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Economic Sustainability Models for Land Uses on Rural Territory – The Case of the Olive Tree

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Group Part

Abstract

This thesis evaluates the economic viability of five land-use systems - maritime pine, eucalyptus, cork oak, olive groves, and solar panels - through growth, financial, and geospatial modelling. The case of the olive tree is the main focus of this document; olive trees were assessed across three cultivation systems to balance profitability and sustainability. The remaining work was conducted by other group members as part of the common group document. For forestry cultures, APIs linked to StandsSIM and SUBER 5.0 simulators were used to simulate and assess profitability of Mação's management approach and provide recommendations. The Solar farms were evaluated using GIS and financial models, identifying optimal sites based on socio-environmental, location and climate. Findings highlight strategies for sustainable resource use, improved land-use practices, and renewable energy development in Mação.

Keywords

Business Analytics, Territory Sustainability, Economic Models, Forest, Wildfires

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1. Introduction

This first chapter introduces the document and is divided into three sections. The first section describes the origin of the project, the context in which it is situated, and the motivation for its development. The second one presents the problem addressed and summarizes the approach used to resolve it. Finally, the third and last section discusses the organization of this document.

1.1 Motivation and Context

Historically, in the 1950s and 1960s, the agro-silvo-pastoral systems that characterized rural areas maintained a multifunctional landscape from both economic and ecological perspectives. However, with significant population exodus, most of the territory was abandoned and left unmanaged, leading to the widespread accumulation of vegetation, serving as fuel for wildfires.

Mação, a Portuguese region located in the district of Santarém, is a living example of these challenges. This Portuguese territory covers 41,000 hectares and is divided into 80,000 properties owned by 20,000 individuals, averaging 0.7 hectares (Médio Tejo 2019). Since most property owners left their land unmanaged, the territory has become highly vulnerable to fires.

Over the past 30 years, Mação's municipality has seen its territory being devastated by wildfires. Between 1991 and 2019, large wildfires burned a significant proportion of the territory, the most severe ones being those that took place in 2003, 2017, and 2019 (Fernandes et al. 2020). In 2017 (ICNF 2017), 27,000 hectares were affected by wildfires, corresponding to 67% of the territory's area. In 2019, although the burned area was smaller compared to 2017, the wildfires affected the areas that had not burned in the previous wildfire, leaving a total of 90% of the territory affected (ICNF 2019). These numbers show the necessity of changing the current design of the rural landscape to reduce the fire vulnerability of this Portuguese territory.

Currently, in response to these challenges, Mação has developed 9 Integrated Landscape Management Areas (AIGP) (Câmara Municipal de Mação 2021). These areas are designed with the objective of promoting sustainable landscape management through collective agroforestry exploitation, especially in areas with a high risk of wildfires. Each AIGP includes the development of Integrated Landscape Management Operations (OIGP), consisting of strategies for landscape transformation, territorial enhancement, and revitalization. They also address practical aspects including financing, management, and monitoring ensuring long-term success.

These operations are detailed through two key maps: the POSA (Current Land Use Map) and the POSP (Proposed Land Use Map). The POSA documents the existing land use, while the POSP outlines the planned changes, focused on reducing wildfire risks, improving ecosystems, and revitalizing the local economy. It follows a transformation strategy based on the natural characteristics of the territory and land suitability, following preventive forestry laws and territorial programs. The POSP includes the proposed land use units (based on the COS 2018 nomenclature, a land occupation map that provides a structural view of the territory), the ecological and resilience structures and the structural elements, such as notable landmarks, hedges, walls, terraces, and infrastructure necessary for landscape transformation and management. The landscape transformation matrix compares the POSA with the POSP, providing a summary table showing the variation of values across different land use categories.

In total, AIGPs cover 20,209 hectares which corresponds to around 50% of the municipality's total area (Matias 2023). Within these areas, conditions will be created for the development of OIGPs, executed by a collective management model overseen by a managing entity. The OIGPs are supported by a long-term, multi-fund program that provides financial backing for initial investments and ongoing management activities (Câmara Municipal de Mação 2021).

To design and implement these AIGPs it is essential to assess the medium and long-term economic sustainability of the proposed landscape models. This project's objective is to address this challenge by studying, implementing, and evaluating the most efficient models available in the literature for the AIGPs. These will be integrated into the LAND IT system (Computer-Aided System for the Design of Integrated Territory Management), currently being developed in a partnership between NOVA School of Science and Technology and AZR - Gestão Territorial, S.A., a company established in Mação that manages the AIGP of Mação and is responsible for developing its Integrated Landscape Management Operation (OIGP). A more detailed explanation on the LAND IT platform can be found in Section 3.

1.2 Objectives and Approach

This thesis integrates various approaches to model and analyze the economic and environmental performance of five selected land use systems: maritime pine, eucalyptus, cork oak, olive groves, and solar panels. The order of analysis reflects the temporal scale, progressing from long term forestry crops (maritime pine, eucalyptus, and cork oak) to a one-year agricultural system (olive groves), and finally to solar panels. Forestry systems prioritize sustainability and profitability over extended timelines, while agricultural systems aim to optimize yields, and solar panels focus on site feasibility and financial modelling to maximize energy production.

I. Forest Species – Maritime Pine, Eucalyptus and Cork Oak

The StandsSIM simulator served as the foundation for the development of a growth and economic model for both eucalyptus and maritime pine, while cork oak modelling was based on SUBER 5.0. To enhance usability, APIs were created for each species, to integrate these models into the LAND IT platform. The APIs enable users to customize simulations by inputting parameters such as tree density and planning horizon, generating tailored outputs like cash flow projections and operational costs. To provide practical guidance for sustainable forest management, both univariate and multivariate sensitivity analyzes were conducted so that optimal management strategies could be identified.

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II. Olive Tree

The analysis of olive tree cultivation focuses on three distinct systems: traditional, potted, and hedge. The model is built on practical inputs, including annual maintenance costs, installation expenses, olive oil market price and yield dynamics, that are going to vary according to the age of the olive grove. The main goal of the developed model is to provide actionable recommendations that balance profitability with sustainability practices in olive production.

III. Solar Panels

The feasibility of utility-scale solar farms was assessed through a combination of geospatial and financial modelling. Using Geographic Information Systems (GIS), 16 polygons from the OIGP database were evaluated based on criteria such as slope, solar radiation, and proximity to substations. This analysis shortlisted four viable sites, which were further analyzed. Financial models integrated investment costs and operational expenses with the objective of identifying the most economically viable options for renewable energy development.

1.3 Document Structure

This thesis is structured into nine sections, each addressing specific parts of the research. The first section introduces the motivation, context, and objectives of the study, highlighting the challenges addressed, and the methodologies applied to achieve the thesis' main objectives. It concludes with this overview of the document structure. The second section focuses on Mação's geography and territorial characteristics, as well as the relevance of the AIGPs. The third and fourth introduce and give key insights regarding both LAND IT and sIMfLOR, respectively. From the fifth to seventh section the maritime pine, eucalyptus, and cork oak are analyzed, respectively. These sections present the development of an API, sensitivity analyzes, and recommendations for sustainable management practices. Section eight analyzes olive trees, and its different cultivation systems to evaluate their economic and operational performance in

Mação, while the ninth section evaluates the feasibility of solar farms, incorporating geospatial and financial modelling to optimize site selection and assess economic viability.

2. Mação

This chapter provides a detailed analysis of Mação, focusing on its location, territorial characteristics, and implementation of AIGPs (Integrated Landscape Management Areas).

2.1 Mação's Location and Territory Characteristics

Mação, located in the district of Santarém, lies at the geometric center of Portugal, and spans approximately 41,000 hectares. Figures 2.1 and 2.2 show the most recent land use cartography, COS 2018, and that the predominant land use is forestry, marked in green in Figure 2.1, with maritime pine and eucalyptus dominating the landscape with 48.6% and 27.7%, respectively. On the other hand, agricultural lands, including olive groves occupy smaller areas, accounting for 4.89%, represented in orange, while buildings and roads are represented by red polygons.

