334643	11783484
576	2048	0,0646							0,947318733	0,424373567	11816856
588	2049	0,0646							0,949868619	0,425356001	11848664
600	2050	0,0646							0,952298641	0,42629537	11878973