PRESENT AND FUTURE SCENARIOS FOR CARBON SEQUESTRATION AND STORAGE IN CONTINENTAL PORTUGAL

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Dissertation supervised by Professor Doutor Mário Caetano and Professor Doutor Pedro Cabral

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DECLARATION OF ORIGINALITY

I declare that the content of this document is my own and not from somebody else. All assistance received from other people is acknowledged and all sources (published or not published) are referenced.

This work has not been previously submitted for evaluation at NOVA Information Management School or any other institution

Lisbon, February 24, 2019

DEDICATION

To my family.

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To you Helena, for all the love, care and trust. For all those hard moments where you became my main support. For everything that you mean in the accomplishment of my dreams. My success is our success.

To my parents, for their daily fight that gave me the opportunity of follow my dreams.
For all the pride they make me feel.

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ABSTRACT

Among the main goals for the climate change, defined in the International protocols, are: i) to maintain of the global average rise of the temperature bellow 2º C, and ii) to reduce the Greenhouse Gases (GHG). The carbon dioxide (CO_2) is the biggest responsible for GHG effect. Aiming at mitigating the CO2 emissions, the Portuguese government, under the international directives, has created plans and strategies. Some of this plans and strategies directly impact the Land Use and Land Cover (LULC) Management and they also directly influence the Ecosystems Services (ES) regardless of their nature. Carbon sequestration and storage for the LULC constitutes one of the ES and it brings important benefits for the accomplishment of the 2030 national goals, at an environmental level.

Against this background, this project intends to evaluate the LULC management over carbon sequestration and storage performance, in a future perspective, using scenarios approaches combined with GIS tools.

The intervention scenarios in the High case scenario show that policies effect over the ES produces 8% more than current policies and the Low case scenario produces 1%. The Business-as-Usual approach results indicate that the current policies performance over a future perspective may be responsible for the production of 5%. However, according the LULC trade-offs, current policies may reveal a loss of carbon sequestration and storage capacity over the territory, while in the intervention scenarios there is no loss evidence.

This analysis allows us to conclude that the policies improvement may create conditions for a suitable LULC management, particularly in the carbon sequestration and storage, rather than the current framework of the policies.

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RESUMO

Nos Protocolos internacionais encontram-se definidos os objetivos para o combate às alterações climáticas. Entre eles estão a manutenção do aumento da temperatura média anual abaixo dos 2º C e a redução da emissão dos gases de efeito estufa. O dióxido de carbono (CO_2) é o principal gás responsável pelo efeito estufa. Por esse motivo, Portugal criou um conjunto de planos e estratégias, visando a mitigação das emissões de CO_2. Alguns destes planos e estratégias, têm um impacto direto na Gestão do uso e ocupação do solo, influenciando, ainda, os serviços de ecossistemas, independente da sua natureza. O sequestro e armazenamento de carbono constituem um desses serviços, cujos benefícios se repercutem no cumprimento das metas nacionais para 2030 em matéria ambiental.

Neste contexto, este projeto tem como objetivo a avaliação das políticas de gestão do uso e ocupação do solo no desempenho futuro do sequestro e armazenamento de carbono, com recurso a abordagem de cenários e à sua combinação com ferramentas SIG.

Os dados obtidos mostram que os cenários de intervenção no cenário Alto apresentam resultados que compravam a eficiência e a eficácia na implementação de políticas na produção dos serviços de ecossistemas, com resultados de 8%, situando-se, assim, acima daquilo que é produzido atualmente. Já o cenário Baixo indica que uma implementação não tão eficaz conduzem a resultados de 1%. Por sua vez, uma análise corrente mostra que os impactos das políticas em vigor, numa perspetiva futura, poderiam conduzir a um incremento de 5% na produção dos serviços e ecossistema.

Desta forma, é possível concluir que, mesmo no pior cenário, as implementações de políticas criam condições mais apropriadas do que as políticas em vigor no desempenho dos serviços de ecossistema, particularmente no que diz respeito ao sequestro e armazenamento de carbono

