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Eco-innovations in companies - The case of introducing a battery storage system at EDP

Niklas Benedikt Westerbeck – Student Number: 2309

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Professor *Youtha Cuypers*

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Abstract

In the work 'Eco-innovations in companies - The case of introducing a battery storage system at EDP' a model was developed in order to assess the viability of such a PV-coupled battery storage project. European regulations pressure EDPD to shift away from fossil energies to renewable energy sources. Therefore, EDPD thinks about introducing a PV-coupled battery storage system in their service building in Evora in order to increase its efficiency. Although the developed model shows that this project is not viable from a financial viewpoint, other aspects such as the learning opportunities would support such a pilot. Furthermore, input prices are expected to decrease over the next years, making battery storage systems a viable solution in the near future. The project is assessed from the more theoretical point of view of eco-innovation and what key drivers motivate companies to engage in environmental friendly innovations.

- Eco-innovation
- Battery storage system
- Building efficiency

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1. BRIEF CONTEXT

a. Client

Energias de Portugal (EDP) is a vertically integrated utility corporation. EDP acts as the major electricity generator, distributor and retailer in Portugal and ranks as the third largest player in the Iberian Peninsula. It is present in 14 countries and its nearly 12,000 employees serve 9.7 million electricity customers (EDP, 2015).

EDP Distribuição (EDPD) is the subsidiary of EDP, which distributes low, medium and high voltage electricity in Portugal. EDPD manages the grid under 278 low voltage concessions and a high/medium voltage concession during 35 years, renewed in 2009. Its responsibility is to ensure to customers the supply and quality of energy, grid management and commercialization options. Additionally, the activity's remuneration is regulated by Entidade Reguladora dos Serviços Energéticos (ERSE). Moreover, EDPD plays a crucial role as the facilitator of the energy sector development, promoting initiatives such as electrical vehicles, smart grid implementation or matters such as the analysis conducted on this report – the study of self-consumption solar energy optimization.

b. Market overview

EDPD is mainly operating in the Portuguese electricity market; one that is highly influenced by European regulations and directives. Environmental concerns regarding global warming led to new regulatory guidelines influencing the electricity production. Overall the global electricity market is under a severe transformation, shifting away from fossil energy production towards renewable sources of energy such as photovoltaic (PV) and wind generated electricity. These developments are affecting the business models of European and Portuguese utility companies. The integrated energy and climate change strategy adopted by the European Commission in 2008 sets the goals to reduce greenhouse emission by at least 20%, increase the share of renewable energy by at least 20%, and achieve energy savings of 20% or more by 2020 in the European Union (EU). In the longer term, by 2030, renewable energy should reach a share of 27% of the overall energy consumption (European Commission, 2016; Eurostat, 2016). The EU therefore published a priority list and especially wants to foster building efficiency and the deployment of PV modules and battery storage in order to increase total renewable energy production. Overall, renewables covered already 15% of the total energy consumption in the EU in 2015 where renewables in Portugal already had a share of 23.5%. The share of PV generated electricity of the overall renewable electricity production increased tremendously from only 0.1% in 2003 to 9.6% in 2013 but is still ranked behind wind generated energy (26.5%) and biomass (17.8%) (Eurostat, 2016). In 2014, 88.6 gigawatts (GW) of solar generated energy were produced in the EU. Portugal only covers 0.5% of the total production but experienced a phase of high growth from only 50 megawatts (MW) in 2008 to 400 MW's in 2014 (see appendix 1). For this project, also the two markets of PV modules and storage battery systems and their technological specifications as well as expected developments were important (see Appendix 14.1 - 14.5).

c. Current client situation

The consequences for EDPD of the current changes in the electricity markets and especially the EU 2020 climate goals of reducing greenhouse emissions significantly are twofold. First of all, the overall production of renewable energy increased significantly over the past years and is expected to grow further. Although growing PV production has a positive effect on the environment, the intermittent renewable energy sources result in highly volatile energy production. As electrical grids need a balance between supply and demand to function properly, renewable energy is threatening this balance leading to fragility in the grid network (ENEA, 2012). This leads to challenges for EDPD as the grid infrastructure is fundamental for

EDPD's electricity distribution business and thus they also need to maintain the grid quality (EDP, 2016). EDPD would need to invest into upgrading or redesigning their infrastructure in order to cope with this challenge. Secondly, EDPD itself needs to reduce emissions. As buildings account for approximately 40% of the total global energy consumption, EDPD is mainly focusing on improving the energy efficiency of its service buildings. They therefore installed PV modules for self consumption on some of their buildings and, coupled with other improvement initiatives, were able to increase the energy efficiency classification of those.

d. The Business Project challenge

In order to further improve their service building efficiency, EDPD is also looking for innovative solutions in the market. Until now EDPD mainly focused on deploying PV modules on their service buildings in order to generate renewable energy. This poses a drawback as sometimes PV modules generate more electricity than can be used for self consumption. This would not be a problem for a private consumer as they are granted feed-in tariffs, meaning they get a monetary reward when injecting PV generated electricity into the grid network. EDPD is not granted this benefit and therefore injects PV generated electricity into the grid without getting compensated, thus wasting valuable energy. The battery storage technology is a new development in the market and can solve this issue as it stores energy for later use instead of injecting it into the grid. It can store electricity in times of high energy production and discharge itself when the load of the building is higher than the energy production of the PV modules and therefore better utilizes the PV generated energy. Furthermore, battery system can be a solution to the problem of volatile energy production of renewable energy sources. As storage batteries capture surplus electricity (load – PV production) it allows for a stabilization of the network as less energy in excess of aggregate demand will be injected into the grid at peak hours. This mechanism is called peak shaving and can minimize grid maintenance costs and the necessity of investing in further grid reinforcements as the total volatility is lowered. It is also relevant to the project itself as peak shaving allows for the stabilization of PV production and a higher percentage of local usage of PV generated energy.

In order to test he viability of such a PV coupled battery storage system, EDPD provided data for PV production, underlying electricity prices, needed investments as well as consumption (load) of the building itself. The ultimate goal was to develop a model that tests for the financial viability of such a project, the value drivers as well as risks that have to be taken into account. Furthermore, the model would need to be developed in a way that it could be transferred to similar projects of a different scale or other input variables.

2. REFLECTION ON THE WORK DONE AND INDIVIDUAL CONTRIBUTION

a. Problem definition

EDPD is facing two pressing issues in the current industry environment. Firstly, they have to comply with the European directive to reduce CO_2 emissions and improve the energy efficiency of their service buildings. Secondly, different from private end consumers, EDPD does not benefit from injecting PV generated energy into the grid. Although private consumers are incentivized to install PV mainly for self-consumption, they still can benefit from the sale of energy to the grid in the cases where production exceeds consumption with the so-called feed-in tariffs. EDPD as a distribution system operator (DSO) company injects access PV generated energy into the grid without getting any compensation in return.

EDP is looking to introduce a PV coupled battery storage system in their service building in Evora as a solution to these two problems. Furthermore, a pilot project on a small scale would give EDPD the opportunity to accumulate knowledge about this evolving technology and therefore prepare for future projects on a larger scale. Since EDPD is acting as both a producer of energy but also a consumer as they are self-consuming the PV produced energy, two business cases can be exploited with the installation of the PV coupled battery system: peak shaving and price arbitrage.

The so-called peak shaving would give EDPD the opportunity to better utilize the PV modules. One of the main limitations of PV modules is the highly volatile energy production. Often, a peak is reached during the day whereas in other times nearly no energy is produced. Especially in the summer the production is much higher than the load of a building and therefore most of the energy is injected into the grid and in case of EDPD wasted at zero compensation. Through a storage battery, the surplus PV production can be captured for a later use when the load is higher than the production thus allowing for a stabilization of PV production and a higher percentage of local usage of PV generated energy. From the perspective of a utility company, this established another opportunity. As in the whole network PV, generated energy is stored in batteries instead of being injecting into the grid, less energy energy in excess of the aggregated demand of a network is pumped into the grid. The grid network therefore isn't as strained as less energy is flowing through the network. For EDPD as a system operator this leads to lower lower grid maintenance costs.

Price arbitrage with storage batteries is the process of charging the battery when electricity prices are low and sell the energy back to the grid during peak hours, when the electricity prices are high. The difference between peak and off-peak electricity prices lead to a profit that can be captured. As stated before, EDPD is not compensated for injecting energy into the grid and therefore only benefits from the spread between off-peak and peak electricity prices. By charging the storage battery with electricity during hours of low energy prices and using the stored energy in peak hours, EDPD can save money in the amount of the difference of the prices.

The aim of EDPD of deploying a PV coupled battery storage system is to better utilize the PV modules and thus reaching the EU directives regarding higher building efficiency. An excel-based model was developed in order to assess the financial viability of a PV coupled battery storage system in the service building in Evora. Finally, a recommendation on the scale of the relevant system is given and key risks identified.

b. Methodology

i) Hypothesis

The ultimate aim of the developed model is to test the technical and financial implications of a PV coupled battery system project deployed in EDPD's service building in Evora. No direct hypothesis was postulated but ultimately a positive NPV would mean to engage in such a pilot project whereas a negative NPV would mean that a PV coupled battery system is not recommendable from a financial perspective. As EDPD is not benefitting from injecting PV generated energy into the grid, the main driver of profitability is the spread between off-peak and peak electricity prices, thus the business case of price arbitrage. If the spread is large enough it can offset the initial investment for a battery storage system and the PV modules. If the spread is not large enough, the expected savings on electricity would not cover the investment.

From a non-financial perspective, it can be expected that the installation of a battery storage system would increase the utilization of the PV modules and therefore increase the building efficiency as less energy would be consumed from the grid. Furthermore, as battery storage systems are a new technology with benefits reaching beyond this project, it can give valuable insights to EDPD as a whole and provide learning effects for later projects on a larger scale.

Overall, it is expected that the deployment of a storage battery coupled with PV modules will have a positive effect on the overall building efficiency but due to high investment costs might not be financially viable at this point in time.

ii) Methodology

For the purpose of simplicity, the model was split into two stages, following two different algorithms (see Appendix 2.1 & 2.2). The first stage was a simplified approach to the problem, only focusing on one business case – peak shaving. The lessons learned from the first stage were used in order to build a more sophisticated, second stage of the model. First of all, a stochastic forecast for the production and load was implemented in order to make the model more realistic. Secondly, price arbitrage as a second business case was included in order to make use of the spread between off-peak and peak electricity prices (see Appendix 3). The spread under the current contract is 0.13€/kWh (0,2097 €/kWh – 0.0747 €/kWh). Lastly, a more efficient battery discharge mechanism was integrated in order to better utilize the advantages of the storage battery. A simplified visual representation of the two stages can be found in Appendix 4.1 & 4.2.

To test the economic viability of the project, a NPV was computed. A NPV gives a direct feedback on the financial viability of the project overall and furthermore identifies the relevant value drivers and risk components that must be considered (Fisher, 1907).

In this model, the NPV has three main components:

- Capex of the PV modules and the battery storage system
- Operating cash flow as the savings generated by the difference between electricity costs in the project versus the current state
- Cost of capital as the opportunity costs of the deployed capital (weighted average cost of capital (WACC))

Furthermore, the models endogenous variables are the PV production capacity in kilowatt (kW) and the battery storage capacity in kilowatt hours (kWh). Regarding the PV modules, four capacity scenarios (15, 17, 20 and 25 kWn) were looked at. The capacity determines the maximum energy that can be captured by the PV module whereas a higher PV system's capacity generates more energy but also needs a higher investment. The storage capacity determines the maximum amount of PV produced energy in excess of load that can be stored instead of being injected into the grid.