Additionally, Mação is divided into six parishes: Amêndoa, Cardigos, Carvoeiro, Envendos, Mação, Penhascoso, Aboboreira, and Ortiga. These geographic features define a diverse landscape but with challenges related to land management and environmental sustainability.

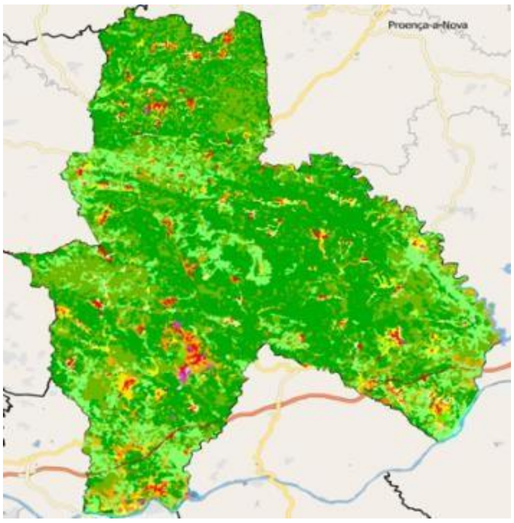


Figure 2.1: COS Map | Source: Matias 2023

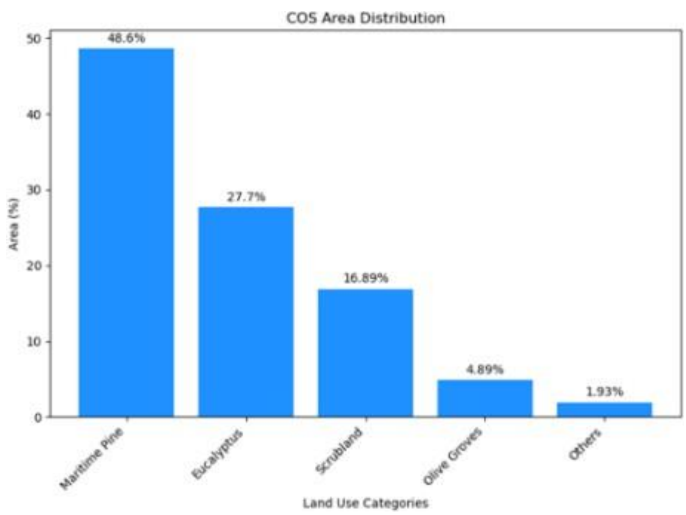


Figure 2.2: COS Area distribution

The topography of Mação is highly varied with more than 55% of the terrain exhibiting slopes between 5º and 15º, which makes the area prone to erosion and increases the risk of wildfire propagation, especially in steeper regions. Also, the hypsometry further highlights its varied land with 50% of the area situated 250–350 meters above sea level (Figures 2.3 and 2.4).

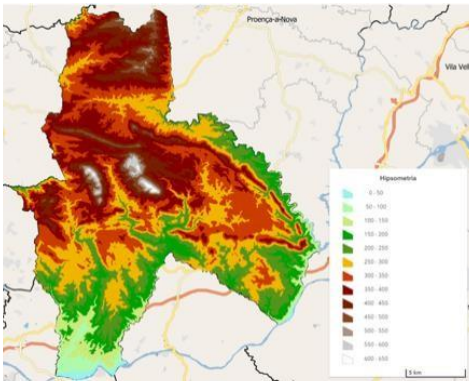


Figure 2.3: Hypsometry in Mação

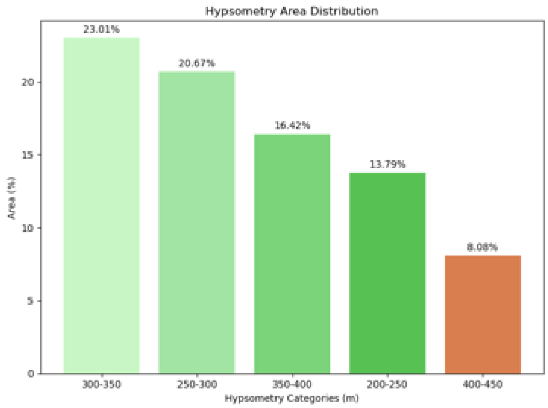


Figure 2.4: Map Hypsometry in Mação | Source: Matias 2023

These physical characteristics, combined with abandoned properties, biomass accumulation, and high summer temperatures exacerbated by climate change, make Mação one of Portugal's most wildfire-prone zones. Figures 2.5 and 2.6 show that 60% of its territory is classified as high or very high fire risk.

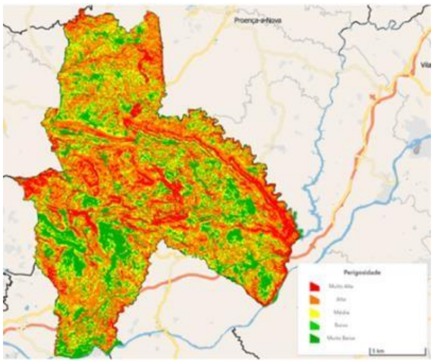


Figure 2.5: COS Hypsometry in Mação

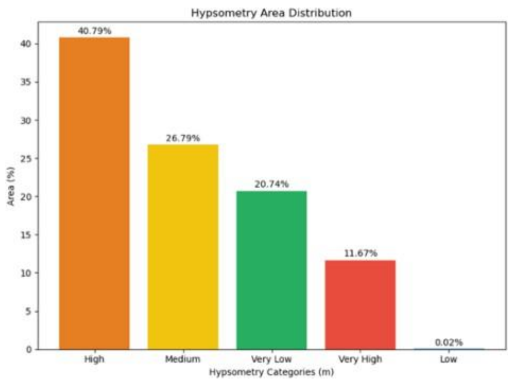


Figure 2.6: COS Map Mação | Source: Matias 2023

2.2 Mação's AIGPs

Mação has established nine AIGPs: Aboboreira, Amêndoa, Cardigos, Carvoeiro, Castelo, Envendos, Mação, Ortiga, and Penhascoso, which cover approximately 20,209 hectares or about 50% of the municipality's total territory. These AIGPs are a response to the critical need to reduce wildfire vulnerability while aiming to promote environmental, social and economic sustainability. This project focuses on analyzing four AIGPs: Amêndoa, Ortiga, Castelo, and Carvoeiro, which were selected by the Municipality of Mação for their strategic importance.

2.3 POSA and POSP: Current and Proposed Landscape Design

Mação's strategy for landscape management relies on two essential tools: the Current Land Use Map (POSA) and the Proposed Land Use Map (POSP). POSA provides a detailed overview of the current land use, revealing the dominance of maritime pine and eucalyptus forests, while agricultural areas, such as olive groves are presented in a smaller portion. This distribution reflects historical land management patterns, heavily focused on forestry, which has contributed to the region's economic activities. However, this increases vulnerability to wildfires, given the high flammability of these species. Figure 2.7 shows the areas occupied by the cultures under study in each AIGP. The POSP presented in Figure 2.8, shows the proposed changes to Mação's landscape, aiming to address the fire hazards and ecological imbalances identified in the POSA. A key change is the reduction of maritime pine and eucalyptus forests in favor of fire-resistant vegetation, such as cork oak forests and agroforestry systems. These adjustments aim to diversify land use, integrating sustainable agricultural practices and increasing the coverage of olive groves and cork oak forests, which offer greater ecological resilience and economic value. Additionally, the POSP introduces innovative land uses, such as renewable energy projects of solar farms to enhance economic productivity while reducing dependence on common forestry.