KEYWORDS

Ecosystems Services

Carbon Sequestration and Storage

Land Use and Land Cover

Scenarios

Geographic Information Systems

PALAVRAS-CHAVE

Serviços de Ecossistema

Sequestro e armazenamento de Carbono

Uso e Ocupação do Solo

Cenários

Sistemas de Informação Geográfica

LIST OF ABBREVIATIONS AND ACRONYMS

BAU – Business-as-Usual

DGT – Direção Geral do Território

ES – Ecosystems services

EU – European Union

GHG – Green House Gases

LULC – Land use and Land Cover

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1. INTRODUCTION

It is recognized by the scientific community that the main cause for the global warming is the Greenhouse Gas (GHG) emissions among them, carbon dioxide (CO_2) represents about 60% (Adeyemi, Abu-Zahra, & Alnashef, 2017; Seo, Kim, & Park, 2018). The recent Portuguese policies according the International protocols for the 2030 framework, such as the Paris agreement, points to the GHG reduction which is related to the consumption of fossil fuel and the share of renewable energy consumed. However, it is also assumed by the governments that the Land Use, Land Use Change (LULC) and the Forestry sector have a major role in the GHG mitigation strategy (European Council, 2014). Among other goals GHG mitigation strategy aims to maintain the global average rise of the temperature bellow 2º C (UNFCCC, 2015). In Portugal, these strategies are represented by the National Low-Carbon Roadmap (APA, 2012) in which the government implements a low carbon economy, increasing the consumption of the renewables rather than fossil fuel. Another Portuguese strategy is the National Forest Strategy (PCM, 2015), which points to the development of the forest sector at social-economic and environmental level.

These directives, especially those that include the LULC sector within the strategy for the climate change combat, give room for the development of academic projects on the ecosystems services (ES) approach (Cabral *et al.*, 2016). These approaches might be good options for the stakeholders to take into account in the decision processes. In fact, over the past decades the study on ES has been intensive.(Costanza *et al*., 1997; De Groot, 1992, 1994; De Groot, Wilson, & Boumans, 2002; Odum & Odum, 1972) regardless of the nature of their functions: provisioning, regulation, supporting or cultural (MEA 2005). The carbon sequestration and storage for the LULC sector constitute a complex ES within regulation function (MEA 2005) and they are strongly influenced by their internal conditions such as: the specie, the age, the density of the settlement and their own structure (Faias et al., 2007). They are also influenced by external conditions like those from natural order, or even by human activities set out by the LULC management (Smith *et al*., 2008). The inclusion of the ES, particularly the carbon sequestration and storage approach, into the decision maker processes is relevant for the success of a strategy that aims to fight climate change and the reduction of CO_2 emissions (Sharp et al., 2015).

The use of a scenarios approach offers to the decision makers a set of possibilities to describe the effects of their policies in a future perspective (Mckenzie *et al*., 2013) which are very useful for the development descriptions of uncertain systems (Henrichs *et al*., 2010). Nevertheless, there is no agreement in the literature in the definition of the scenario's types, as well as how to choose the best one to represent the goals (Berg, Rogers, & Mineau, 2016). The best way to address a scenario is: i) to review literature and historical data; ii) to review of existing and proposed policies and strategies; and iii) to consider the stakeholders that have the knowledge about local policies and governance conditions (Rosenthal *et al*., 2015). Geographic Information Systems (GIS) tools and spatial temporal analysis are usually used alongside the scenarios projection (De Groot, 1994).

Thus, this project intends to use this combined analysis to evaluate the performance of the Portuguese strategies for the LULC sector, in order to reach not only their own established goals, but also what it is set out on the international agreements. Particularly, we seek to understand the influence of this strategies and agreements on the forest sector by analysing carbon sequestration and storage. This project is also driven by a change-oriented perspective (Berg et al., 2016) and it tries to ask specific questions: What could change? What would it change into? Furthermore, for a better understanding of the policies impact on the ES, another perspective in the scenarios guidelines will be used, from which other type of question emerges: What if there are no changes?

2. MATERIALS AND METHODS

2.1 Study Area

According to the national cartography of the Land Use and Land Cover “*Carta de Uso e Ocupação do Solo*” (COS) (DGT, 2018), Continental Portugal has an area of 8 910 220 hectares. The most part of the territory is occupied by the forest sector (39%) and the agricultural areas (26.3%). Urbanized areas represent 5.1%, and they are mainly located in the coastal region of the country (Fig. 1).

The spatial distribution of the land cover classes is well explained by the physical characteristics of the territory. In the Central and the Northern part of the territory is possible to find a rugged landscape where the relief reaches altitudes of 1993 meters (Ferreira, 2005), creating natural conditions for the forest expansion. The Southern part of the country has favourable conditions for anthropic activities, such as the agroforestry systems, justified by their large plan areas. It is also important to mention some other LULC classes, although there is no spatial pattern in their distribution, - *e.g.* complex cultivation pattern (18%), scrubs and open spaces (12%) and the pastures (7%).