The underlying electrical system was the same for the two stages and can be simplified by the following four components:

- PV production unit with a lifetime of 20 years
- Electrical consumption unit, thus all electrical loads in the building
- Storage battery with a lifetime of ten years
- The grid network as an external provider of electricity

Thus the model runs over over a span of 20 years, with the battery storage system being included in the first ten years.

All the relevant input data required to built such a model were provided by EDPD and will be critically assessed (see part 2.d). For the model it was assumed EDPD can deploy a storage system at costs of 1,200 €/kWh and a PV system at 2,000 €/kWn, Also a sensitivity analysis was done in order to identify the most important value drivers.

iii) Analysis

Although the results of the two stages in terms of best possible solutions are similar, the second stage model improved the validity and accuracy of the model. This is attributable to a refined process of charging and discharging, which both limits energy wastage and ensures deployment at higher prices, maximizing the value of energy. The model computes the highest

NPV for a system with a 15 kWn PV system and no storage system. As for both stages no storage capacity leads to the highest NPV, the optimal solution is 6,414€. In the following, discussions will mainly be about the results of the second stage of the model as the implications for EDPD are similar and the results overall are more precise as the second stage is more advanced compared to the first stage. However, results for the first stage can also be found in the Appendix.

The optimal result to not deploy a storage system with a 15 kWn PV system can mainly be argued by two input factors. On the one hand, the aggregate load is always significantly higher than the aggregate PV production (see Appendix 5). For a 15 kWn PV system the minimum average monthly aggregate deficit occurs in July and it is 2.4M kWh versus a maximum deficit of 4.3M kWh in December. This leads to the conclusion that a storage system is financially not viable, as there barely exists any surplus of PV production over load that can be stored in the battery. As can be seen, the deficit decreases to only 0.3M kWh in July with the installation of a larger PV system, thus making a battery storage system more likely to have an impact. This is also supported by the analysis of the drop in NPV when deploying a battery system of 5 kWh for each size of PV modules. Whereas the NPV of a 15 kWn PV system coupled with a 5 kWh battery storage system drops by 3,795€, the NPV of a 25 kWn PV system coupled with a 5 kWh battery storage system drops by only 3,606€ in the second stage of the model (see Appendix 6). However, the scale of the project in Evora is too small to justify a large PV system. These results lead to a few important conclusions. First of all, storage systems are not financially viable as its energy savings do not cover its Capex. Secondly, higher capacity PV systems can utilize a 5 kWh storage to a fuller potential than lower PV systems and therefore lose less value in absolute terms compared to the solution with zero storage capacity. Thirdly, the incremental cost of the higher PV capacity which allows for a more intensive use of the battery, and thus more savings, far exceeds the revenues from higher battery usage. Comparing the two stages shows the effect of the more sophisticated mechanism for the battery storage system as the NPV's when adding storage capacity to a PV system are constantly higher for each tested alternative in the second stage compared to the first stage of the model (see Appendix 6 & 7).

In order to test the consistency of the results, another metric was introduced to compute the viability of each alternative. Levelised Cost of Energy (LCOE) shows the cost of electricity per kWh generated adjusted by the time value of money for each alternative. The overall costs when sourcing electricity purely from the grid amounted to 9,800€ for an average yearly load of 64 MWh, thus leading to average price of 0.153€/kWh (see Appendix 8.1). In order for any alternative PV coupled battery storage system to create value, it needs to have a lower LCOE than compared to sourcing the electricity solely form the grid. The optimal alternative, a 15 kWn PV system without a storage battery, meets this condition. At investment costs of 30,000€ it deploys an average yearly energy of 21.5 MWh for consumption[1], which accounts for 33% of the total yearly load. This leads to a LCOE of 0.142 €/kWh, thus being 7.6% cheaper than grid sourcing (see Appendix 8.2). This method also shows that small battery storage systems (5 kWn and 10 kWn) are not viable as the Capex costs of 1,200€/kWh storage capacity are not being covered by the energy savings. The LCOE was calculated at 0.56€/kWh for the 5 kWh storage and 0.57€/kWh for the 10 kWh, thus being nearly four times as expensive as grid sourcing (see Appendix 8.3). The LCOE for a larger PV system of 25 kWn coupled with the same storage alternatives led to a result of 0.54 €/kWh, thus being marginally smaller (see Appendix 8.4 & 8.5).

Furthermore, breakeven prices were calculated in order to see at which price level the storage technology becomes viable to deploy with a PV system. Overall, the required breakeven prices on a €/kWh basis for storage capacities are lowest, the higher the PV system capacity

[1] Excluding PV to load surplus

and the higher the storage capacity. The breakeven prices range between [1,669€/kWh; 320€/kWh] for all possible alternatives from a 15 kWn system coupled with a 5 kWh system and a 25 kWn system with a 15 kWh system respectively. The lower the breakeven price is, the longer it will take to reach these price level. The 5 kWh storage system could be deployed without EDPD incurring in a negative NPV for all the PV systems except the 25 kWn. Should battery prices decrease 10% a year (a conservative expectation backed by research[2]), in five years batteries would cost around 700€/kWh (Tesla announced in 2016 a 600€/kWh battery). That would make the 10 kWh system financially viable with all PV systems except the 25 kWn and the 15 kWh system viable for the 15 kWn and 17 kWn PV systems (see appendix 9).

Another metric to assess the financial viability of the project is the payback period. The payback period describes how long a project needs to run until it is profitable. In this case, the payback period ranges between [7.8; 10.8] years.[3] Thus most alternatives would even be profitable within the time-frame of the project of ten years (see Appendix 10). Even a reduction of 50% of battery storage costs in the next five years would lower the payback period to only [7.4; 8.8] years. This rather small change in payback for a rather big change in input prices shows that Storage Capex is a small fraction of total Capex expenditures.

Lastly, it is relevant to know for which level of storage system's Capex the NPV of a coupled PV system with storage becomes superior to the NPV of the stand-alone PV scenario of 6,141€. These breakeven prices for storage range between [369€/kWh; 681€/kWh] for a 25 kWn PV system coupled with a 5 kWh system and a 15 kWn PV coupled with a 15 kWh storage respectively. Furthermore, the higher the PV system capacity, the higher the cost of storage necessary to make a coupled solution financially better than the respective PV standalone one, as higher PV allows for fuller utilization of the same storage system. Additionally, the higher

[2] KPMG, 2016

[3] does not consider the time value of money

the storage capacity, the lower the cost required for a coupled system to be financially superior compared to the stand-alone PV scenario. For the most relevant scenario of a 15 kWn PV system coupled with a 5 kWh storage battery, a Capex of 441€/kWh is required for the coupled system's NPV to match the stand-alone PV scenario's NPV. Under an assumed 10% drop in storage cost a year, the new breakeven point for this alternative would decrease from 7.8 to only 5.4 years (see Appendix 11).

Furthermore, a sensitivity analysis was conducted for the base scenario of coupling a PV system capacity of 15 kWn with a 5 kWh battery storage system in order to identify risk factors that need to be closely watched when implementing such a pilot project (see Appendix 12.1 & 12.2). PV system Capex, peak electricity prices and the WACC were identified as the key value drivers in the model. Furthermore, battery storage Capex was also assessed in order to get a sense of how possible future price changes would affect the project.

A decrease in PV system Capex of only 10% would increase the NPV by 128% from 2,345€ to 5,345€. An increase of the PV system Capex of 10% on the other hand would decrease the NPV by 128% to only 655€. Given the historic trend of price decreases for PV modules, it seems unlikely that NPV losses would materialize. Peak electricity prices exhibit a smaller impact on the NPV with an increase/decrease of 10%, is expected to impact the NPV with an increase/decrease of 70%. With the prospect of further future liberalization of the distribution market, this is an important area to keep track of. Regarding the WACC an increase/decrease of 1 p.p. is expected to decrease/increase NPV by 110%/124%. It is important to note that the WACC exhibits a lower downside than upside impact. This can be explained by the large project horizon, which means distant future cash flows are already heavily discounted and therefore not materially affected by a WACC increase. The battery storage Capex exhibits a linear inverse relationship between its value and the NPV. Whereas an increase/decrease of 25% in storage Capex is expected to decrease/increase NPV by 64%, a change of 50% in Capex would impact the NPV by 128%, thus double as much. Moreover, the 50% drop in prices is expected to occur between 5-6 years under current rates.

c. Recommendations to the company

Given the current cost of battery systems and its impact when coupled with a PV system, it is more financially profitable to opt for PV systems alone. This is shown by the model as the highest NPV of 6,414€ over the 20-year time horizon is reached by only installing a 15 kWn PV system with no storage battery attached.

However, as this is a pilot project and the NPV of 6,414€ for a company a net profit of 1.04 bn € in 2014, it can also be recommended to install a small battery system without incurring a loss, but also not making a profit (EDP, 2015). While keeping a 15 kWn PV system for the building in Evora, EDPD would be able to install a battery storage system with a capacity of 7 kWh and would still reach a positive NPV of 267 €. It is also important to consider the specifications of the pilot project in Évora. It becomes apparent that the project size in Évora might be too small to justify the installation of a battery storage system. One of the main take-aways is the fact that for larger PV systems, battery storage can add considerable value as the overall production compared to the load is higher, therefore making the technology valuable for EDPD in service buildings with a higher consumption.

Furthermore, the sensitivity analysis conducted provided valuable insights into the most important value drivers that EDPD needs to keep track of. For the pilot project in Évora it is critical for EDPD to pay special attention to the price developments of the PV system and the electricity prices. As the battery system gets the most value from making use of the spread between peak and supervazio prices, this spread is important to follow. If the spread increases, it would be beneficial for this and similar projects and increase the justification for a battery storage system. Another important finding of the sensitivity analysis is that the battery storage

Capex itself is not a very important driver for the project itself. Anyway, as the technology is just evolving, huge improvements in terms of prices and other quality characteristics are expected to take place, making the technology maturing over the next few years. Under current developments, it would take 9.5 years for storage Capex to decrease to a point where the NPV of the recommended alternative (15 kWn PV system coupled with a 5 kWh battery) would be superior to a 15 kWn PV system alone. That would match the point in time where the first battery becomes obsolete (ten years), which suggests its replacement at that time could be made at a financial gain.

Beneath the quantitative analysis of the project, there are also qualitative aspects to take into account when analyzing a potential implementation of the storage system in Evora. Despite the negative NPV scenarios there might be non-measurable value, which makes the project worthwhile. First of all, the project in Evora is only a pilot on a rather small scale. Thus it could give valuable insights in order to how to reach an optimal solution in what concerns the technical aspects of the project. Furthermore, it can result in value creation for EDPD in the future, as it will be more prepared to tackle this emerging trend in the electrical sector especially in order to stabilize its grid network. Being a first-mover can give a valuable advantage. The innovation aspect and possible opportunities therefore arising will be further discussed in part 3. Additionally, the value of establishing early contacts with suppliers and other operational partners is another point to take into account. Lastly, EDP and EDPD's growing environmental motivations are one of the main qualitative drivers of this project's pursuit and clearly aligned with the Energy 2020 European strategy.

d. Concerns

A few limitations have to be taken into account by EDPD when looking at the model and the further implementation of a PV coupled storage battery system. First of all, in order to forecast PV production a weather forecast model should be used in order to better predict the optimal solution for the storage battery. Secondly, the battery's degradation is not modelled throughout its ten-year lifetime. Instead it is expected to work at its full potential until it completely breaks down. Although the exact rate of degradation is uncertain as the technology is still in a development phase, in a more sophisticated model, the battery would experience a somewhat linear degradation over the years. Lastly, the model does not perfectly appropriate savings opportunities. It either discharges the battery on peak periods, therefore missing on the also profitable cheia periods, or it discharges the battery in cheia and peak periods, accumulating a larger storage. A fully charged battery can sometimes cause zero marginal cost PV production in excess of Load to be injected into the grid. Right now, the battery utilization rate for the base model (15 kWn PV coupled with a 5 kWh battery), measured as the percentage of hours with some charge on, was calculated to be 52%. This result is applicable for a model which only discharges on peak, and therefore maintains storage for long periods. Should a more refined model charge and discharge continuously the real usage rate could go up as well as its average storage.