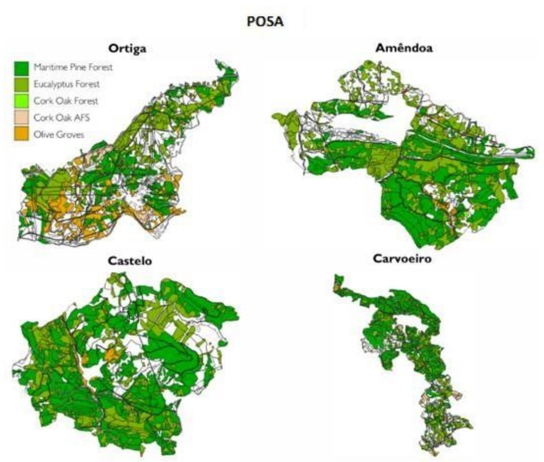


Figure 2.7: Current Land Use Map in four specific AIGPS

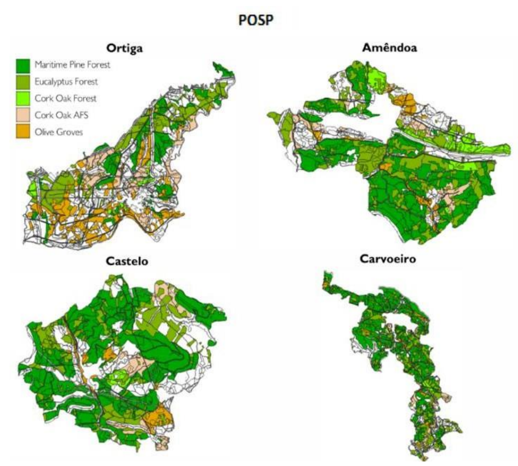


Figure 2.8: Proposed Land Use Map in four specific AIGPs

3. LAND IT Platform

The creation of an OIGP is a highly detailed and iterative process that was designed to address challenges in land-use planning in territories identified as vulnerable in the AIGP (DGT 2023). LAND IT creation emerged to solve the inefficiencies associated with OIGPs creation. It consists of a Decision Support System that integrates advanced geospatial tools and data-driven decision-making capabilities, in order to save time and reduce errors when developing an OIGP.

LAND IT platform is very useful when it comes to automate and enhance the OIGP creation, however, one of its limitations consists in the integration of economic models. Although some models are already integrated within the platform, some are still missing, which restricts the specialists from fully understanding the economic viability of their proposed projects.

Economic models are an essential part to understand the feasibility of the land use proposals (Direção Geral do Território 2023), since they provide the ability to evaluate if a given scenario will generate the income necessary to surpass the initial investment to reorganize a determined area. The values returned by the economic models integrated will give the necessary insights to guide decisions that balance both economic and ecological resilience of the projects developed.

Therefore, this study aims to address this gap in the platform. Models for key land uses such as maritime pine, Eucalyptus, Cork Oak and Olive Trees will be incorporated, as well as a study for Solar Panels' installation. These models will provide detailed information regarding the Net Present Value, Equivalent Annual Annuity, Total Costs and Total Profit, helping them to be more informed when analyzing the viability of their developed projects.

4. sIMfLOR Platform

This chapter introduces sIMfLOR, that integrates diverse simulators for the principal forestry species in Portugal and aims to facilitate the use of growth models by its users. It allows to manage data inputs, running and visualizing outputs. This chapter is divided into two sections, providing a detailed description of the StandsSIM and the SUBER simulators.

4.1 StandsSIM

In the following subsections the StandsSIM simulator will be introduced. The first section will give an overview, while the subsequent ones will describe both the inputs and outputs given. Finally, the last section describes some improvements made to the simulator during this study.

4.1.1 StandsSIM Overview

The StandsSIM is a Management Driven Forest simulator developed to model and predict forest growth dynamics for Portugal's primary wood-producing species: eucalyptus (Eucalyptus globulus) and maritime pine (Pinus pinaster Aiton.). Designed to address challenges like deforestation, reduced wood production, and compromised carbon sequestration exacerbated by climate change and wildfires in the Mediterranean region, StandsSIM provides a long-term simulation framework tailored to Portuguese forest landscapes (Barreiro et al. 2016); Simflor Platform 2024). Its advanced growth models allow for simulations at both the individual-tree and stand levels, offering flexibility for even-aged and uneven-aged stands. By incorporating theoretical models and customizable silvicultural operations — such as harvesting, thinning, and planting — StandsSIM ensures adaptability for diverse forest management scenarios.

StandsSIM's unique advantage lies in its integration of climate dynamics, wildfires risks, and economic variables into forest simulations, filling the gaps left by earlier simulators. Users can tailor parameters like basal area targets, thinning intensity, and planting densities to meet specific goals while evaluating financial metrics, such as operation costs and production receipts (Barreiro et al. 2016). These features empower landowners and forest managers to make informed decisions. By combining cutting-edge models, StandsSIM is an indispensable resource for addressing the evolving challenges of forest management in Portugal.

4.1.2 Inputs

The StandsSIM requires a variety of inputs related to the forest management approaches, costs of operations, prices and site characteristics. Moreover, data on the climate of a specific country, region or even management unit is integrated, tailoring the predictions to each specific land.

Firstly, data on the stands' characteristics is received for new and existing stands. For both, information on the species – if the simulation is for maritime pine or eucalyptus –, age of the stand in years, number of trees planted per hectare, if the stand is even- or uneven-aged, and the time horizon planning, is gathered. For the specific case of existing stands simulations, there is a need for additional data related to tree measurements, such as height and diameter. At this stage, the user can also specify the beat-up rate, representing the percentage of trees planted that are expected to die, making it possible for the simulator to account for the mortality rate.

Moreover, data on silvicultural operations is gathered. This accounts for all silvicultural practices taking place in the culture's lifetime. There is a wide variety of operations for the user to choose, from land preparation, planting, cleaning, thinning, final harvesting, debarking and shoot selection. Thinning operations involve selectively cutting individual trees of a stand while the final harvesting is the last cut when trees reach commercial maturity (Mendes et al. 2017), where fully-grown trees are collected. Both operations generate income (Centro *Pinus* 2016). Although thinning occurs more than once in the life cycle of maritime pine, it generates less revenue compared to the final cut, as trees are smaller. Moreover, the simulator operates under the constraint that shoot selection must take place in the same ordinary year across all rotations. For the eucalyptus, information on the duration of each rotation cycle is also necessary.

Furthermore, growth conditions are mandatory inputs for the simulator to predict the trees' growth over time. To measure the productivity capacity of a specific site, the simulator receives the site index. This forestry measurement is expressed as the expected height of dominant trees, based on previous plantations in that land, and at a specific reference age that depends on the species and region (ICNF 2021). The height of the tallest or most vigorous trees reflects the quality of the growing conditions, making the predictions for the tree growth more accurate.

For accurate financial predictions, it is important to gather economic inputs, such as costs and revenues. The costs of each silvicultural operation and corresponding unit –tree, kilometer or hectare –, costs on wages and products such as seeds, pesticides, and fertilizers are necessary to calculate total cash outflows. For the revenue's calculation, it is necessary to input wood and biomass prices. Lastly, climate data such as number of rainy days per year, precipitation, average temperature and frost days is gathered to simulate the growth pattern of each species.

By integrating all this information, the simulator generates highly accurate and customized predictions for each forest management unit. This high volume of inputs ensures a realistic simulation, providing a robust tool for informed decision-making in forestry planning.

4.1.3 Outputs

With the inputs presented in Section 4.1.2, the simulator generates some outputs, in the form of comma separated files, with the growth and financial predictions for each site index inputted.

The first output file provides information about the number of trees alive throughout the species' lifespan and their corresponding diameters. As such, for each site index and year, the simulator predicts the number of alive trees and distributes them across different diameter ranges. An overview of this file is presented in the Appendix IV Section, in Figure IV.2.

Moreover, the simulator creates another output file with financial predictions. For each site index, the simulator calculates the Net Present Value (NPV) and Equivalent Annual Annuity (EAA) for discount rates of 3%, 4% and 5%, allowing users to select the rate that aligns with their desired rate of return. The NPV assesses the project's profitability by calculating the present value of future cash flows and comparing them to the initial investment (Brealey et al.

2020). The EAA translates the NPV value into a constant annual cash flow, helping to access the evaluation of projects with different time horizons (Brealey et al. 2020). A visual of this file is depicted in Figure IV.3 present in the Appendix IV Section.

Lastly, the final output file combines all calculations from the simulator. For each year and site index, the simulator computes over 50 indicators. Starting with the final cut, thinning and debarking operations, the file marks the year in which these were performed. This is of extreme importance because, maritime pine is subject to Wilson Factor criteria.