Having in mind the aim of this project, it is important to better understand the forest sector mapped in the Fig. 1, which describes the spatial distribution of the main species in Continental Portugal. These species include the Maritime Pine (30.1%) that represents the major part of the forest sector, whose concentration is located in the Central Portugal. Alongside this specie, the eucalyptus has a large distribution in the country (25.4%), and its spatial distribution has the same pattern of the Maritime Pine. The Portuguese forest complex is also characterized by large forest stands of cork oak (17.6%) associated to agroforest exploitations, which is one of the main reasons for the concentration in Southern Portugal. The forest complex is also described by some other species, although with less expression in the territory, such as: the stone pine (5.8%), the holm oak (5.8), and some other species that are grouped in broadleaf forests (14.2%) and other coniferous species (1.1%) (Caetano *et al*, 2018).

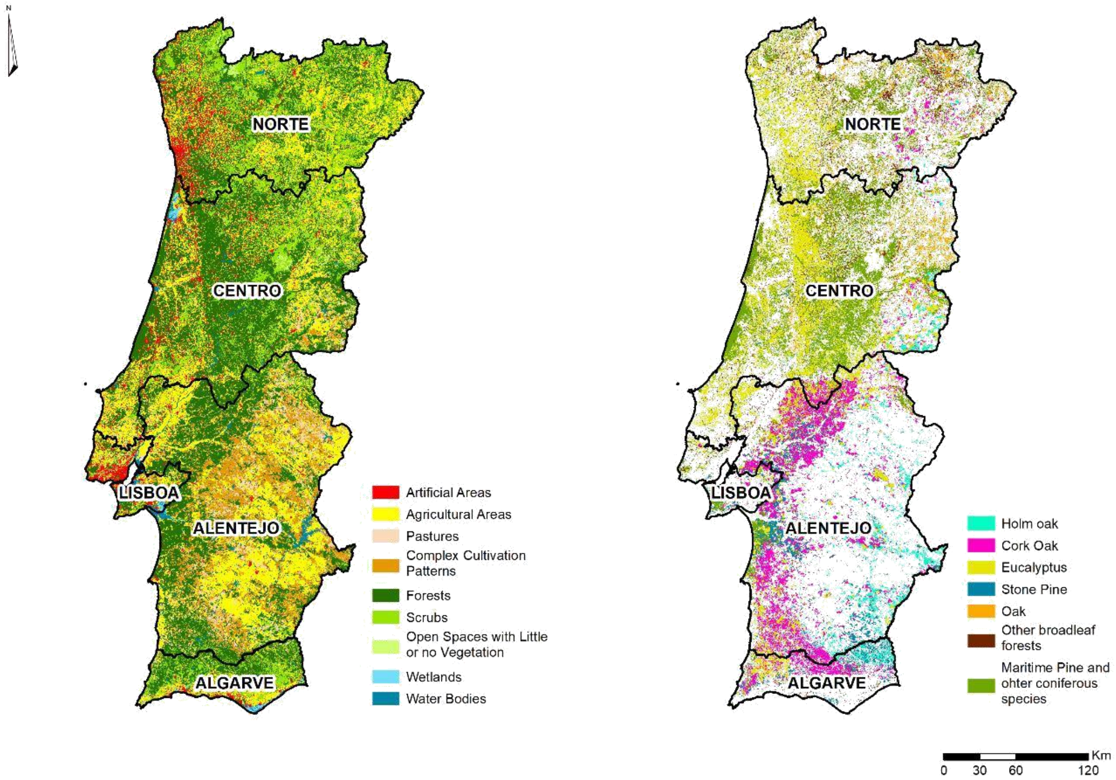

Fig. 1. Land Use and Land Cover (map on the left) and forest species distribution (map on the right) in Continental Portugal in year 2015 (Data Sources: DGT, 2018)

2.2 Modelling Ecosystems Services (ES): Carbon Sequestration

Every model is always a reality generalization and simplification (Box & Draper, 1987). Modelling ES is always a generalization of a complex ecosystem, such as the carbon cycle (Sharp *et al.*, 2015). The natural capital project present us with some tools that are compiled in the InVEST 3.5.0 software, that has been implemented in some projects of this nature (Cabral *et al.*, 2015; Sil *et al.*, 2017). This tools enables to present effective results when we are trying to map the LULC performance in the ES analysis.

The carbon sequestration and storage model requires specific inputs mainly a raster format of the LULC and an input table that provides the amount of carbon that may be stored by each of these classes, according to their pools. The IPCC report (2006) describes these pools in 5 sections: i) the above-ground biomass (AGB), which includes the living vegetation, woody and herbaceous, above the soil; ii) below-ground biomass, characterized by the live roots; iii) dead wood, where the all non-living wood is concentrated; iv) litter, described by all non-living biomass; and v) dead wood and litter and the soil organic matter, that includes organic carbon in mineral soils.