It is also important to validate the input factors given by EDPD regarding the Capex for PV and battery storage systems as well as the WACC. The PV system price of 2,000 €/kWn as well as a battery storage system price of 1,200 €/kWh, a lifetime of ten years and an efficiency factor of 85% were in line with market research and therefore do not reduce the accuracy of the model (see Appendix 13.1 – 13.3). A given discount rate of 8% was also in line with industry peers and the current market environment (see Appendix 13.4).

Other problems can occur when implementing the project. As already said, it is recommended to install a battery storage system although it does not lead to the best possible result. As the technology is still evolving, many uncertainties have to be kept in mind that can occur when implementing the technology. First of all, lithium-ion batteries, which is the recommended battery type for this project, require a rather sophisticated battery management system. Installation and maintenance therefore lead to unexpected problems during the life of the battery. Furthermore, the lack of experience and documented performance of battery storage systems pose further uncertainties for EDPD. The efficiency factor and overall lifetime of each battery highly depend on influencing factors such as temperature and usage patterns and therefore need some experience in order to evaluate those. Most input data such as the lifetime of the battery system follow a rather conservative estimation and therefore try to minimize the downside risk of the model. As seen in the sensitivity analysis, some of the factors such as electricity prices and PV system Capex have a tremendous impact on the viability of the project and therefore need to be watched closely. Thus an early implementation poses risks but also the opportunity to get some early insights into the technology.

e. Individual contribution

My position in this team was clearly the team leader. This included scheduling meetings with EDPD itself but more importantly organizing all the team work. As the team had very different schedules and was not placed in Lisbon constantly, this involved a lot of planning and trying to accommodate everyone's preferences regarding the meeting schedule. Furthermore, after figuring out what the company was expecting and working out an agenda for the project, I tried to distribute the work evenly and based on everyone's strength. As the team leader I always tried to keep the overall goal in mind and make sure results are delivered in order to get progress of the project. Lastly, it involved taking notes on problems, schedule deliverables for each team member and spot potential problems early on in the project in order to accommodate potential changes.

Since this project was technically not in my domain, rather engineering than business, I first of all needed to understand the technical implications of the project – such as load, power usage, regulations etc. Furthermore, the first of weeks of the project were about getting a sense of how to structure the model and what to start with. I was very much involved in the early setting of a structure of the whole work and therefore how to structure the excel model and how to tackle the issues arising.

Overall I mainly focused on the research part, meaning market research about the two relevant technologies of PV systems and battery storage systems. I was especially pleased since I have been very interested in renewable energies for years. Furthermore, as Germany is one of the key players on the market for renewables, some sources were only available in German. It involved understanding the technology itself and think about the best options for EDPD. Furthermore, it included to understand if the data that EDPD gave us was actually in line with market data. Therefore, I did research about the current state of the technologies as well as expected changes within the next years that will have an impact on the project.

3. ACADEMIC DISCUSSION

a) Possible links with your MSc field

Innovation was always one of the key research topics in management science, as it is the true driver of value. Whether learning how to foster innovation, manage innovators, or monetizing innovation, management studies brings many tools for these topics. It is one of the main drivers of value creation in an economy. Successful R&D as well as technological advancements in a company's operations are key for them to stay competitive in the industry. Numerous frameworks for strategic innovations were published and show the important stance it has for academics such as the term path dependency became a fixed term in regard of innovation efforts.

On the one hand, internal conditions determine the capability of companies to innovate.

The resource-based view is examining the capability of a company to use internal resources in order to be successful in the long run. But also external drivers, such as regulations in the case of EDPD, have an important impact on companies. As every company, EDPD is influenced by these internal and external circumstances. Started as a state-owned utility company, EDP got privatized stepwise between 1997 and 2005 and since then needs to compete in the free market and is closely watched by shareholders and regulators (EDP, 2016). Furthermore, as stated above, regulations by the EU are targeted to improve energy efficiency in Europe and thus force EDP to engage in environmental friendly operations in order to meet the CO_2 reduction targets. These influences that led firms to adopt environmental friendly technologies therefore led to the emergence of the field of eco-innovation, which examines the drivers of innovation and adoption in the field of ecological technologies.

b) Relevant theories and empirical studies

Although innovation overall got a lot of attention over the last years, the concept of eco-innovation is a fairly new concept as it is placed between the disciplines of innovation economics and environmental economics (Rennings, 2000). It only emerged in the literature end of the 1990's in a book of Fussler and James and most of the research was only published after 2010 (Fussler & James, 1997; Bossle et al., 2016). In order to assess in how far EDPD is following an eco-innovation approach in its adoption of a battery storage technology, first the term eco-innovation will be defined and its differentiation from the innovation term overall assessed. Afterwards key drivers and motivation factors that influence companies in adopting eco-innovations and, if applicable, underlying theories are identified through literature research. As EDPD itself is not engaging in R&D efforts of the battery technology, research review about general drivers will be conducted. Lastly, the importance of these drivers for the diffusion of the technology will be assessed as this is the most important topic in case of EDPD.

Although different definitions of the concept of eco-innovation exist, all these definitions have some similarities. First of all, all definitions stress the environmental component of an innovation. Furthermore, the consequences of eco-innovation mainly include 'fewer adverse effects on the environment and more efficient use of resources' (Hojnik & Ruzzier, 2016). Therefore, the battery storage technology overall can be identified as an eco-innovation as the technology helps to better utilize PV systems and thus lower emissions.

Eco-innovation has some important peculiarities and thus distinctions from innovation in general. First of all, it can take many forms such as technological, organizational, social or institutional. In the case of this project, battery storage systems are a technological innovation in the market of renewable energy. Secondly, whereas general innovation is mainly driven by a company's willingness to improve its product portfolio and disrupt the market, for eco-innovation, the environmental policies of public institutions play a crucial role in forcing companies to invest in innovation in this field. Another peculiarity is its impact on stakeholders and the environment, thus its externalities. Companies engaging in eco-innovation benefit from the usual knowledge accumulation in the research and adoption phase leading to spillovers for other operations. Furthermore, the society as a whole benefits from companies engaging in eco-innovation as emission are reduced (Rennings, 2000; Bossle et al., 2016). However, companies engaging in these eco-innovations bear the investment costs of the technology and therefore have a disadvantage to their polluting competitors. This, to a certain extent, can also be seen in the case of EDPD as positive externalities would evolve by implementing a battery storage system. However, competitors, who are not deploying such a system, would save the investment costs (Hojnik & Ruzzier, 2016).

Four main drivers for the diffusion of eco-innovation can be identified: prices, regulation and market demand (Beise & Rennings, 2005).

The first driver for the diffusion of eco-innovations as for other innovation is the price of a technology, thus the prospects of cost saving opportunities (Hojnik & Ruzzier, 2016; Beise & Rennings, 2005; Bossle, 2016). Nowadays, prices are still too high for EDPD in order to deploy a battery system at the project size of Evora. As EDPD would not benefit from engaging in this new technology, cost savings cannot be identified as one of the main drivers for EDPD in this pilot project. But taking the results of the model into account, an expected decrease of prices of 50% within the next five years, make battery systems worthwhile in the future. Thus this is a driver that, although not important nowadays, is expected to gain importance in the upcoming years.

As discussed earlier, another important driver is the regulatory push factor which is ultimately grounded in the institutional theory (Hojnik & Ruzzier, 2016; Rennings, 2000). The institutional theory argues that 'organization survival is determined by the extent of the alignment with the institutional environment' (Kostova, Roth & Dacin, 2008) which also includes regulations by the government. Also throughout the literature, regulatory pressure by governments appears to be the dominant driver (Triguero, Moreno-Mondejar & Davia, 2013; Cai & Zhou, 2014; Bossle, 2016). It is also shown in a new program recently published by the EU called the 'Eco-Innovation Action Plan' that focuses on eco-innovations in order to reach the EU climate goals (Triguero, Moreno-Mondejar & Davia, 2013). The importance of this driver is definitely seen in the case of EDPD. Although a PV coupled battery storage system is not the best alternative from a financial viewpoint it would definitely help to increase PV generated self consumption and therefore improve the buildings efficiency, thus complying with EU regulations.

The third important driver of eco-innovation in companies are the so-called market pull factor which mainly summarize factors such as the corporate image or customer preferences for environmentally friendly products (Rennings, 2000). This pressure to engage in environmental friendly operations can come from NGO's, suppliers, consumers or competitors (Bossle, 2016). On the one hand, whereas for companies selling a rather heterogeneous product such as car manufacturer, the image might be an important driver, EDPD sells electricity, which is a very homogenous product and therefore not important. On the other hand, their image towards customers and especially investors is important and therefore effects the importance to adopt innovative solutions. Eco-innovation initiatives can be found in Corporate Social Responsibility reports and thus communicate a positive image of the company as a environmental leader (Bossle, 2016). This driver has some importance but is not the main driver behind eco-innovations.

Overall it seems that the the most important driver of innovation in the case of EDPD can be seen as the regulatory factor which is also backed by empirical research (Rennings, 2000). This can be argued with the fact that the other drivers alone are not strong enough and therefore need specific regulatory support. The EU regulations to increase buildings efficiency are the main reason for EDPD to engage in the technology. Furthermore, it seems that regulation is an important driver in the beginning but will diminish in importance whereas the price as a driver will increase in importance for the diffusion of batteries with the technology becoming more mature. However, 'empirical evidence shows that some environmental innovations require a lengthy period of time before they are adopted, which are directly related to their diffusion rate' (Karakaya, Hidalgo & Nuur, 2014). This is seen in the case of storage batteries. Although the battery technology itself is in the market for several decades, the development accelerated only recently. Therefore, the diffusion can be expected to gain momentum when the prices decline in the upcoming years.

c) Implications for theory and future research

The unique characteristics of eco-innovations lead to various implications for different stakeholders. As seen from the findings, a PV coupled battery storage system is not viable from a financial perspective for EDPD but has positive effects on the environment around them and also their efforts to reach the EU climate goals. Since cost savings is an important driver for companies to engage in eco-innovations, policy makers have an important role to fill. As literature research shows, policy makers are crucial in their actions to regulate in order to foster eco-innovation (Bossle, 2016). As the society overall is benefiting from companies engaging in eco-innovation but incur a loss for themselves, policy makers should need to think about actions to promote eco-innovation (Triguero, Moreno-Mondejar & Davia, 2013). One way is to reimburse companies in order to lessen the negative impact. In this case it can be done by granting feed-in tariffs to EDPD as a system operator or to subsidize the investment into storage systems.