Wilson's Factor consists of a relative measure of stand density, which evaluates the appropriate number of trees per hectare in a stand, as a function of the dominant tree height, being a key measure in guiding thinning operations. The logic behind the Wilson Factor is that larger trees (with greater heights or diameters) require more space, resulting in fewer trees per hectare for the same stand density. In contrast, smaller trees can support a higher density.

Thinning is an operation performed to optimize growth conditions. If the number of trees per hectare in a stand is already below the threshold determined by the chosen Wilson Factor, no thinning is applied, ensuring that the stand is not under the deserved number of trees per hectare. The site index has a certain influence, as trees in higher site indexes achieve greater heights and diameters than those at lower site indexes, at a faster rate. This rapid growth means that trees occupy more space earlier in their development, reaching thresholds of competition and crowding sooner, therefore requiring thinning operations to occur sooner. Conversely, trees that grow in less productive soils achieve smaller height and diameter, taking longer to reach the thresholds associated with competition. This leads to the delay of thinning operations.

For the maritime pine case, the simulator works under these explanations. Even if a thinning operation is prescribed by the user, the simulator will only execute it if the conditions mentioned above are fulfilled. Specifically, for thinning operations, the simulator checks if the tree density is sufficient, given the site index conditions applied, to proceed with the operation. As such, if a thinning operation is scheduled for a year when the stand density falls below the required threshold, the operation is skipped and a 0 is recorded for that year in the output file. This distinction is very important since it ensures the simulation is realistic and intelligent, avoiding operations that violate the imposed requirements.

Additionally, the file also provides the expected tree's dominant height for each year, along with the number of trees that are expected to be alive or dead. Other calculated indicators include the basal area, wood volume with and without bark, total wood volume produced and cut, and biomass volume – distinguishing between branches, leaves, resin and more. Lastly, the file also includes financial data, detailing the inflows from wood and biomass sale, and outflows related to management schedules, assortments and labor costs. The revenues generated by biomass are also recorded, allowing the simulator to calculate the Net Present Value (NPV) for each year, its cumulative, and the Equivalent Annual Annuity (EAA) of the project.

This final output file is the most important to analyze, as it consolidates all information in one place, shown by Figure IV.4 in the Appendix IV Section. As such, for further evaluations, it should be the main focus, as it can reveal essential insights and trends.

4.1.4 StandsSIM Improvements

The StandsSIM simulator requires a significant amount of information. As a result, consulting forestry specialists in Mação became critical to determine fixed parameters applicable across the region. For example, it was clarified that Mação only sells wood in eucalyptus plantations, while biomass is also sold for maritime pine stands. Additionally, the costs associated with land preparation, plantation, maintenance and harvesting are uniform across all AIGPs. This allowed these parameters to be treated as fixed inputs for the model. To obtain these values, consultations with experts such as Margarida Tomé, professor at *Instituto Superior de*

Agronomia, and António Louro, president of AZR and Aflomação, were conducted. By these, practiced prices in the municipality, the typical planning horizons for maritime pine and eucalyptus stands, and other critical metrics were gathered. These values and operations are explained in Sections 5.7.1 and 6.7.1 of the maritime pine and eucalyptus chapters, respectively.

One of the most important inputs for the simulator is the site index, as previously mentioned. Unfortunately, no specific data was available regarding site indexes for maritime pine and eucalyptus lands in Mação. To address this issue, data from the Inventário Florestal Nacional was used, covering parcels in Mação and nearby municipalities (Proença-a-Nova, Sertã, Vila de Rei, Sardoal, Abrantes, Gavião, Nisa, and Vila-Velha de Ródão). Based on this information, three possible site index scenarios were calculated: low (*Mação 5*), medium (*Mação med*), and high (*Mação 95*). These site indexes - 15.44, 20.69, and 25.86 for low, medium, and high productivity levels, respectively - enabled simulations to be evaluated under different growth scenarios. Since the productivity of maritime pine and eucalyptus soils is similar in Mação, the same site indexes were applied for both species in the simulations.

However, working with the StandsSIM simulator posed significant challenges during this thesis. The simulator had to be replaced, updated and improved eight times due to errors and inconsistencies identified throughout the research process. These repeated changes required constant adaptation and recalibration of the models, which added complexity to the analysis. Despite these difficulties, the iterative process led to more accurate simulations and a deeper understanding of the proposed landscape management strategies.

4.2 SUBER

This section introduces SUBER, its inputs, simulation process and outputs.

4.2.1 SUBER Overview

The SUBER simulator was specifically developed for the management of cork oak stands in Portugal. By providing simulations for cork oak plantations, it enables analysis of cork production, stand growth and economic viability along the tree's lifecycle.

This simulator has various improved versions, the most recent one the SUBER 5.0. This can calculate cork production independently of the tree's age, allowing more flexible simulations for different management scenarios. Additionally, SUBER 5.0 integrates a site quality index that considers the management practices, soil and climatic variables. The index assesses the productivity potential of a stand to plan the strategies that will maximize the cork production and economic returns. Another distinctive feature of SUBER 5.0 is its classification as an individual-tree and distance-independent model. This approach simplifies calculations by excluding spatial competition indices, making it applicable across various management scenarios while maintaining robust predictions for tree growth, cork production, and stand dynamics. This version also simulates new cork oak stands without requiring prior forest data, expanding the model's usability to areas where historical data is unavailable.

To improve its utility, the model incorporates a graphical user interface within the sIMfLOR platform, enabling visualization of simulation results. Overall, SUBER 5.0 represents a comprehensive tool that allows the simulation of long-term cork oak stands and its evolution, allowing to better understand the impact of the management practices.

4.2.2 Inputs

SUBER 5.0 requires a detailed and structured set of inputs to guarantee accurate predictions. These inputs are the foundations for predicting growth and economic parameters over time and can be distinguished between inventory and economic data. The inventory data contains variables such as tree identification, height, cork thickness, and harvesting height collected during forest inventories. The model also incorporates specific parameters for cork harvesting, including the minimum age for the first stripping, coefficients for cork removal, and whether subsequent harvests will increase the harvesting height. This data must follow strict validation rules on cork age, harvesting height and the number of cork layers removed, ensuring it aligns with structural and legal requirements of cork oak management. This validation is important as it helps to avoid errors that could compromise the accuracy of the simulations.

Regarding the economic inputs, it includes information on labor costs, machinery, consumables and management operations, as well as revenues derived from cork and wood products. To calculate revenue, cork and wood, prices are necessary and can be differentiated by cork type, such as virgin or "amadia" cork. Cork price ranges can also be defined by five caliber classes (e.g., <18mm, 18–23mm, 23–27mm, 27–41mm, 41–90mm) and three quality levels (e.g., grades 3, 4, and 5), creating up to 15 combinations that reflect real market conditions. The discount rate used to calculate the NPV and EAA is 5% by default but can also be adjusted.

Lastly, the stand's operational plan is received as input. Users can specify operations for regular or irregular stands, reflecting the diverse realities of cork oak stands. Finalizing input configuration process, users can save the inputs in formats compatible with sIMfLOR's platform, enabling seamless integration and its future reuse for multiple simulations.

4.2.3 Simulation

There are two types of simulations: one for newly established stands and another for existing forests, allowing users to simulate different scenarios, depending on available data.

For new established stands, as there are no measurements, the model uses data collected from forest inventory plots, allowing for a precise analysis of growth. Users can choose between simulating each plot individually, enabling highly specific projections, or aggregating data to represent a larger stand, used when data is not available or when the objective is a general overview of forest dynamics. For the specific case of already existing forest, users must add information on the number of branches, total height, cork caliber, and cork quality. If tree measurements are not available, the model estimates them from existing data.

Regardless of the approach, the simulations executed and its results are accessible, enabling the analysis of outputs such as production trends, biomass growth, and cork quality over time.

4.2.4 Outputs

Outputs are tailored to provide insights into tree and stand level. At the individual tree level, the model analyzes variables like height, basal area, and diameter growth.