The report for National Forestry Inventory (ICNF, 2010) introduces the carbon sequestration and presents the results for each specie composition. Since this project intends to analyse public data and policies performance, we believe that datasets from public administration sources may produce better results. Although the amount of carbon data collected from the inventory and presented in the Table 1 was insufficient to describe all the carbon classes, that are presented in all national territory. In order to complete the carbon sequestration dataset, the InVEST guidelines approaches were adopted (Sharp et al., 2015). These consist in the literature review of recent publications (Freibauer *et al*, 2004, Sil *et al*., 2017; Smith *et al*., 2008). These data were adjusted to the Portuguese reality.

Table 1 presents all the carbon values for each class, in contrast to the InVEST user's guide recommendations, there is no representation by pool, since the ICNF (2010) report has no such detailed information. For that reason, the carbon sequestration and storage model in this project were processed taking just into account the above-ground biomass pool.

Table 1 - Carbon sequestration and storage matrix

Carbon sequestration and storage	**LULC Class**	**Reference**
35.2	Holm oak	(ICNF, 2010)
55.7	Cork Oak	(ICNF, 2010)
79.8	Eucalyptus	(ICNF, 2010)
83.1	Stone Pine	(ICNF, 2010)
5	Agricultural areas	(Freibauer *et al.*, 2004)
7	Scrub and/or herbaceous vegetation associations	(Freibauer *et al.*, 2004, Sil *et al.* 2017)
4	Pastures	(Freibauer *et al.*, 2004, Smith *et al*, 2008)
1	Complex cultivation pattern	(Freibauer *et al.*, 2004)
60.5	Oak	(ICNF, 2010)
69	Other broadleaf forests	(ICNF, 2010)
92.2	Maritime Pine and other coniferous species	(ICNF, 2010)
0	Other areas	–

An important step regarding the carbon sequestration and storage modelling is the conversion of the LULC data for Continental Portugal into a group of classes that better represent the ES. The Portuguese LULC for 1995, 2007 and 2015 (DGT, 1995, 2007, 2018), was reorganized and then converted the LULC vector (shapefile) into a raster format (GRID) with a cell size of 50 ^{2} using GIS tools (ArcGIS 10.6.1). The spatial resolution of 50 ^{2} was used because the InVEST software has no capacity to process detailed information.

In the conversion process it was necessary to consider several options that influence the results of the models. The LULC data for Continental Portugal has suffered some transformations along time, specially related with the number of classes that were used (89, 225 and 48 respectively). The most detailed, as the LULC for 2007, describe the forest classes, using a range of areas (*e.g.* pure forest stands, mixed forest stands with a dominant one, cuts ad new plantations and burnt areas). The less detailed, as the LULC for 2015, groups all these classes, defining them as pure forest stands.

It is assumed in the modelling process that this distinction will increase the amount of carbon for each carbon class. However, considering our subject scale (Continental Portugal) we believe the modelling process produces consistent results regarding the variation of the carbon sequestration.

2.3 Scenarios approach

2.3.1 Scenarios development

Following Mckenzie *et al*. (2013) we adopted to different scenarios approaches in this project:

i. The intervention scenarios, also called policies scenarios, are used to identify effective and equitable interventions to meet policy goals and their purpose is to include someone’s vision in an uncertain future.
ii. The future projection or the Business-as-Usual (BAU), is the most suitable approach for the evaluation current policies future consequences and it point to a situation without any kind of interventions or changes in other scenarios; it can be based on historical trends or stakeholder expectations.

The evaluation of carbon sequestration and storage is highly dependent of the LULC changes. Thus, modelling representative future scenarios for this ES involves the analysis of the trade-offs among the LULC classes.

In order to modelling the intervention and BAU scenarios we use InVEST – Scenario Generator: Ruler Based model (Sharp et al., 2015). This tool works as a multicriteria process, for which is necessary to assign weights for the trade-offs between each class (Eastman, 2006). The weights are given in the scenario generator model by a transition likelihood matrix. The matrix must submit the trade-off between classes, given by a weight varying from 1to 9. Additionally, it should be complemented with the percentage of growing for each class. The table reflects the scenario approach selected for the evaluation.

2.3.1.1 The intervention scenario

The intervention scenarios are the best way to achieve a future that is idealized by the stakeholders. In other words, this approach is useful to represent how politics or other intervention are projected in the future and to foresee the consequences (Mckenzie et al., 2013). In this analysis were considered two possible scenarios for Continental Portugal: the Low scenario and the High scenario. These scenarios represent the stakeholder vision, particularly the 2030 National Strategy for the Forests goals (PCM, 2015). In this strategy, the government adds not only the environmental function of the forest, where the carbon sequestration is included, but also the social-economic one. The main goal for the forest sector in the Low scenario is to improve in 3% the forest areas. On the other hand, the High scenario produces an increase of 12%.