As the research about eco-innovation only evolved recently and is gaining in importance due to new regulations, there are many open questions. First of all, the total number of research papers is still limited, thus the results of the literature research in terms of motivations and drivers might be incomplete. Therefore, further research in this field is needed in order to get a better overview about key concepts. Furthermore, it would be interesting to quantify the positive externalities companies have on the environment in order to get a sense of the value of eco-innovation. Additionally, this quantification would help to introduce measures to promote eco-innovation in other companies and thus encourage early adoption of new technologies.

Lastly, most research is focused on the R&D part of eco-innovation, thus not taking the diffusion phase into account. Especially for this project it would be interesting to get more insights into the diffusion process of eco-innovation as EDPD itself is not engaging in the R&D phase of the battery system itself. Additionally, not only the driver itself would be an important extension but also its relative importance for companies. Incentives for the innovators could be more directed by these insights and thus foster eco-innovation.

4. PERSONAL REFLECTION

a) Personal experience

i) Key strengths & weaknesses observable during the project

I realized that my key strength mainly was leading the team, having the aim of the project in mind and structure the work in a way that accommodates the problem statement. Especially my internship in a consultancy helped me to get a sense of the importance of a strong story line throughout a project. Furthermore, I always tried to maintain a structured approach to problems. This included making meetings as efficient as possible by making sure every group member prepared some work. Furthermore, I tried to use my communication and leadership skills by fostering communication between the different team members and schedule meetings on a regular basis.

My key weakness was on the one hand of technical nature. Especially as we had a model to develop, strong Excel modeling skills were required during the project. Whereas finance students are confronted with these kind of problems throughout their studies, in my master in management this is barely taught. Therefore, it was great to have two finance students in the group who were mainly working on the model but also explained to me very detailed every single step they pursued.

Lastly I realized that I am sometimes too focused on getting work done quickly rather than coaching others on certain topics. Especially towards the end of the project, where time becomes a constraining factor, I sometimes worked on problems by myself instead of consulting the whole group. Furthermore, I sometimes lacked a bit of time management during the work. Especially as other deadlines were approaching as well I realized that a stricter time schedule would have helped a lot.

ii) Plan to develop of your areas of improvement

Especially for the time management skills I am planning to have a more structured and organized approach towards a project the next time. We missed to establish a time table with exact schedules when which part of the project should be done. My research part could have been started earlier as it was not direct input into the model. Related to time management skill is that I want to be a better listener and also act more calm in situation of stress. I learned that pushing things forward too quick does not add to the overall quality of the delivered work. Therefore, I need to take a step back sometimes and get a clear view on a problem without being stressed about of about a quick solution.

In line with time management skills is a better structuring of the work. I realized that sometimes things were done twice as no clear communication was given. I am planning to better communicate the most important steps in a project in my upcoming group works.

Additionally, I further plan to improve my leadership abilities. Although I am comfortable with leading a group, I now realized again how important it is to take different needs into account. Especially differences in cultures that emerge inevitable need a special response. Therefore, I am planning to get further experience in dealing with very heterogenous groups.

b. Benefit of hindsight: What added most value? What should have been done differently?

One of the key aspects during the whole business projects were the weekly meetings of the team with the business advisors of EDPD. It made sure that the model was developed in the right way and potential mistakes were detected early.

Furthermore, it was very helpful to have a heterogeneous team. As already said, the experience of the finance students was extremely insightful. On the other hand, management students have stronger background for the research part. Therefore, the whole team was able to bring in its strength and improve in areas of weaknesses.

But also some things should have been done differently. First of all, it took EDPD a while until they provided the data und ultimately let to a delay of the start of the project of nearly four weeks. Furthermore, some things could have done differently in the team. First of all, as not all team members were constantly based in Lisbon, meetings were sometimes difficult to achieve. Furthermore, as already said before, a clear and structured time table with deadlines and deliverables would have been helpful as sometimes work was not delivered in time and resulted in a delay of the project.