At stand level, the outputs analyze general trends of the stand, such as the basal area with and without cork, the density of trees per hectare, and canopy coverage. This perspective provides a better understanding of the stand's overall growth trajectory. Cumulative to that, the data on biomass components, including wood, branches, leaves and roots, show the total productive capacity of the stand. The metrics on the weight and quality of the cork harvested (virgin and "amadia") provide insights into economic outputs over multiple harvest cycles.

The outputs also record the metrics before and after interventions, such as cork harvesting or thinning, and help to understand the changes in growth dynamics and the impact of the interventions. The diameter class evolution and carbon stock are other metrics present in the outputs. The diameter class evolution demonstrates how trees progress through various size categories, while the carbon stock reflects the stand's role in carbon sequestration.

The SUBER simulator also integrates visualization tools. The generated graphics and charts allow for easier interpretation of complex datasets and aim to help strategic decision-making. By analyzing detailed quantitative data with environmental and operational considerations, the outputs allow forest managers, researchers, and policymakers to make informed decisions that balance economic returns with ecological awareness on the cork oak.

5. The Case of the Olive Tree

5.1 Olive Tree in Portugal and Mação

Portugal has become one of the most important regions for growing olive trees, due to its favorable climatic conditions. Thus, the olive tree has not only become a crucial element of Portuguese countryside, but also an economic pillar, mainly due to the olive oil's production, which is recognized for its high quality (Jordão 2014). As a result, Portugal is the fourth-largest olive oil producer in the EU, accounting for around 5% of total production (European Commission 2024), which reflects strong investment in modern olive growing systems and the strategic importance of olive tree in the national economy.

The olive tree is widely cultivated in Portugal, with the main producing regions in the Alentejo and Trás-os-Montes. Alentejo is a region that stands out for its high productivity, which is the result of the introduction of more modern olive groves, potted and hedge, explained later. This region, which covers around 50% of the country's olive area, is responsible for approximately 80% of national olive oil production, benefiting from the Alqueva irrigation perimeter, which has led to exponential growth in olive oil production since the early 2000s (BPI Research 2023).

Other regions such as Trás-os-Montes, Beira Interior, where the district of Mação is located, and Ribatejo maintain more traditional practices, with a focus on preserving quality and local varieties. Figure 8.1, clearly shows that different olive grove management techniques, but also different soil and climatic conditions result in significant variations in productivity, as an example, while Alentejo has an average production of 4833kg/ha, regions such as Between Douro and Minho have considerably lower values, such as 1379kg/ha, which represents almost four times less production than Alentejo (INE 2023).

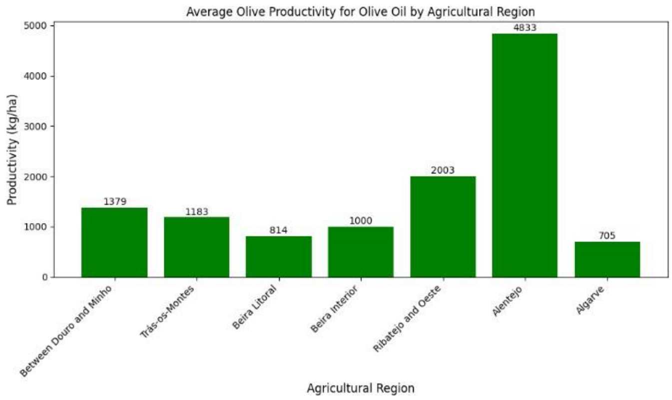


Figure 8.1 - Average production by agricultural region. (INE 2023)

High national production reinforces the critical role of the olive oil sector in the Portuguese economy. Since 2011, Portugal has been a net exporter of olive oil, and in 2023 exports reached around €1.06 billion, while imports totalized €505.74 million (Comtrade Plus 2024). This positive trade balance, which exceeded €552 million, highlights the competitiveness of Portuguese olive oil on the global market. Analyzing Figure 8.2, we can observe that olive oil exports significantly outstrip imports, with a considerable difference between the lines. This performance is sustained not only by the increase in production, but also by investment in modern technology in the plant, ensuring that Portuguese olive oil has high quality and is highly competitive (BPI Research 2023).

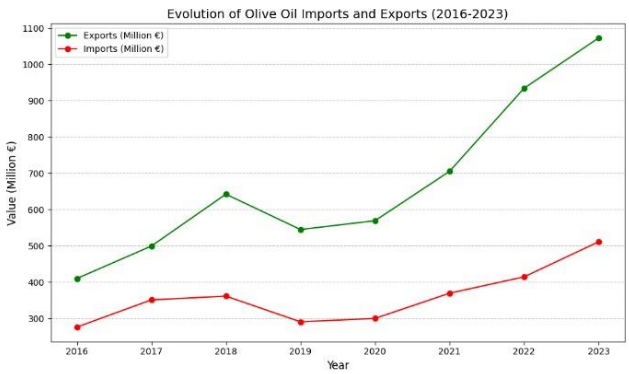


Figure 8.2 - Olive oil imports and exports in Portugal (Comtrade Plus 2024)

To obtain a more detailed understanding of the distribution and impact of olive cultivation in Portugal, it is essential to look at specific areas where the activity is extremely important. In this sense, the Mação region stands out not only for its vast expanse of land dedicated to olive cultivation, but also for being a clear example of the importance of the crop, with approximately 50% of the cultivated agricultural area.

The olive tree is predominantly present compared to other crops such as vineyards, strawberry trees and lemon trees (Matias 2023). By analyzing Figure 8.3, we can observe that in the four AIGP's under study, Carvoeiro, Castelo, Ortiga, and Amêndoa, the olive tree stands out in relation to the other crops. This improves the understanding of the olive tree's economic contribution to local agriculture, but also its central role in the region's rural identity.

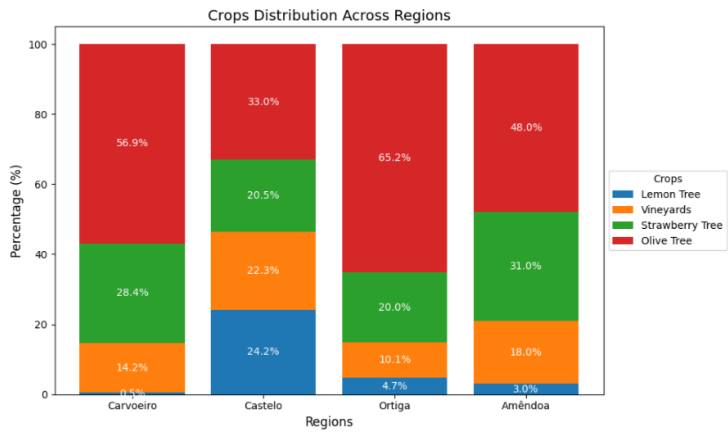


Figure 8.3 - Distribution of agricultural crops in four AIGPs in Mação (Municipality of Mação)

After emphasizing the economic importance of the culture in the region, it is also important to consider its ecological value, since the culture also makes a significant contribution to environmental sustainability. The valorization of biomass, using waste such as branches and leaves from pruning, enables the production of renewable energy and other valuable products, reducing environmental contamination and minimizing CO2 emissions. Separately, Traditional rainfed olive groves, which dominate in Mação, represent the most resource-efficient cultivation system, requiring minimal external inputs, which makes them inherently more sustainable, supporting local biodiversity and improving the resilience of rural ecosystems. Together, these practices underscore the olive tree's pivotal role in promoting sustainability in regional agriculture (Sales et al. 2022).

5.2 Olive Growing Systems

The olive tree's life cycle is influenced by environmental factors, such as temperature and the availability of water, which determine yields and the overall sustainability of olive growing. The impact of these factors varies according to the cultivation system used, which rises to three completely different olive groves: traditional, potted and hedge, which are going to be analyzed ahead.

5.2.1 Traditional Olive Grove

The traditional olive grove is characterized by low density, between 80 and 100 trees per hectare. In this growing system, the trees are planted with wide space, which allows the development of extensive canopies and deep roots. The trees start producing between 5 and 7 years, reaching 100% productivity around 10 and 12 years, and can live and produce for quite a long time, up to 100 years, with consistent production cycles of up to 25 years (AGRO.GES 2021).