Both scenarios are designed in order to consider trade-offs between foreign species (as eucalyptus) and autochthonous species (as oak and stone pine and maritime pine). Above all, the key for a regulated forest, according to the National Forest Strategy, is the expansion of forest stands instead of the deforested areas.

2.3.1.2 The Business -as-Usual (BAU) projections

Aiming at measuring the future effect of the current policies, the BAU seems to be the must to be the most appropriate and reasonable approach. Generally, this projection is used when the objective is to establish a baseline that depicts the current situation (Mckenzie *et al*., 2013).

In this sense, it is necessary to find changes in the LULC existing data. These changes can be quantified through variation along time (1) in the latest 20 years (1995 – 2015).

$$_{1995-2015} = \left[\frac{_{2015} - _{1995}}{_{2015}}\right] \times 100 \qquad (1)$$

where $_{1995-2015}$ is the total variation between the LULC for 2015 ($_{2015}$), and LULC for 1995 $_{1995}$.

Assuming that the variation *per* year is the same during the 20 years, the projection spread this variation for the next 15 years (2) to reach the analysis period to the 2030 target (Seo *et al*., 2018).

$$_{2030} = \times (1 +)^2 \qquad (2)$$

where $_{2030}$ is the goal set on the National Strategy for the Forest sector (PCM, 2015) and the goals set for the EU (European Council, 2014).

3. RESULTS

3.1 Scenarios evaluation

Fig. 2 shows the results of all the scenarios approaches. According to the figure, it is possible to measure trade-offs between each class and find the main differences in line with each scenario.

The results of the intervention scenarios suggest a very ambitious goal for the forest sector in Continental Portugal. The strategy defines an increase for autochthonous species, since the main goal is a suitable development for the forest sector. The increase of autochthonous species based on the occupation of the deforested areas by species with better adaptation to the soil and climate conditions are the main guideline for this strategy (PCM, 2015). To accomplish the stakeholder goals, the main changes into the carbon classes indicate an increase of maritime pine and other coniferous species of 35% and in the Low case scenario 6.4%. Another finding, in the intervention scenarios, is the high growing of the stone pine stands, which represent 24.8%, in the High scenario, and 13%, in the Low scenario. Finally, the analysis also reveals a significant increase of the stone pine stands, 28.5%, in High scenario, and 9%, in the Low scenario. The Forest National Strategy supports the development of the forest sector in the trade-offs among forest classes for the deforested areas. For that reason, the results presented in Fig. 2 reveal a high decrease of the scrub and/or herbaceous vegetation associations (-40% and -27.7%), since the deforested areas are part of this class.

The BAU model represents the variation that is possible to observe in the 1995-2015 period, although it is not so significant. Obviously, these are expected results, once that the variation for 1995-2015 represents the development of the LULC trade-offs for a time window for 20 years and in the BAU analysis a time window for 15 years. BAU results for 2030, emphasise the decline of the maritime pine and other coniferous species in 18.9%, and a low decline of the scrub and/or herbaceous vegetation associations (-3.4%). Furthermore, BAU results highlight the improvement of the stone pine (34.3%), the eucalyptus (21.1%) and the other broadleaf forests class (18.7%).