List of abbreviations

Capex – Capital expenditure

CAPM – Capital Asset Pricing Model

EDP – Energias de Portugal

EDPD – Energias de Portugal Distribuição

EU – European Union

GW – Gigawatt

IEA – International Energy Agency

kWh – Kilowatt hour

kWn – Kilowatt nominal

LCOE – Levelised Cost of Electricity

MW – Megawatt

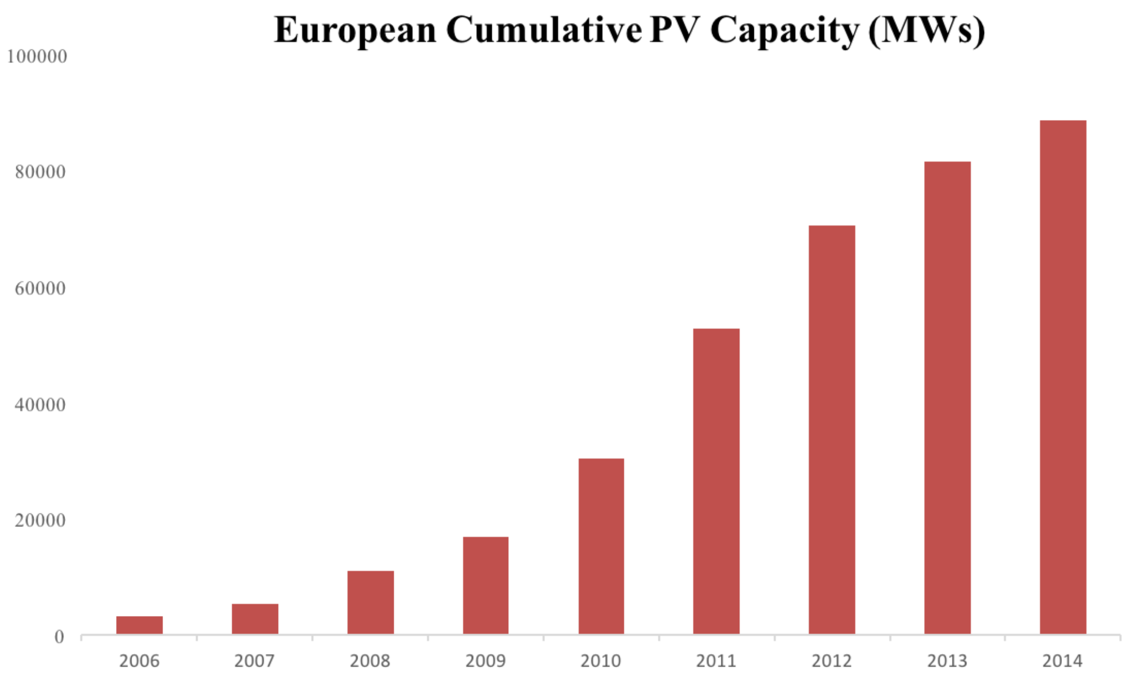
NPV – Net Present Value

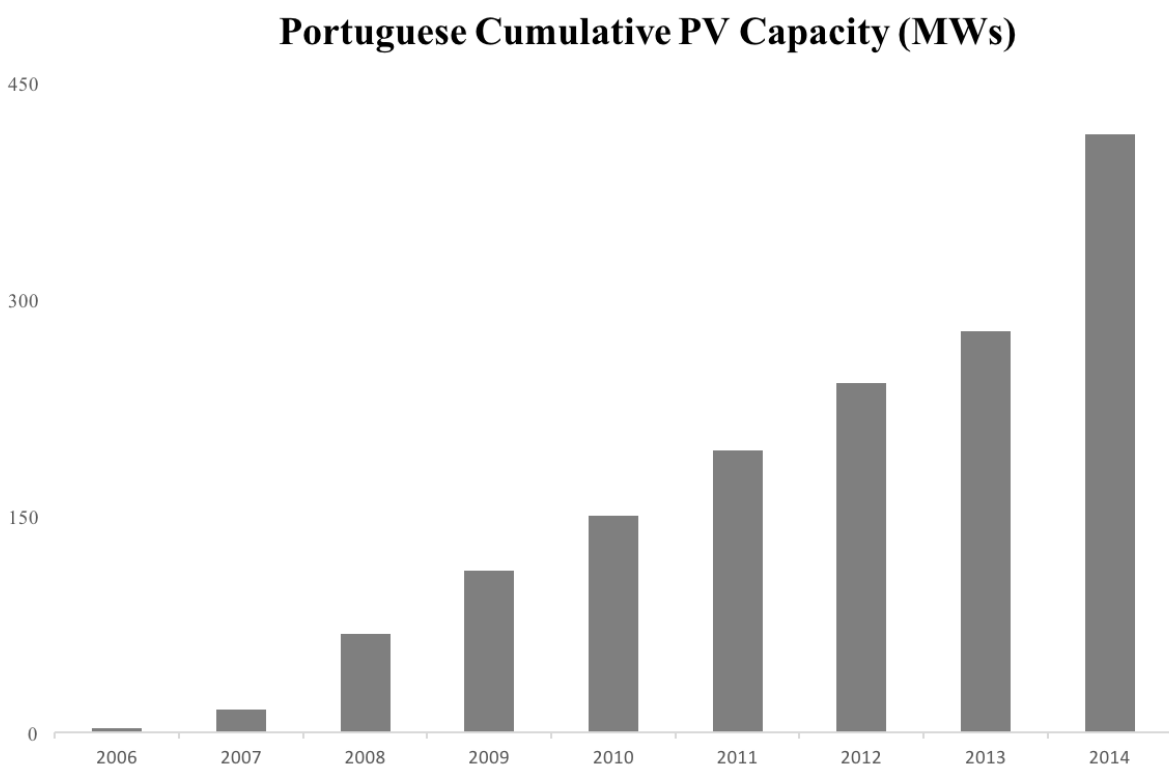
PV – Photovoltaic

WACC – Weighted Average Cost of Capital

Appendix

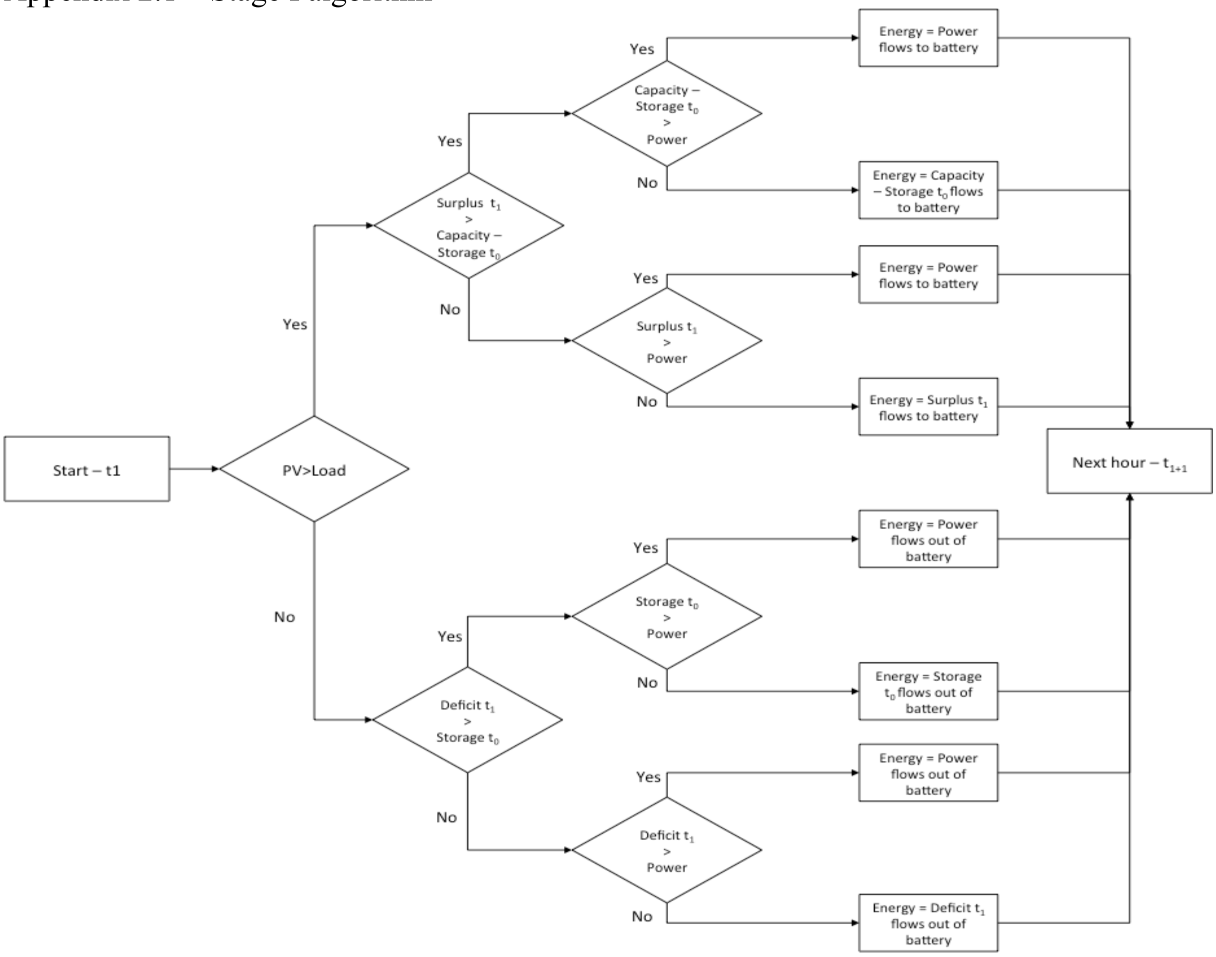
Appendix 1 – Evolution of Cumulative PV Capacity in Europe and Portugal 2000-2014



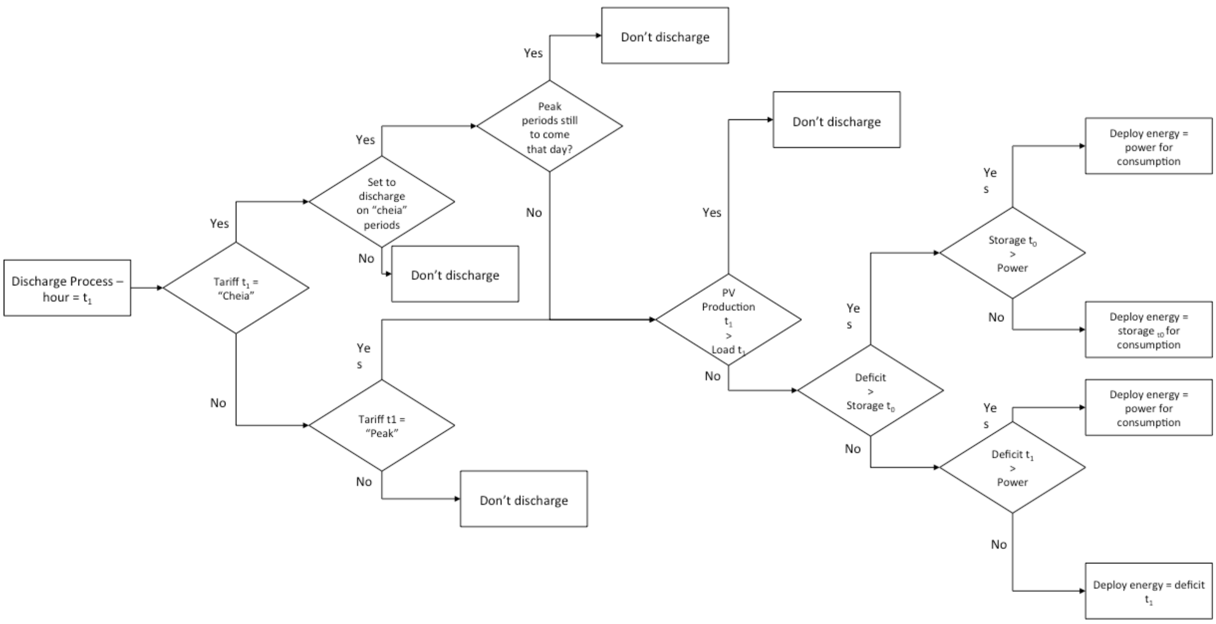


Source: Bloomberg

Appendix 2.1 – Stage I algorithm



Appendix 2.2 – Stage II battery discharging algorithm



Appendix 3 – Tariff overview

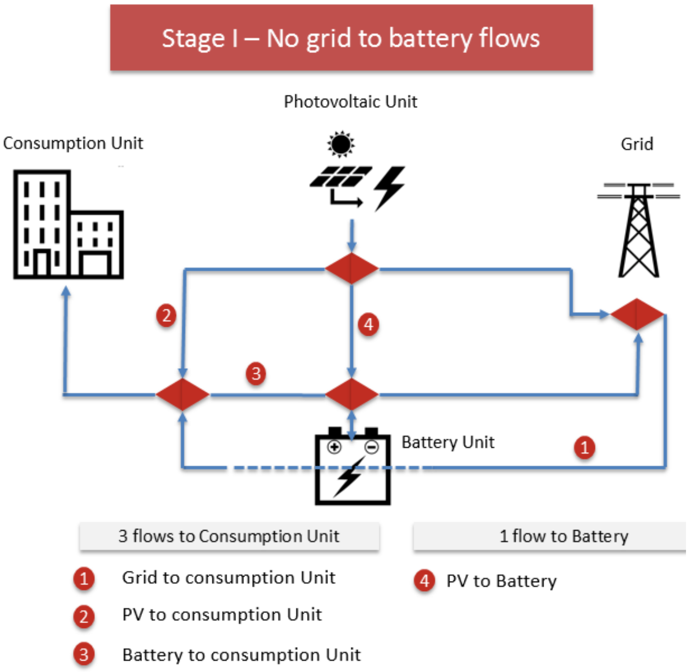
Termo tarifário fixo		EUR/mês	EUR/dia*
		25,32	0,8326

Encargos de potência	Termo	EUR/kW.mês	EUR/kW.dia*
Médias utilizações	Horas de ponta	14,407	0,4737
	Contratada	0,628	0,0206
Longas utilizações	Horas de ponta	20,467	0,6729
	Contratada	1,449	0,0476

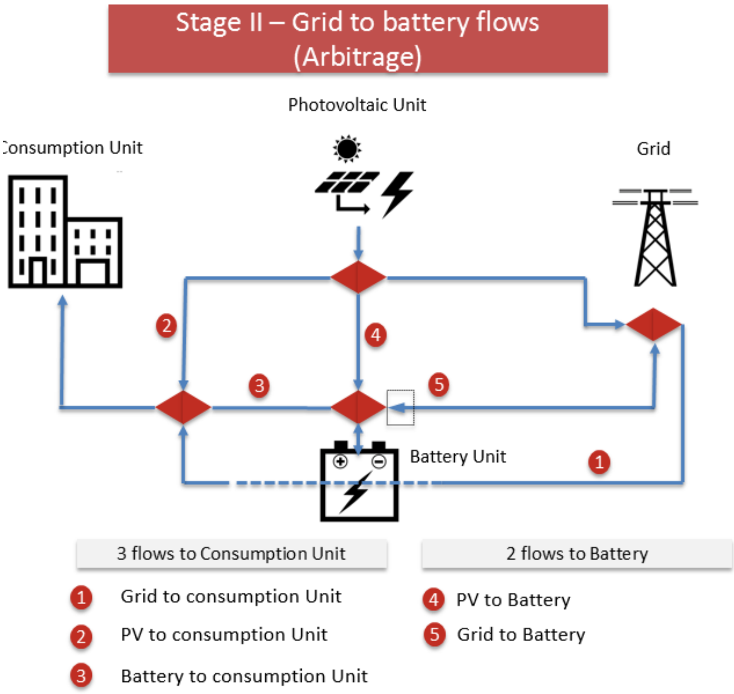
Preço da energia ativa	Período horário		EUR/kWh
Médias utilizações	Horas de ponta	p	0,2097
	Horas de cheias	c	0,1211
	Horas de vazio normal	vn	0,0849
	Horas de super vazio	sv	0,0747
Longas utilizações	Horas de ponta	p	0,1491
	Horas de cheias	c	0,1164
	Horas de vazio normal	vn	0,0776
	Horas de super vazio	sv	0,0685

Preço da energia reativa	EUR/kVArh
Fornecida pela Rede (indutiva)	0,0293
Recebida pela Rede (capacitiva)	0,0223

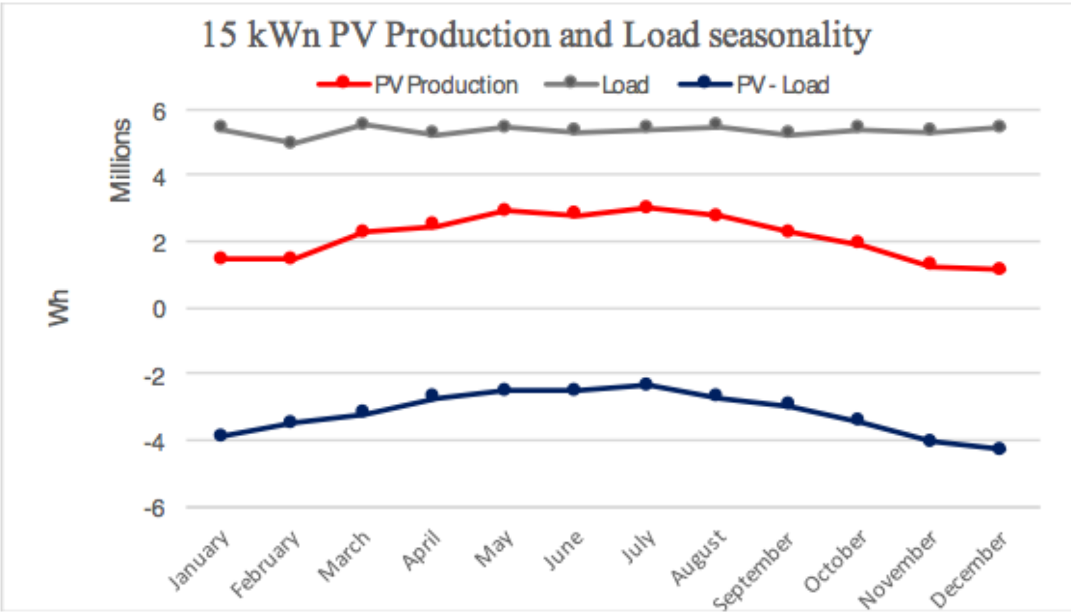
Appendix 4.1 – Stage I underlying electrical system