According to Mação's Municipality, this system is the most widely used in the region, where tradition and environmental sustainability are priority factors. This growing system has the advantage of preserving the soil structure, maintaining biodiversity and using fewer external resources, which make it ideal for areas that value sustainable practices. However, productivity is lower compared to other modern types of olive groves, and climatic variations usually have a significant impact, since the system depends solely on seasonal rainfall (Oliveira 2022).

5.2.2 Potted Olive Grove

Potted Olive Grove has a higher density than traditional groves, between 200 and 500 trees per hectare. In terms of the planting method, the trees are spaced less widely apart and are irrigated in order to optimize growth and production. In this way, the olive tree starts producing earlier, between 3 and 4 years old, reaching its peak productivity at 8 years, with lifespan of 25 years

(AGRO.GES 2021). The fact that this growing system is irrigated allows more efficient growth management and significantly higher productivity.

This system is mostly used in regions such as Alentejo, where Alqueva irrigation project has helped to maximize the potential of plantings (Ferreira 2020). In Mação's case, the transition from traditional to potted olive grove is considered to increase productivity and consequently economic income, although investment in irrigation system is one of the challenges that need to be considered (Pereira 2014).

5.2.3 Hedge Olive Grove

The Hedge olive grove is the most up-to-date and has a density between 1600 and 2000 trees per hectare. In this olive grove, trees start producing around 3 years old and reach maximum production at 5 years, earlier than in the two previous olive groves, although their lifespan is the shortest, between 12 and 15 years (AGRO.GES 2021).

The main advantage of this system is its high productivity and efficient harvesting, which is completely mechanized, reducing labor costs. Although it is the type of olive grove with the highest production values, it requires investments in technology and demanding resource management, as well as having a significant environmental impact, especially in terms of water consumption and soil composition (Silva 2022).

In order to make easier to compare the three types of olive groves, Figure 8.4 shows the main differences between the characteristics of each olive grove, the planting density, the age at which production starts, the age at which maximum production is reached and the longevity of the tree, as well as the irrigation method and the main olive tree varieties that are most suitable.

Characteristic	Traditional Olive Grove	Potted Olive Grove	Hedge Olive Grove
Plantation Density	80-100 trees/ha	200-500 trees/ha	1600-2000 trees/ha
Age of Start of Production	5-7 years	2-3 years	3 years
Age of Maximum Production	10-12 years	8 years	5 years
Tree Longevity	>100 years	Around 25 years	12-15 years
Irrigation Method	Rainfed	Irrigation	Irrigation
Main Varieties	Galega, Cobrançosa, Cordovil, Verdeal	Arbequina, Cobrançosa, Picual	Arbequina, Arbosana

Figure 8.4 - Characteristics of the three types of olive groves (AGRO.GES 2021).

For each olive grove, the best main varieties chosen are most adapted to the conditions and characteristics of each growing system. In traditional olive grove, "Galega", "Cobrançosa", "Cordovil" and "Verdeal" are the most used due to their resilience to drought conditions and low water requirements. For potted and hedge olive groves, varieties such as "Arbequina", "Picual" and "Arbosana" are the most suitable, as they have a positive response to the irrigation method, which results in mechanized harvesting and more efficient production, but also a significant reduction in labor costs.

5.3 Related Work and State of the Art

During the research, several models were analyzed to estimate olive grove production, to use them later in the simulation; however, each model has limitations that could make its practical application unfeasible.

5.3.1 Linear Regression Model based on Root System

The Root-based Linear Regression Model is based on the characteristics of olive tree's root system to predict yield, using three variables: Root Weight Density, that represents the tree's ability to absorb water and nutrients; Root Length, that correlates with the surface area for nutrient absorption; and Root Biomass, that indicates the overall health and vigor of the tree. This model is useful for management practices that seek to improve root growth; however, it assumes a constant linear relationship between root growth and yield, which may not be verified in different soil types and climatic conditions. In addition, measuring root characteristics on a large scale can be laborious and costly (López-Bernal et al. 2018).

5.3.2 Yield Estimation using Weight and Number of Fruits

The Yield Estimation Model using weight and the number of fruits consists in a simple formula that multiplies the number of fruits per tree by the average weight of each fruit. In this way, the model provides a direct and practical estimate of production, especially useful in smaller groves or in experimental studies. Despite this, the model assumes uniformity in the fruit of all trees and disregards variations caused by age, management practices and environmental factors, which once again limits its application (Fernández et al. 2021).

5.3.3 Trunk Cross-Sectional Area (TCSA) Model

In this model, production is estimated based on the cross-sectional area of the trunk, considering that a larger trunk generally indicates a more resilient and productive tree. This method is useful in orchards where tree size reflects potential production, but it does not consider factors such as pruning and irrigation that can influence productivity, nor differences in age or even specific characteristics of each variety (Martin-Verdedor et al. 2020).

5.3.4 Tree crown area method (TCA)

This method, as the name suggests, uses the area of the tree's crown as an indicator of production, assuming that a larger crown increases the tree's photosynthetic capacity. TCA is particularly advantageous in potted or hedge olive groves, where the size of the canopy is more uniform and controlled. However, it assumes that whenever the canopy is larger, production is also higher, disregarding effects such as excessive pruning and shading. Furthermore, measuring the crown is very challenging in irregular trees (Oliva et al. 2022).

Each model examined had limitations that restricted its applicability for accurate and practical olive grove production forecasts. As a result, detailed and specific information on the olive crop was gathered, and a customized simulation was developed to meet the specific needs and conditions of the olive grove, intended for later integration into the LAND IT platform.

5.4 Methodology

The extraction of the data needed to build the model and the simulation of olive grove production was carried out using a structured methodology that was articulated in different stages. The main objective was to ensure that the information collected was specific, taking into account the variation in maintenance costs and productivity.

The first step involved identifying credible sources of information. To this end, contact was made with the company Fitolivos, recognized for its expertise in foliar nutrients and bio protection of agricultural crops, including olive trees.

With the help of Fitolivos, it was possible to establish contact with a professional with consolidated experience in olive cultivation. This expert contributed to a detailed analysis of the model's needs, emphasizing the importance of adjusting cost and production data based on variables such as the age of the trees and the cultivation system used (traditional, potted or hedge). The exchange of knowledge at this stage was crucial for identifying errors in the data and directing the next stages of the research.

Based on the guidance provided, it was decided to carry out further research with agricultural consultancies, Consulai and AGRO.GES, both recognized for their consultancy experience in the agricultural, food and rural sectors. Both consultancies were contacted to collaborate in providing data and after a detailed presentation of the study's needs, a response was obtained from AGRO.GES.

After analyzing the requests, the consultant provided detailed information on annual maintenance costs, productivity and other essential parameters. Finally, the data was analyzed, taking into account the specific challenges of growing olive trees in different systems and stages of development. The methodology adopted ensured the integration of practical and theoretical information from experts and a renowned agricultural consultant, resulting in a model adjusted to the real conditions of the olive sector.

5.5 Developed Model

The goal of the developed model was to create a practical tool for assessing the economic viability of different cultivation systems. The model is based on carefully collected inputs, combines information with olive tree's lifecycle and presents clear and intuitive outputs that allow an objective assessment of the results.

5.5.1 Inputs

The model's inputs have been organized into three main categories, as can be observed in Annex VIII.1: (1) those provided by AGRO.GES, (2) those defined by the user, and (3) those obtained via the European Commission's API, making it possible to personalize the simulation calculations according to real information and user-adjustable criteria.

The inputs provided by Category (1) focuses on olive groves in Portugal, highlighting modernization and sustainability in Alentejo's region, especially the Alqueva irrigation area. These inputs from AGRO.GES include three essential elements for the simulation purposes: annual maintenance costs, installation costs, and the annual yield production.