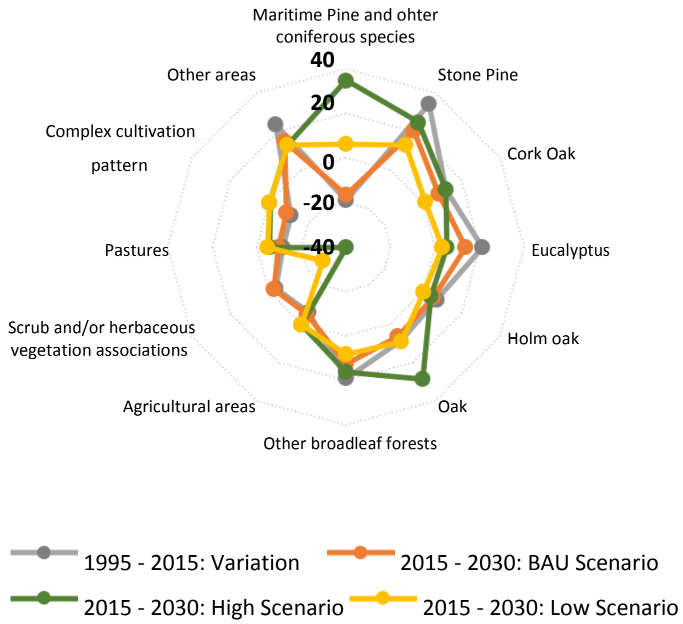

Fig. 2. Variation of the carbon classes in each scenario

3.2 Carbon sequestration and storage scenarios

After modelling the scenarios, according to the main objective of this paper, it is important to understand the impact of them in what concerns the ES under discussion. The main results for the carbon sequestration variation, pointed out the Portuguese forest will improve their capacity for carbon sequestration and storage, regardless of the scenarios results.

According the Fig. 3, the BAU scenario, with a sharp decline of the maritime pine forests, could indicate an increase of the carbon sequestration and storage of 5%.This fact can be justified on a large scale for the increase of the eucalyptus forests and the stone pine, due the fact of this two classes represent those with the largest capacity for carbon sequestration and storage (see Table 1).

The Low scenario presents lower results than the BAU scenario. The increases of the carbon sequestration if the policies achieves the lower results could be 1%. The Low scenario comparing to the other scenarios could not be based on a sharp increase of any specie. This scenario is also conditioned in large scale by the constraints of the Forest National Strategy (PCM, 2015), since the strategy tried to block the evolution of foreign species and develop the autochthonous ones. It’s important to mention that, according to

Table 1, autochthonous species, as the oak or the holm oak, have a lower capacity for the carbon sequestration and storage.

High scenario is the one in which it is possible to find more efficiency, regarding the carbon sequestration, improving in 8% the capacity of the Portuguese forest in this ES. The main factor for the higher performance comparing to the lower scenarios is the higher decrease in the scrub and/or herbaceous vegetation association class (-40%), and high grow rates in species, such as maritime pine and the oak.

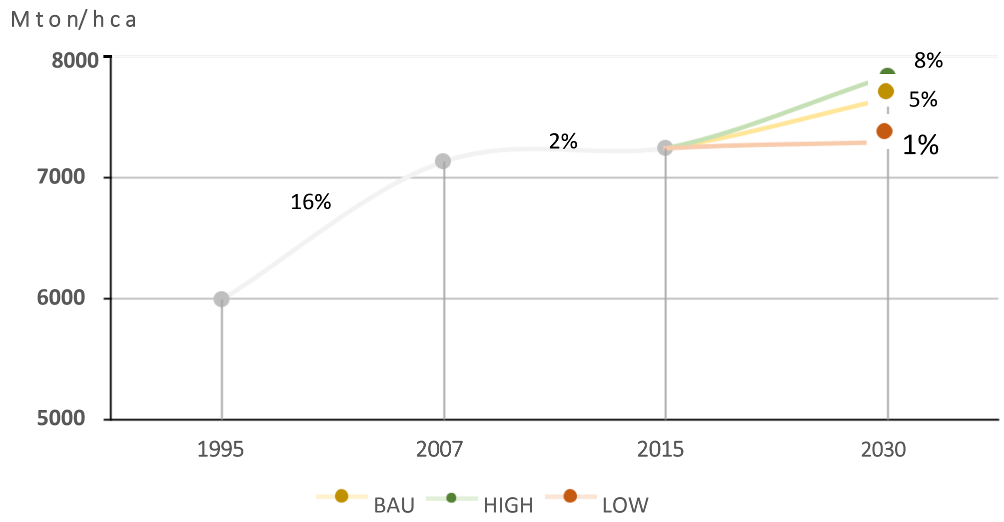

Fig. 3. Evolution of the carbon sequestration and storage scenarios in Continental Portugal

The spatial analysis for carbon sequestration and storage models constitutes an important indicator in this project. At this point it is important to observe the results for the carbon sequestration and storage scenarios spatial distribution for the future perspectives that were considered.

The central part of the country consists of a high concentration of the forest areas compared to other country's NUT. Therefore, the results underline that the concentration of the highest amounts of carbon sequestration and storage are precisely located in this region.

Fig. 4, reveals that the North and Algarve regions, as well as the central region are positively affected by the intervention scenarios, especially in the High case scenario. This fact is highly related to the high concentration of deforested areas in these regions.