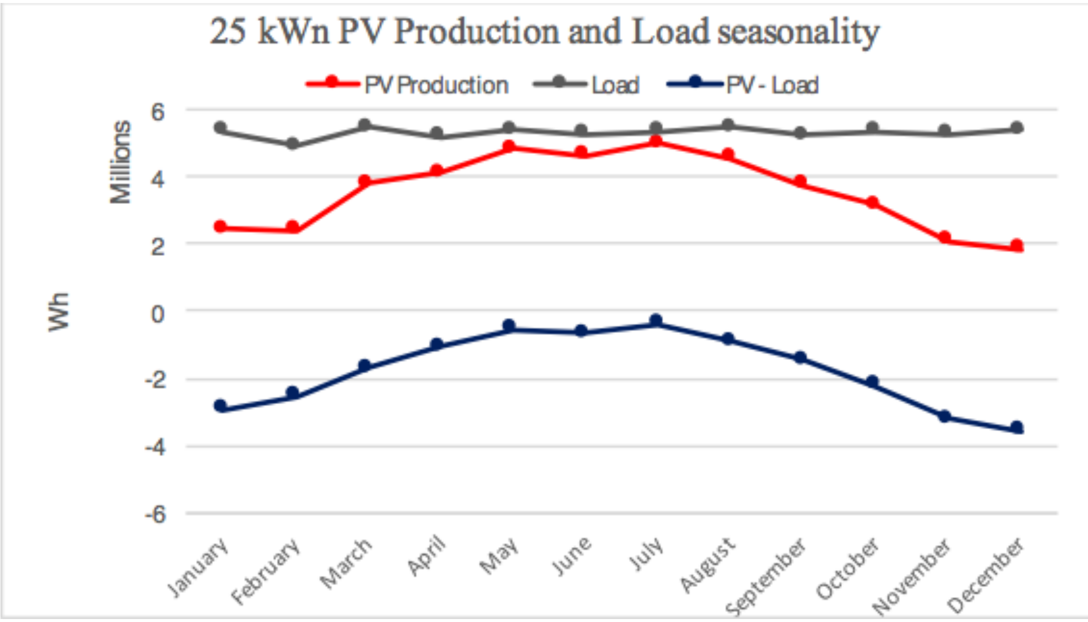


Appendix 4.2 - Stage II Underlying electrical system



Appendix 5 - Analysis of seasonality in PV Production and Load (15 kWn PV and 25 kWn PV)





Appendix 6 – Data for the “Analysis on the impact of storage on NPV” – Stage II

NPV 15 kWn Plot auxiliary		NPV 17 kWn Plot auxiliary		NPV 20 kWn Plot auxiliary		NPV 25 kWn Plot auxiliary	
Capacity Level	NPV	Capacity Level	NPV	Capacity Level	NPV	Capacity Level	NPV
0,0	6140,752219	0	5585,2	0	4050,2	0,0	-1067,1
1000	5391,6	1000	4869,1	1000	3372,4	1000	-1745,3
2000,0	4630,65214	2000	4120,0	2000	2649,7	2000,0	-2451,9
3000	3869,5	3000	3365,3	3000	1906,1	3000	-3179,6
4000,0	3110,288348	4000	2607,9	4000	1152,9	4000,0	-3919,9
5000	2345,0	5000	1845,6	5000	391,6	5000	-4673,6
6000,0	1565,89239	6000	1072,2	6000	-381,1	6000,0	-5441,3
7000	752,2	7000	267,4	7000	-1187,7	7000	-6244,8
8000,0	-90,5639289	8000	-573,0	8000	-2028,0	8000,0	-7083,3
9000	-942,2	9000	-1423,9	9000	-2880,0	9000	-7934,8
10000,0	-1805,63222	10000	-2290,9	10000	-3748,5	10000,0	-8807,1
11000	-2681,4	11000	-3166,6	11000	-4618,3	11000	-9683,8
12000,0	-3572,42945	12000	-4049,4	12000	-5486,5	12000,0	-10558,5
13000	-4477,9	13000	-4940,1	13000	-6354,6	13000	-11431,5
14000,0	-5396,892568	14000	-5841,9	14000	-7226,1	14000,0	-12309,2
15000	-6329,5	15000	-6757,4	15000	-8103,4	15000	-13193,3
16000,0	-7273,951407	16000	-7687,7	16000	-8986,9	16000,0	-14081,2
17000	-8230,5	17000	-8632,1	17000	-9876,7	17000	-14970,2
18000,0	-9200,291909	18000	-9594,5	18000	-10777,9	18000,0	-15861,1
19000	-10190,1	19000	-10574,5	19000	-11695,1	19000	-16754,5
20000,0	-11196,13584	20000	-11573,9	20000	-12627,1	20000,0	-17652,9

Appendix 7 – Data for the “Analysis on the impact of storage on NPV” – Stage I

NPV Plot 25kWn auxiliary		20 kWn NPV Plot auxiliary		NPV 17 kWn Plot auxiliary		NPV 15 kWn Plot auxiliary	
Capacity Level	NPV	Capacity Level	NPV	Capacity Level	NPV	Capacity Level	NPV
0	-1066,7	0	4050,2	0	5585,5	0	6140,8
1000	-1932,9	1000	3140,2	1000	4588,1	1000	5089,1
2000	-2799,0	2000	2229,4	2000	3580,8	2000	4046,6
3000	-3648,3	3000	1327,9	3000	2578,4	3000	3020,7
4000	-4493,5	4000	424,0	4000	1580,5	4000	2006,0
5000	-5346,0	5000	-494,6	5000	577,8	5000	988,8
6000	-6207,6	6000	-1429,0	6000	-432,6	6000	-37,8
7000	-7092,8	7000	-2387,6	7000	-1456,7	7000	-1075,7
8000	-8008,2	8000	-3387,3	8000	-2513,6	8000	-2144,1
9000	-8939,4	9000	-4417,0	9000	-3592,0	9000	-3235,5
10000	-9876,3	10000	-5463,8	10000	-4679,6	10000	-4334,8
11000	-10820,7	11000	-6524,2	11000	-5773,0	11000	-5438,1
12000	-11775,4	12000	-7598,0	12000	-6875,0	12000	-6546,3
13000	-12739,2	13000	-8681,6	13000	-7986,9	13000	-7662,8
14000	-13711,1	14000	-9771,2	14000	-9107,3	14000	-8786,0
15000	-14688,1	15000	-10863,6	15000	-10232,4	15000	-9914,2
16000	-15675,8	16000	-11962,9	16000	-11362,9	16000	-11047,2
17000	-16672,1	17000	-13066,7	17000	-12497,0	17000	-12185,2
18000	-17674,8	18000	-14173,4	18000	-13632,4	18000	-13324,8
19000	-18680,6	19000	-15284,2	19000	-14769,2	19000	-14465,9
20000	-19689,2	20000	-16400,6	20000	-15906,9	20000	-15608,3

Appendix 8.1 – Grid LCOE

Grid Sourcing		
Average yearly energy load kWh		63930,05
Average yearly energy cost	€	9 802,57
Average energy price - grid sourcing	€	0,153

Appendix 8.2– 15kWn PV system considered alone

PV 15 kWN alone		
Average "non-wasted" yearly energy kWh		21561,51651
Average yearly value of energy	€	3 744,54
Average energy price	€	0,142

15 kWn PV alone	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	(...)	2035
Energy Produced	21 561,5	21 561,5	21 561,5	21 561,5	21 561,5	21 561,5	21 561,5	21 561,5	21 561,5	21 561,5		21 561,5
PV of Energy Produced	19964,4	18485,5	17116,2	15848,4	14674,4	13587,4	12580,9	11649,0	10786,1	9987,2		4626,0
CAPEX	€ 30 000											
Levelised Cost of Energy	€ 0,142											

Appendix 8.3 – Storage Systems 5 and 10kWh – 15 kWn PV

PV 15kWn	5 kWh Storage		10 kWh Storage	
Average Yearly Energy Stored kWh		1849		3599
Average energy price @ consumption €/kWh	€	0,2553	€	0,2357
Average yearly value of energy	€	472	€	848
Average Yearly cost of grid to bat energy	€	145	€	248
Average yearly Price arbitrage P&L	€	327	€	600
Average energy price - grid sourcing	€	0,56	€	0,57

5 kWh Storage	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Average Cost of Energy	€ 145	€ 145	€ 145	€ 145	€ 145	€ 145	€ 145	€ 145	€ 145	€ 145
PV of CF	€ 134,07	€ 124,14	€ 114,94	€ 106,43	€ 98,54	€ 91,24	€ 84,48	€ 78,23	€ 72,43	€ 67,07
Energy Stored	1849	1849	1849	1849	1849	1849	1849	1849	1849	1849
PV of Energy Stored	1712	1585	1467	1359	1258	1165	1079	999	925	856
CAPEX	6000									
Levelised Cost of Energy	€ 0,56									

10kWh Storage	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Average Cost of Energy	€ 248	€ 248	€ 248	€ 248	€ 248	€ 248	€ 248	€ 248	€ 248	€ 248
PV of CF	€ 229,7	€ 212,7	€ 197,0	€ 182,4	€ 168,9	€ 156,4	€ 144,8	€ 134,1	€ 124,1	€ 114,9
Energy Stored	3599	3599	3599	3599	3599	3599	3599	3599	3599	3599
PV of Energy Stored	3332	3085	2857	2645	2449	2268	2100	1944	1800	1667
CAPEX	12000									
Levelised Cost of Energy	€ 0,57									

Appendix 8.4 – 25kWn PV system considered alone

PV 25 kWN alone		
Average "non-wasted" yearly energy kWh		44 444,6
Average yearly value of energy	€	5 028,13
Average energy price - grid sourcing	€	1,01

25 kWn PV alone	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	(...)	2035
Energy Produced	5028,1	5028,1	5028,1	5028,1	5028,1	5028,1	5028,1	5028,1	5028,1	5028,1		5028,1
PV of Energy Produced	4655,7	4310,8	3991,5	3695,8	3422,1	3168,6	2933,9	2716,5	2515,3	2329,0		1078,8
CAPEX	€ 50 000											
Levelised Cost of Energy	€ 1,01											

Appendix 8.5 – Storage Systems 5 and 10kWh – 25 kWn PV

PV 25kWn	5 kWh Storage	10 kWh Storage
Average Yearly Energy Stored kWh	1961,085828	3787,73835
Average energy price @ consumption €/kWh	€ 0,2560	€ 0,2286
Average yearly value of energy	€ 502,1097	€ 865,74
Average Yearly cost of grid to bat energy	€ 144	€ 229
Average yearly Price arbitrage P&L	€ 358	€ 637
Average energy price - grid sourcing	€ 0,53	€ 0,53

5 kWh Storage	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Average Cost of Energy	€ 144	€ 144	€ 144	€ 144	€ 144	€ 144	€ 144	€ 144	€ 144	€ 144
PV of CF	€ 133,40	€ 123,52	€ 114,37	€ 105,90	€ 98,05	€ 90,79	€ 84,07	€ 77,84	€ 72,07	€ 66,73
Energy Stored	1961	1961	1961	1961	1961	1961	1961	1961	1961	1961
PV of Energy Stored	1816	1681	1557	1441	1335	1236	1144	1060	981	908
CAPEX	€ 6 000,00									
Levelised Cost of Energy	€ 0,53									

10 kWh Storage	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Average Cost of Energy	€ 229	€ 229	€ 229	€ 229	€ 229	€ 229	€ 229	€ 229	€ 229	€ 229
PV of CF	€ 212,21	€ 196,49	€ 181,93	€ 168,46	€ 155,98	€ 144,42	€ 133,73	€ 123,82	€ 114,65	€ 106,16
Energy Stored	3788	3788	3788	3788	3788	3788	3788	3788	3788	3788
PV of Energy Stored	3507	3247	3007	2784	2578	2387	2210	2046	1895	1754
CAPEX	€ 12 000,00									
Levelised Cost of Energy	€ 0,53									

Appendix 9 – Breakeven (0 NPV) prices for storage Systems

Breakeven Price per kWh (€/kWh)	PV System			
Storage - Stage II	15 kWn	17 kWn	20 kWn	25 kWn
5kWh	€ 1 669,0	€ 1 569,1	€ 1 278,3	€ 467,3
10kWh	€ 1 019,4	€ 970,9	€ 825,2	€ 319,3
15kWh	€ 778,0	€ 749,5	€ 659,8	€ 320,4

Appendix 10– PV systems coupled with battery payback period

Payback period - Years	PV System			
Storage - Stage II	15 kWn	17 kWn	20 kWn	25 kWn
5kWh	7,8	8	8,4	9,1
10kWh	8,7	8,8	9,1	10,1
15kWh	9,7	9,7	9,1	10,8

Appendix 11 – Breakeven with NPV (Coupled system's NPV > PV alone's NPV) and estimate of the number of years until that breakeven takes place.