Annual maintenance costs (€/ha) cover detailed operational expenses such as pruning, fertilization, irrigation, herbicide use and vegetation management, and harvest and transport of olives, varying according to the type of cultivation system. Figure 8.5 shows how these expenses are distributed. In the traditional system, the highest costs are related to harvest and transport of olives, while in the potted and hedge systems, the most significant costs are concentrated in fertilization, irrigation and phytosanitary treatments.

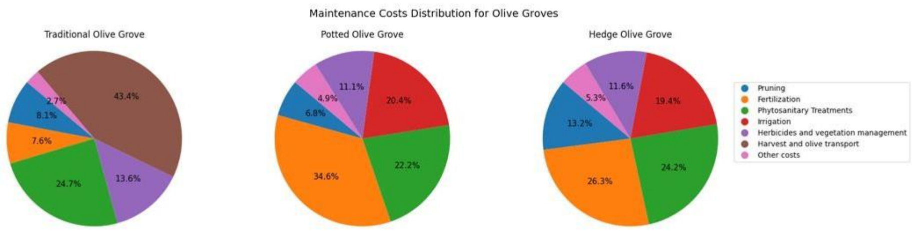


Figure 8.5 - Distribution of Maintenance costs for the three cultivation system's types (AGRO.GES 2021).

On the other hand, olive grove's installation costs (€/ha) include land preparation, planting, trellising and the irrigation system, reflecting the initial investments needed to implement two cultivation systems, potted and hedge. Unlike these modern systems, traditional growing systems generally don't have significant installation costs as they rely on existing trees and traditional farming practices, that's why it's not shown in the representation below. In this way, Figure 8.6 highlights the differences between potted and hedge groves, showing that the costs of the hedge olive grove are higher, due to its higher density and complex structure, compared to the potted olive grove.

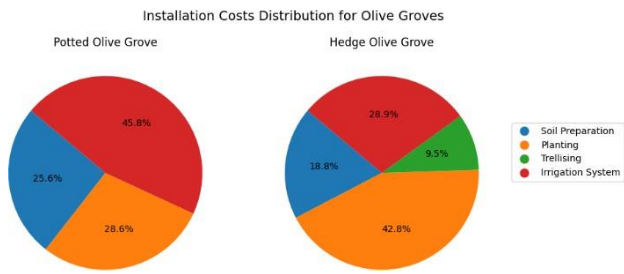


Figure 8.6 - Installation costs' distribution for potted and hedge olive groves (AGRO.GES 2021).

Lastly, the Annual yield (kg/ha) mainly varies with the type and age of olive grove. Figure 8.7 highlights the yield differences between the three systems: traditional system exhibit a slower productivity, only starting production in year 5 with steady yield of 2,000kg/ha thereafter; potted system begin production earlier in year 4 with 2,500 kg/ha, quickly increasing to 9,000 kg/ha by year 8 and maintaining this peak; and hedge system show the fastest growth, achieving significant yields as early as year 3 with 5,400 kg/ha, reaching 12,000kg/ha by year 5, and sustaining this high productivity through year 10.

Annual Yield (Kg/ha/year)

Type of Olive Grove	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Traditional	0	0	0	0	2000	2000	2000	2000	2000	2000
Potted	0	0	0	2500	4250	6900	8000	9000	9000	9000
Hedge	0	0	5400	9000	12000	12000	12000	12000	12000	12000

Figure 8.7 - Annual Yield Production by Year (Kg/ha) (AGRO.GES 2021).

Additionally, the simulation can be tailored to specific needs through Category (2), which include five key variables: the cultivation system (traditional, potted, or hedge), the age of the olive grove, the simulation duration in years, the cultivated area, and the selling price of table olives. Adjusting the cultivation system and the cultivated area ensures the data reflects the unique characteristics of each olive grove. Additionally, factoring in the age of the olive grove aligns costs and yields with the various stages of the crop's lifecycle, improving the simulation's accuracy and relevance.

According to the European Commission table olive's price shows a general increase, between 2020 and 2023, in the main European and productive countries, which can be observed in Figure 8.8. Italy consistently leads with the highest prices, Greece shows some fluctuations, with a peak in 2021, followed by a decline in 2022 and a sharp recovery in 2023, Portugal, on the other hand, has maintained moderate growth, with relatively low prices.

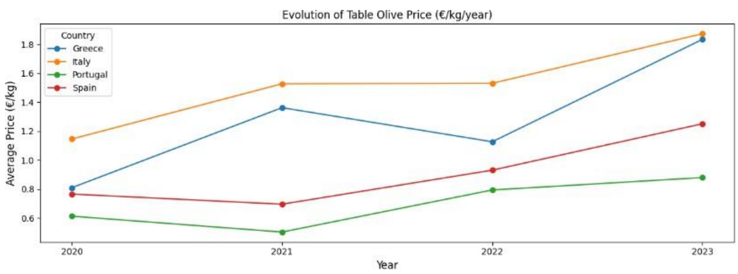


Figure 8.8 - Evolution of table olives' price (European Commission)

Lastly, data obtained through Category (3) that provides up-to-date information on the average price of olive oil (€/kg), a variable automatically adjusted in the simulation based on periodic reports from the European Commission, allowing a precise analysis of the olive oil price, ensuring the simulation keeps pace with market fluctuations. Figure 8.9 shows the olive oil's evolution between 2010 and 2024, with Croatia standing out with a sharp increase, especially from 2022 onwards. The other countries, such as Greece, Italy, Spain and Portugal had more gradual increases. In Portugal, the price raised the most in 2021, reaching around €6/kg in 2024.

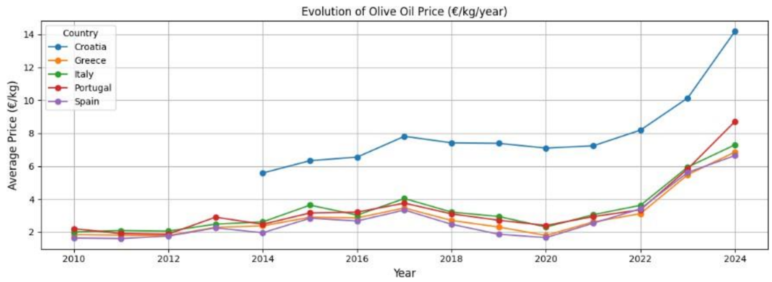


Figure 8.9 - Evolution of olive oil price by year (European Commission)

Despite the successive increase in prices, recent sources, such as El País, expect a significant increase in olive and olive oil production in Spain, which is expected to grow by around 50% (El País 2024). This increase in supply could put downward pressure on olive and olive oil prices, resulting in a stabilization or reduction of prices in Europe, which is extremely important for future forecasts.

5.5.2 Simulation

The simulation model evaluates the economic performance of olive groves by accounting for installation costs, annual maintenance costs, and productivity, tailored to the specific type of cultivation system, and olive grove's age, as seen in Annex VIII.2. Installation costs are applied exclusively in the first year, reflecting the initial investment required for establishment, such as planting and system setup. These are combined with maintenance costs for the first year to capture the total initial financial effort.

On the other hand, maintenance costs are incurred annually and vary according to the cultivation system, the area cultivated, and the grove's lifecycle stage. The simulation recognizes three main stages: (1) Establishment Period, during which trees are maturing, there is no productivity, and maintenance costs are relatively high to support growth; (2) Peak Productivity, when the grove reaches maximum production potential with regular maintenance costs; and (3) Decline or End-of-Life, when productivity drops and maintenance costs are minimized.

The model dynamically adjusts costs and yield based on the grove's age and type, using specific functions for each cultivation system to reflect their unique characteristics. For example, traditional groves have a longer establishment phase and steady productivity, while hedge systems reach peak production faster but have a shorter productive lifespan.

5.5.3 Outputs

The simulation model focuses on key financial outputs that provide valuable insights for producers and investors, which ensures a comprehensive understanding of olive grove economic viability. These outputs include: (1) Annual Operating costs that encompasses maintenance costs incurred each year, as well as installation costs during the first year; (2) Annual Revenue calculated based on the income from table olives (80% of production) and olive oil (20% of production), using average market prices given by the user and the European commission respectively; and (3) Financial Metrics, like cumulative profit, that enable a holistic assessment of grove's financial performance throughout its lifecycle, in order to capture the relation between investment, operational costs, and revenue generation. The production percentages (80% table olives and 20% olive oil) were determined by the Municipality of Mação and reviewed by a professional from Fitolivos. To facilitate practical observation, Annex VIII.3 clearly represents the selected outputs.