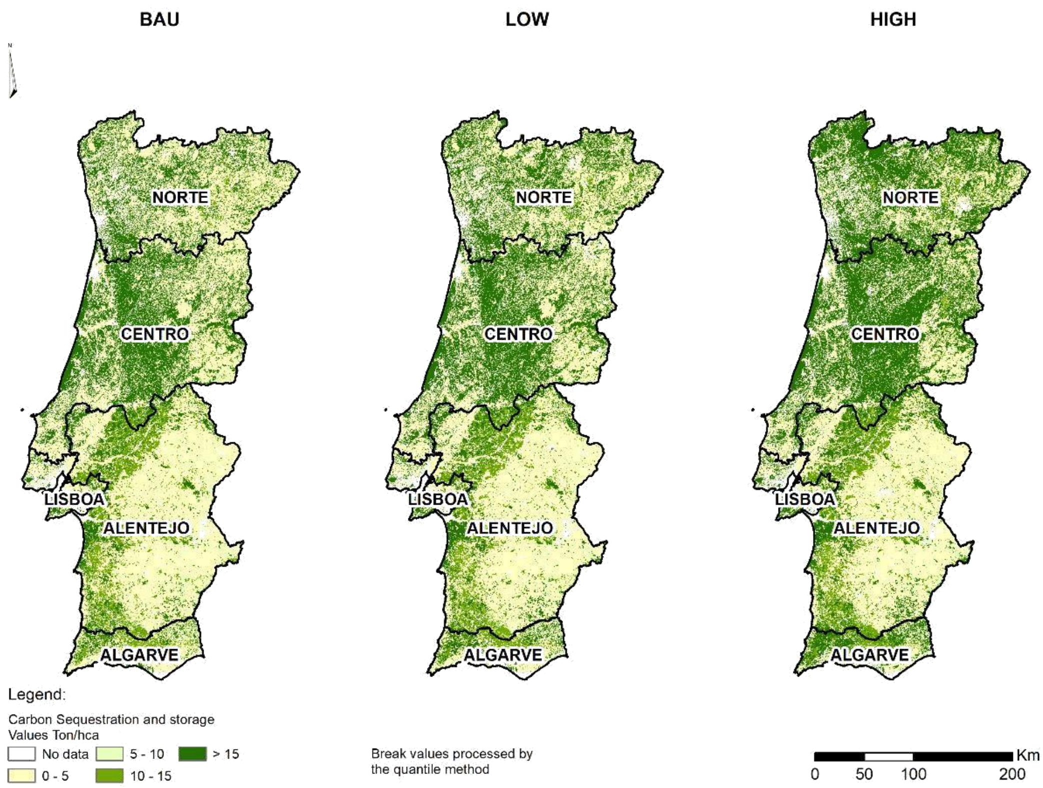

Fig. 4. Carbon sequestration and storage for each designed scenario

Fig. 5 shows the scenarios approaches in the ES and allows us to get interesting conclusions over the carbon sequestration and storage projections. Intervention scenarios reveals that policies interventions cause a good behaviour in the ES and that, with the policies implementation, it is possible to find no carbon capacity losses by the carbon classes. Otherwise, the BAU scenario trade-offs among carbon classes, will produce negative results and carbon losses in many areas, particularly in the southern area of the territory, even producing better results in the total carbon sequestration and storage capacity than the Low case scenarios.

This result allows us to conclude that, even with a non-effective implementation of policies, such as the Low case scenario, the Forest National Strategy demonstrates effectively results in the LULC management and, consequently in the carbon sequestration and storage.