Breakeven Price per kWh (€/kWh)	PV System			
Storage - Stage II	15 kWn	17 kWn	20 kWn	25 kWn
5kWh	€ 440,9	€ 452,1	€ 468,3	€ 680,7
10kWh	€ 405,4	€ 412,4	€ 420,2	€ 426,0
15kWh	€ 368,7	€ 377,2	€ 389,8	€ 391,6

Years until breakeven with PV	PV System			
Storage - Stage II	15 kWn	17 kWn	20 kWn	25 kWn
5kWh	9,5	9,3	8,9	5,4
10kWh	10,3	10,1	10,0	9,8
15kWh	11,2	11,0	10,7	10,6

Appendix 12.1 – 15 kWn PV system sensitivity analysis

NPV		Peak Prices				
		-20%	10%	0%	10%	20%
WACC	-12,5%	€ 1 719,0	€ 7 002,8	€ 5 241,5	€ 7 002,8	€ 8 764,0
	-6,25%	€ 349,5	€ 5 452,0	€ 3 751,1	€ 5 452,0	€ 7 152,8
	0%	-€ 942,3	€ 3 988,7	€ 2 345,0	€ 3 988,7	€ 5 632,4
	6,25%	-€ 2 161,8	€ 2 606,9	€ 1 017,3	€ 2 606,9	€ 4 196,5
	12,5%	-€ 3 314,2	€ 1 300,9	-€ 237,5	€ 1 300,9	€ 2 839,3

NPV		PV Capex				
		-10%	-5%	0%	5%	10%
Wacc	-12,5%	€ 8 241,5	€ 6 741,5	€ 5 241,5	€ 3 741,5	€ 2 241,5
	-6,25%	€ 6 751,1	€ 5 251,1	€ 3 751,1	€ 2 251,1	€ 751,1
	0%	€ 5 345,0	€ 3 845,0	€ 2 345,0	€ 845,0	-€ 655,0
	6,25%	€ 4 017,3	€ 2 517,3	€ 1 017,3	-€ 482,7	-€ 1 982,7
	12,5%	€ 2 762,5	€ 1 262,5	-€ 237,5	-€ 1 737,5	-€ 3 237,5

NPV		PV Capex				
		-10%	-5%	0%	5%	10%
Peak Price Electricity - I	-20%	€ 2 057,7	€ 557,7	-€ 942,3	-€ 2 442,3	-€ 3 942,3
	-10%	€ 3 701,4	€ 2 201,4	€ 701,4	-€ 798,6	-€ 2 298,6
	0%	€ 5 345,0	€ 3 845,0	€ 2 345,0	€ 845,0	-€ 655,0
	10%	€ 6 988,7	€ 5 488,7	€ 3 988,7	€ 2 488,7	€ 988,7
	20%	€ 8 632,4	€ 7 132,4	€ 5 632,4	€ 4 132,4	€ 2 632,4

NPV		PV Capex				
		-10%	-5%	0%	5%	10%
Storage Unit Capex	-50%	€ 8 345,0	€ 6 845,0	€ 5 345,0	€ 3 845,0	€ 2 345,0
	-25%	€ 6 845,0	€ 5 345,0	€ 3 845,0	€ 2 345,0	€ 845,0
	0%	€ 5 345,0	€ 3 845,0	€ 2 345,0	€ 845,0	-€ 655,0
	25%	€ 3 845,0	€ 2 345,0	€ 845,0	-€ 655,0	-€ 2 155,0
	50%	€ 2 345,0	€ 845,0	-€ 655,0	-€ 2 155,0	-€ 3 655,0

NPV		Storage Unit Capex				
		-50%	25%	0%	25%	50%
Storage Unit Capacity	-50%	€ 5 750,3	€ 3 500,3	€ 4 250,3	€ 3 500,3	€ 2 750,3
	-25%	€ 5 549,5	€ 2 174,5	€ 3 299,5	€ 2 174,5	€ 1 049,5
	0%	€ 5 345,0	€ 845,0	€ 2 345,0	€ 845,0	-€ 655,0
	25%	€ 5 116,4	-€ 508,6	€ 1 366,4	-€ 508,6	-€ 2 383,6
	50%	€ 4 831,4	-€ 1 918,6	€ 331,4	-€ 1 918,6	-€ 4 168,6

Appendix 12.2 – 25 kWn PV system sensitivity analysis

NPV		Peak Prices				
		-20%	10%	0%	10%	20%
WAC	-12,5%	-€ 4 912,8	€ 1 349,7	-€ 737,8	€ 1 349,7	€ 3 437,2
	-6,25%	-€ 6 792,2	-€ 749,1	-€ 2 763,4	-€ 749,1	€ 1 265,3
	0%	-€ 8 564,2	-€ 2 728,3	-€ 4 673,6	-€ 2 728,3	-€ 783,0
	6,25%	-€ 10 236,3	-€ 4 596,3	-€ 6 476,3	-€ 4 596,3	-€ 2 716,3
	12,5%	-€ 11 815,5	-€ 6 360,9	-€ 8 179,1	-€ 6 360,9	-€ 4 542,7

NPV		PV Capex				
		-10%	-5%	0%	5%	10%
Wacc	-12,5%	€ 4 262,2	€ 1 762,2	-€ 737,8	-€ 3 237,8	-€ 5 737,8
	-6,25%	€ 2 236,6	-€ 263,4	-€ 2 763,4	-€ 5 263,4	-€ 7 763,4
	0%	€ 326,4	-€ 2 173,6	-€ 4 673,6	-€ 7 173,6	-€ 9 673,6
	6,25%	-€ 1 476,3	-€ 3 976,3	-€ 6 476,3	-€ 8 976,3	-€ 11 476,3
	12,5%	-€ 3 179,1	-€ 5 679,1	-€ 8 179,1	-€ 10 679,1	-€ 13 179,1

NPV		PV Capex				
		-10%	-5%	0%	5%	10%
Peak Price Electricity - I	-20%	-€ 3 564,2	-€ 6 064,2	-€ 8 564,2	-€ 11 064,2	-€ 13 564,2
	-10%	-€ 1 618,9	-€ 4 118,9	-€ 6 618,9	-€ 9 118,9	-€ 11 618,9
	0%	€ 326,4	-€ 2 173,6	-€ 4 673,6	-€ 7 173,6	-€ 9 673,6
	10%	€ 2 271,7	-€ 228,3	-€ 2 728,3	-€ 5 228,3	-€ 7 728,3
	20%	€ 4 217,0	€ 1 717,0	-€ 783,0	-€ 3 283,0	-€ 5 783,0

NPV		PV Capex				
		-10%	-5%	0%	5%	10%
Storage Unit Capex	-50%	€ 3 326,4	€ 826,4	-€ 1 673,6	-€ 4 173,6	-€ 6 673,6
	-25%	€ 1 826,4	-€ 673,6	-€ 3 173,6	-€ 5 673,6	-€ 8 173,6
	0%	€ 326,4	-€ 2 173,6	-€ 4 673,6	-€ 7 173,6	-€ 9 673,6
	25%	-€ 1 173,6	-€ 3 673,6	-€ 6 173,6	-€ 8 673,6	-€ 11 173,6
	50%	-€ 2 673,6	-€ 5 173,6	-€ 7 673,6	-€ 10 173,6	-€ 12 673,6

NPV		Storage Unit Capex				
		-50%	25%	0%	25%	50%
Storage Unit Capacity	-50%	-€ 1 312,7	-€ 3 562,7	-€ 2 812,7	-€ 3 562,7	-€ 4 312,7
	-25%	-€ 1 484,6	-€ 4 859,6	-€ 3 734,6	-€ 4 859,6	-€ 5 984,6
	0%	-€ 1 673,6	-€ 6 173,6	-€ 4 673,6	-€ 6 173,6	-€ 7 673,6
	25%	-€ 1 887,8	-€ 7 512,8	-€ 5 637,8	-€ 7 512,8	-€ 9 387,8
	50%	-€ 2 163,7	-€ 8 913,7	-€ 6 663,7	-€ 8 913,7	-€ 11 163,7

Appendix 13.1 – Detailed information on the limitations regarding the PV System

In Europe 2015, prices for residential PV systems (5-20kWn) are around USD 2000/kW (Confais, E., Fages, E., & Van Den Berg, W., 2015). Consequently, the incorporated price assumption of €2000/kW in the model is well-founded. EDPD uses monocrystalline Silicon (mono-Si) based PV module in Évora. According to Jordan & Kurtz 192 mono-Si modules in Arcata, CA, USA, over 11 years of exposure display on average a low 0.4%/year degradation rate (Jordan & Kurtz, 2012). Arcata and Évora are subject to similar climatic conditions as they are on the same latitude. Thus the use of 0.7% PV degradation rate is justified.

Appendix 13.2 – Detailed limitation of the battery storage market

Most of the input data was given by EDP directly and therefore needs some critical assessed to what extent they represent values that can be found in the market. Therefore, the most important metrics of a Li-ion storage battery were reviewed and future developments and the influence on the NPV assessed. As performance and prices of Li-ion batteries are highly dependent on the chemicals used, market research was studied in order to assess the relevant metrics (see Appendix 4.5).

EDP provided a price for the whole battery system of € 1,200/kWh. Although there are cheaper availabilities in the market, in order to reach a certain level of efficiency and durability, the price is reasonable, although a rather moderate assumption. Furthermore, moderate predictions regarding the price expect a decrease over the next years to only around €600/kWh in 2020 (Lazard, 2015; IRENA, 2015). Other research gives an estimated linear decrease of 10% per year (KPMG, 2016). This would have a positive effect on this project and the diffusion of the technology overall. All in all it has to be said that there is a wide range of prices in the market regarding different chemical specifications of batteries and therefore make an exact assumption difficult (see Appendix 4.6).

Furthermore, EDP provided a lifetime of the battery of ten years which corresponds to around 3,600 cycles overall. It is a reasonable, though rather conservative assumption. Contemporary research characterises normal ageing of Li-ion batteries as a lifetime of 15 years and strong ageing as a lifetime of 12.5 years (Naumann et al., 2015). Furthermore, battery R&D is expected to slightly improve the life expectancy of batteries. Therefore, a longer than expected lifetime of the battery would have a positive impact on the NPV. Li-ion batteries are expected to improve in terms of durability and can be expected to hold 20 years in the near future and up to 30 years and 10,000 cycles in 2030 (Fuchs, 2012)..