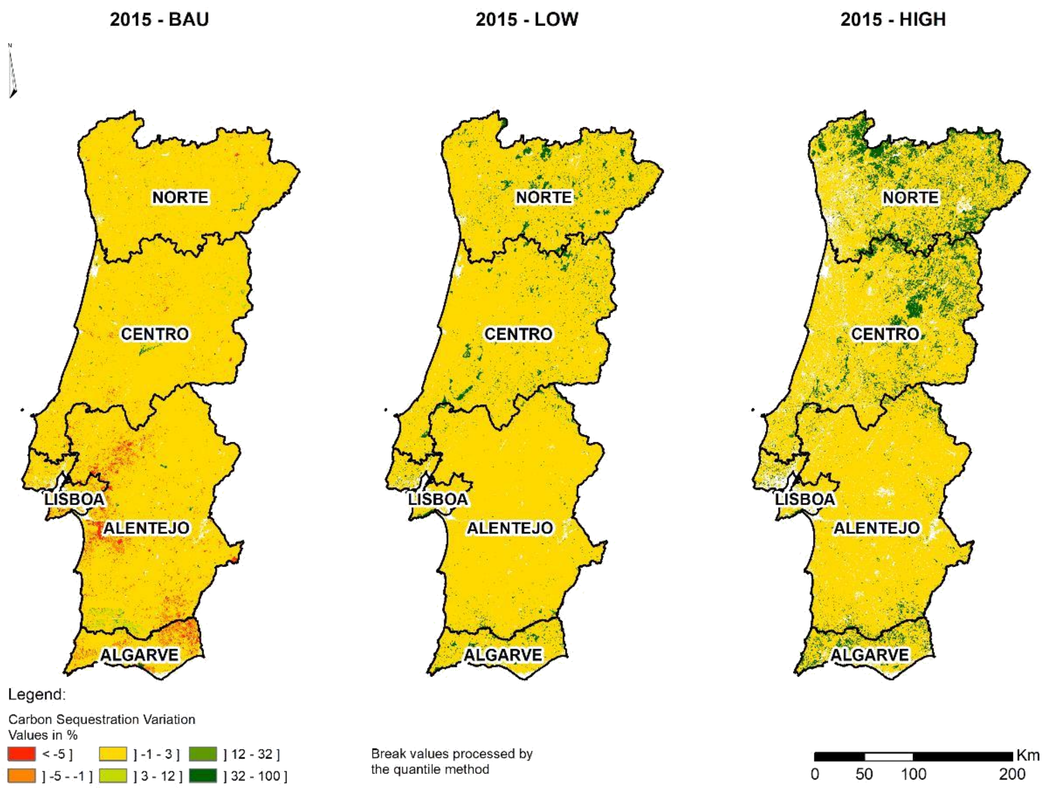

Fig. 5. Carbon sequestration variation in Continental Portugal

4. DISCUSSION

4.1 Free modelling tools for ecosystems services and scenarios

This study evaluate the performance of current policies and new strategies for the LULC management that may impact ecosystems services, particularly in carbon sequestration storage, with the use of free tools. It is necessary to take some precautions with the InVEST scenarios, especially with the carbon model, which has several limitations (Sharp *et al*., 2015). The scenarios of the carbon model represent a static modelling, conditioning the model processes to the hypothesis of LULC short period changes. Furthermore, the model results are highly dependent of the LULC inputs, and the conversion of the carbon classes should be carefully processed, once it may induce to wrong results. Results should be carefully considered to avoid wrong interpretations and, for this reason, this project is focused in the variation rate rather than on the quantities of carbon stored. One of the main limitations is related to the data collection guidelines of carbon model (Sharp et al., 2015). These guidelines recommend to make literature review for this process. However, this process is complex because it may induce us to choose inaccurate data for the study area.

During the scenarios modelling process it is also possible to find some limitations of Scenario Generator tool. The incapacity to process a big amount of data is the main limitation, since the data conversion induces generalizations into carbon classes and, consequently, produces inaccurate results. Future versions of the study should contrast the results of the modelling process with another dataset, such as the Corine Land Cover.

4.2 Integration of scenarios approaches in decision makers processes

This thesis contributes with a methodology to use COS to monitor carbon sequestration in Portugal. It also contributes with a case study which reflects different policy options and their impact on the climate regulation ecosystem service.

Scenario projections make possible to understand the political influences under the LULC management in future visions (Mckenzie et al., 2013). The study presents effective results of the demonstration of how useful the scenarios approaches could be in the construction of strategies that include ecosystems services and LULC policies. It also underlines the importance of the scenarios projections over the definition of the current policies.

There are several options in what concern the scenarios projections, although this type of analysis must be adopted considering data scarcity and scale (Cabral et al., 2016). This is the main reason that induce us to opt for the intervention scenario rather than other scenarios, where the stakeholders have a more participatory function. We believe that the best approach to represent the stakeholders' vision, according to the scale of this project, is through a national strategy specifically developed for the LULC management.

Nevertheless, a future scenario approach should promote a stakeholders' intervention, where the parts should integrate not only the governance sector, but also economic and environmental actors.

5. CONCLUSION

This study assesses the impact of policies on the land use and land cover management, under the ecosystems services, especially regarding the carbon sequestration and storage, and evaluates the policies performance, using spatial-temporal analysis.

Considering the goal of this project, GIS tools play an important role monitoring the efficiency of political strategies on land use planning.

The intervention scenarios - which are capable of producing a policy overview into a future scenario and comparing them with a projection of current policies - allow us to obtain useful insights about the impact of different strategies for the forest sector. The spatial-temporal analysis has a significant impact and it is the key for the monitoring of policies over time. GIS tools alongside the scenarios analysis has a very important role for the stakeholders to improve their measures in order to ensure their goals.

Overall, this approach leads to very accurate results. Although, for the next research project, the use of other scenarios approaches, such as those that use another type of tools (*e.g.* surveys or stakeholders' participation), seems to be a good recommendation.

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