The last important metric of the storage system is the overall efficiency of the battery. An efficiency factor of 85% is in line with market research data and therefore represents a good approximation. The efficiency factor is not expected to change much during the next years and only slightly improve to around 90% until 2030 (Fuchs, 2012).

Overall it can be said that EDPD's assumptions regarding the battery storage system were consistent with market data. The conservative estimates would even give room for an improved NPV.

Appendix 13.3 – Expected development of key characteristics of Li-ion batteries

	Prices		Efficiency		Calendar Life		Cycle Life	
	2014	2020	2014	2030	2014	2030	2014	2030
ENEA, 2014	300 - 1,200 €							
IRENA, 2015	1,000 - 2,000€	200-900 €						
Lazard, 2015	1,200 €	600						
Fuchs, 2012	1,100 €	750	0,85	0,9	5 - 20 years	10 - 30 years	1,000 - 3,000	5,000 - 10,000

Sources: ENEA, 2014; IRENA, 2015; Lazard, 2015; Fuchs, 2012

Appendix 13.4 – Explanation for the WACC

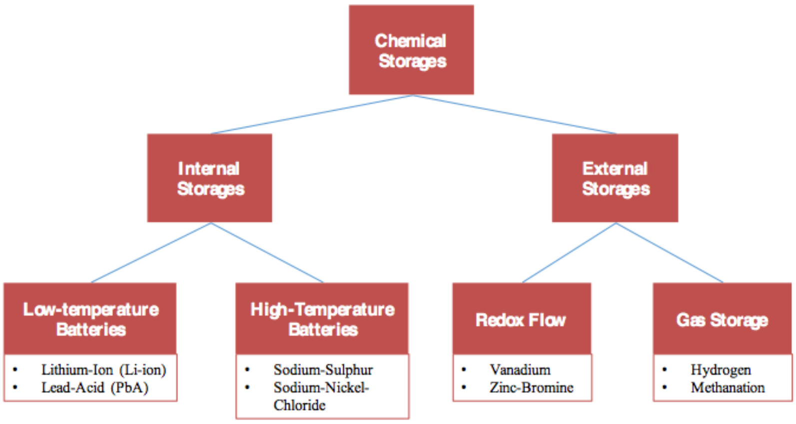
Another input factor that was provided by EDP is the WACC. As there is no information given about the capital structure of the project, CAPM is a good way to calculate the WACC. Based on a 10yrs treasury yield of 2% as a risk-free rate, a beta of EDP of 0.8 (Yahoo Finance, 2016) and an assumed market return of 7% the CAPM would give a discount rate of only 6%. At first this seems to be much lower than the 8% that is given by EDP. But as Portugal is a rather risky market to operate in, a fudge factor of 2% for additional risk can be reasonable.
CAPM:

Appendix 14.1 – PV System Prices

	Prices for PV Systems	Capacity Range	Year	Area
NREL, 2013	2,14 €	10-100 kWn	2013	Germany
IEA, 2013	2,000-2,800 €	5-20 kWn	2012	Italy
Roland Berger, 2015	2,000 USD	5-20 kWn	2015	Europe

Sources: Fraunhofer ISE, 2015; Barbose et al., 2013; IEA, 2012; Confais, E., Fages, E., & Van Den Berg, W., 2015

Appendix 14.2 – Classification of Chemical Storage Systems (named technologies are only examples)



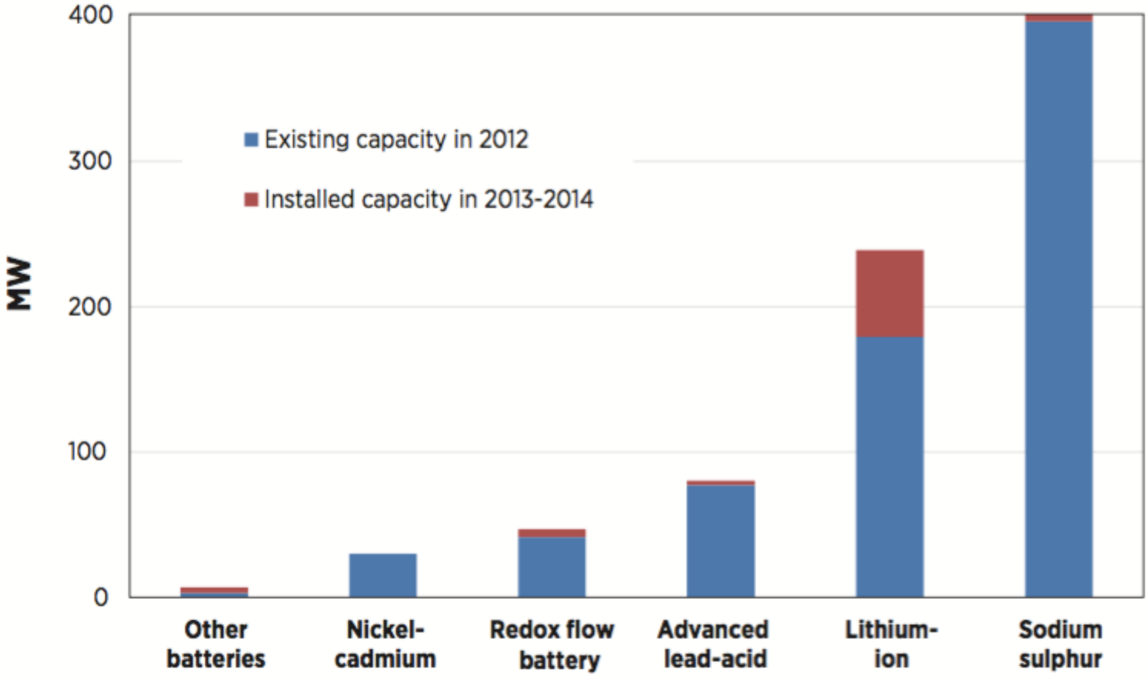
Source: Fuchs, 2012

Appendix 14.3 – Overview of Battery Storage Technologies

	Advantages	Disadvantages	Calendar life	Efficiency	Cycle life	Commercial Maturity
Lead-acid (PbA)	- Low cost and therefore short amortization period - No complex cell management needed - large number of manufacturers available	Short cycle life	5 - 15 years	75 - 80 %	-500 - 2,000 (average 1,500)	High
Lithuium-Ion (Li-ion)	- Long lifetime - High performance - preferred technology in the automobile industry	- sophisticated battery management system needed - high costs - Lithium resources limited to a few countries	5 - 20 years	~ 85%	- 1,000 - 5,000 (average 4,000)	Medium
Redox Batteries	- High cycle life - high storage capacity as storage tanks can be increased - Energy and power independetly scalable	- low energy density - life of the cells is limited - pumps are prone to errors and have high maintenance costs	10 - 15 years	60 - 70 %	> 10,000	Medium
Sodium-Sulphur	- High cycle and calendar life - cheap raw materials - High specific energy	- hazard potential due to high operating temparature - only few producers	15 - 20 years	75 - 80 %	5,000 - 10,000	Medium - High

Source: Rahman et al, 2012; Fuchs, 2012; ENEA, 2012

Appendix 14.4 – Estimated and installed battery capacity (in MW) in the power sector (2014)



Source: Navigant Research, Dehmana et al., 2014

Appendix 14.5 – Expected development of key characteristics of Li-ion batteries

	Prices		Efficiency		Calendar Life		Cycle Life	
	2014	2020	2014	2030	2014	2030	2014	2030
ENEA, 2014	300 - 1,200 €							
IRENA, 2015	1,000 - 2,000€	200-900 €						
Lazard, 2015	1,200 €	600						
Fuchs, 2012	1,100 €	750	0,85	0,9	5 - 20 years	10 - 30 years	1,000 - 3,000	5,000 - 10,000

Sources: ENEA, 2014; IRENA, 2015; Lazard, 2015; Fuchs, 2012

References

Beise, M. & Rennings, K. 2005. Lead markets and regulation: a framework for analyzing the international diffusion of environmental innovations. Ecological Economics. 52 (1), pp. 5-17.

Bossle, M. B., Dutra de Barcellos, M.; Vieira, L. M. & Sauvee, L.2016. The drivers for adoption of eco-innovation. Journal of Cleaner Production. 113, pp. 861-872.

Cai, W. & Zhou, X. 2014. On the drivers of eco-innovation: empirical evidence from China. Journal of Cleaner Production. 79, pp. 239-248.

Confais, E., Fages, E., & Van Den Berg, W. 2015. Solar PV. Paris: Roland Berger Strategy Consultants.

EDP. 2015. Annual Report 2014.

EDP. 2016. EDP Distribucao. http://www.edp.pt/en/aedp/unidadesdenegocio/distribuicaodeelectricidade/Pages/Distribui%C3%A7%C3%A3oPT.aspx (accessed May 13, 2016).

EDP. 2016. EDP Distribucao. http://www.edp.pt/en/Investidores/accaoedp/reprivatizacao/Pages/Reprivatiza%C3%A7%C3%A3o.aspx (accessed May 17, 2016).

European Commission. 2016. 2020 Energy Strategy - Energy - European Commission. https://ec.europa.eu/energy/en/topics/energy-strategy/2020-energy-strategy (accessed May 13, 2016).

Eurostat. 2016. Renewable energy statistics. http://ec.europa.eu/eurostat/statistics-explained/index.php/Renewable_energy_statistics (accessed May 13, 2016).

Fisher, I. 1907. The rate of interest. New York: The Macmillan Company.

Fuchs, G., Lunz, B., Leuthold, M. & Sauer, U. 2012. Technology Overview on Electricity Storage: Overview on the Potential and on the Deployment Perspectives of Electricity Storage Technologies, Institut für Stromrichter-technik und Elekrische Antriebe, RWTH Aachen, Aachen, Germany.

Fussler, C. & James, P. 1996. Driving Eco-Innovation: A Breakthrough Discipline for Innovation and Sustainability, Pitman Publishing: London, 364 p.

Hojnik, J. & Ruzzier, M. 2016. What drives eco-innovation? A review of an emerging literature. Environmental Innovation and Societal Transitions. 19, pp. 31-41.

International Renewable Energy Agency (2015). Battery Storage for Renewables: Market Status and Technology Outlook. January 2015.

Karakaya, E., Hidalgo, A. & Nuur, C. 2014. Diffusion of eco-innovations: A review. Renewable and Sustainable Energy Reviews. 33, pp. 392-399.

Kostova, T., Roth, K. & Dacin, M. T. 2008. Institutional Theory in the Study of Multinational Corporations: A Critique and New Directions. Academy of Management Review. 33 (4), pp. 994-1006.

KPMG. 2016. Development of decentralised energy and storage systems in the UK. A report for the Renewable Energy Association

Lazard 2015. Lazard's Levelized Cost of Storage Analysis. November 2015.

Rahman, F.; Rehman, S.; Abdul-Majeed, M. A. 2012. Overview of energy storage systems for storing electricity from renewable energy sources in Saudi Arabia. Renewable and Sustainable Energy Reviews, 16 (1), pp. 274-283.

Rennings, K. 2000. Redefining innovation — eco-innovation research and the contribution from ecological economics. Ecological Economics. 32 (2), pp. 319-332.

Triguero, A., Moreno-Mondéjar, L. & Davia, M. A. 2013. Drivers of different types of eco-innovation in European SMEs. In: *Ecological Economics*. 92, pp. 25-33.