5.6 Sensitivity Analysis

A sensitivity analysis is a critical step to evaluate the robustness of the developed model for olive cultivation, because it allows for a comprehensive understanding of how variations in key input variables influence the overall outcomes, such as operational costs, revenue and profitability. The analysis spans a 25-year timeframe, which corresponds to the productive lifespan of traditional and potted olive groves, ensuring a consistent comparison even as the hedge olive grove concludes its shorter productive cycle at 15 years. By focusing on parameters directly influenced by user decisions, such as the type of olive grove, the cultivated area, and the average olive price; the sensitivity analysis assesses their individual impact on the model's performance, which ensures that the simulation remains both realistic and adaptable to varying conditions, providing insights for strategic decision-making.

5.6.1 Univariate Analysis

The univariate analysis focuses on three main variables, type of olive grove, cultivated area, and table olive's price because they are primary drivers of model's outcomes' variation. Each of these variables plays a different role: the olive grove type determines directly the correspondents' operational costs and productivity values; the cultivated area scale these costs and influences economies of scale, and the average olive price defines the potential revenue. Together, these parameters capture the most critical interactions between user-defined choices and the economic viability.

5.6.1.1 Type of Olive Grove

The traditional olive grove stands out for its low operational costs driven by minimal reliance on external inputs, like irrigation or fertilization. Figure 8.10 shows the costs remain stable and relatively low throughout the 25-year period, which makes this system a highly sustainable for long-term investments, however the start of production year is delayed compared to the other systems, requiring patience before seeing significant returns.

The potted olive grove represents a middle ground between the traditional and hedge systems, because its moderate installation and maintenance costs reflect the higher input requirements compared to the traditional, such as irrigation and pruning. While these costs stabilize after the first years, they remain consistently higher than those of the traditional grove. The potted olive grove benefits from earlier production compared to traditional grove, which makes it attractive for medium-term economic goals.

The hedge olive grove has the highest installation costs, due to its high-density planting and reliance on mechanized systems, however the operational costs stabilize at a level higher than both the traditional and potted systems, as can be observed in Figure 8.11. The hedge grove's key advantage lies in its accelerated production cycles and efficiency, despite its productive lifespan ends after 15 years, which limits its long-term economic viability.

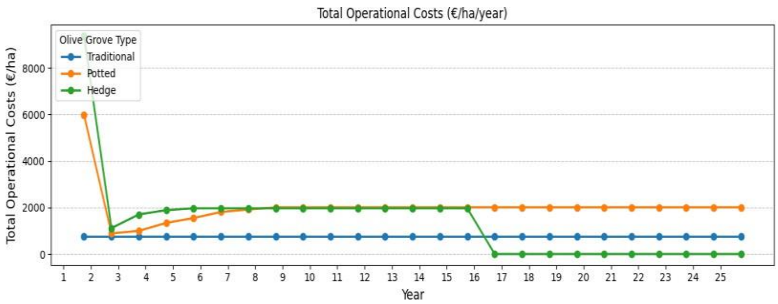


Figure 8.11 - Evolution of Annual operational costs through 25-year period for 50 hectares

The analysis of the operational costs reveals clear trade-offs among the three olive grove systems; the traditional grove is the most cost-efficient, with low operational costs and long-term sustainability, however its delayed production might discourage those that aim for faster returns. On the other hand, hedge grove is the most expensive due to high initial investments and mechanization, delivers high production quicker but is limited by its 15 -year productive lifespan. Lastly, the potted grove balances the two systems before, offering earlier returns than traditional system with moderate costs, which makes it a versatile option.

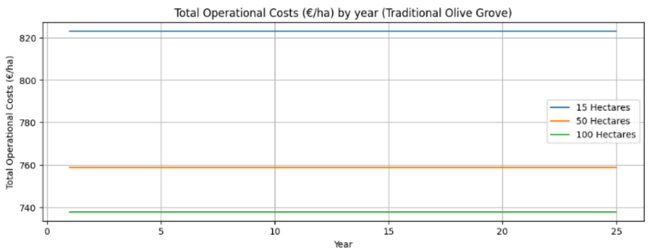
5.6.1.2 Hectares

The operational costs of the three olive grove systems were analyzed across three different cultivated areas (15ha, 50ha and 100ha). This analysis provides insights into how costs scale with the size of the operation, which can be analyzed in Figure 8.12.

For traditional olive groves, operational costs are stable across all areas of cultivation, with slight decrease in costs per hectare as the cultivated area increases, which reflects the minimal dependency on installation cost and technological advanced techniques, despite its high dependence on labor costs.

In the potted grove system, operational costs are higher than in traditional groves but follow a similar stability over time. Figure 8.12 shows that the costs per hectare slightly decrease with increasing area showcasing the benefits of economies of scale.

The hedge system demonstrates the most substantial scaling effects; despite the initial investment is the highest across all cultivated areas, the per-hectare operational costs decrease with larger areas, also represented in Figure 8.12. This reflects the high level of mechanization, which becomes more cost-effective, despite the shorter productive.



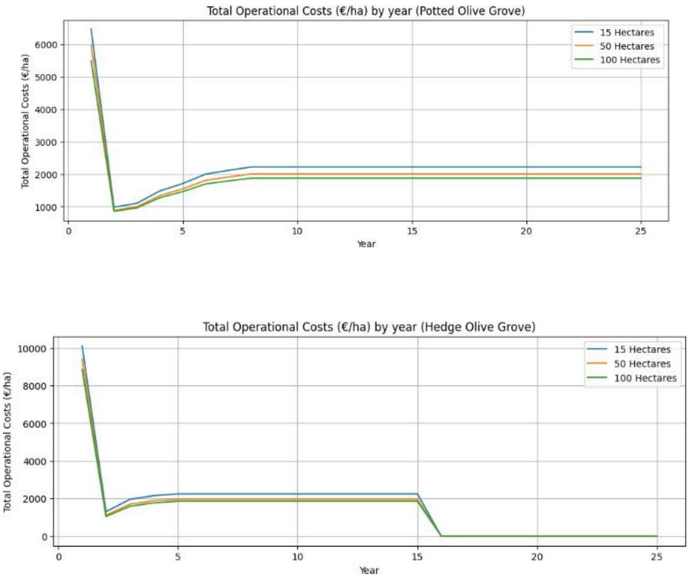


Figure 8.12 - Evolution of annual operational costs through 25-year period for 3 different areas

5.6.1.3 Average Olive Price

The cumulative profit was chosen as the key metric because the average olive price influences directly the revenue, which is a major component of profitability. To conduct this analysis, the cumulative profit was evaluated across three olive grove systems, while considering the same cultivated area of 50 hectares.

Starting with traditional olive grove, in this system the cumulative profit increases steadily with higher average olive prices. Figure 8.13 shows the linear impact of price, with higher price points, like €2/kg, resulting in significantly higher profits compared to lower prices.

Potted groves show a more pronounced sensitivity to average olive price due to their higher production levels, compared to traditional groves. In this system, the cumulative profit increases more sharply as the price rises.

Hedge groves demonstrate the highest sensitivity to average olive prices due to their high productivity during shorter lifecycle. As we observe, Figure 8.13 shows that the cumulative profit rises rapidly at higher price points, despite after a 15-year lifespan the profits stabilize, due to the limited long-term viability of this system.

Across the three olive grove's types, the cumulative profit increases linearly with higher average olive prices, highlighting its significant impact on profitability. Figure 8.13 shows that traditional groves are the least sensitive to price changes due to their lower production, which makes them suitable for stable or low-price markets; potted groves achieve higher profits at moderate price levels while benefiting from scalability, and hedge groves generate the highest profits at elevated price points, especially in larger areas, though their shorter productive life constrains long-term returns.

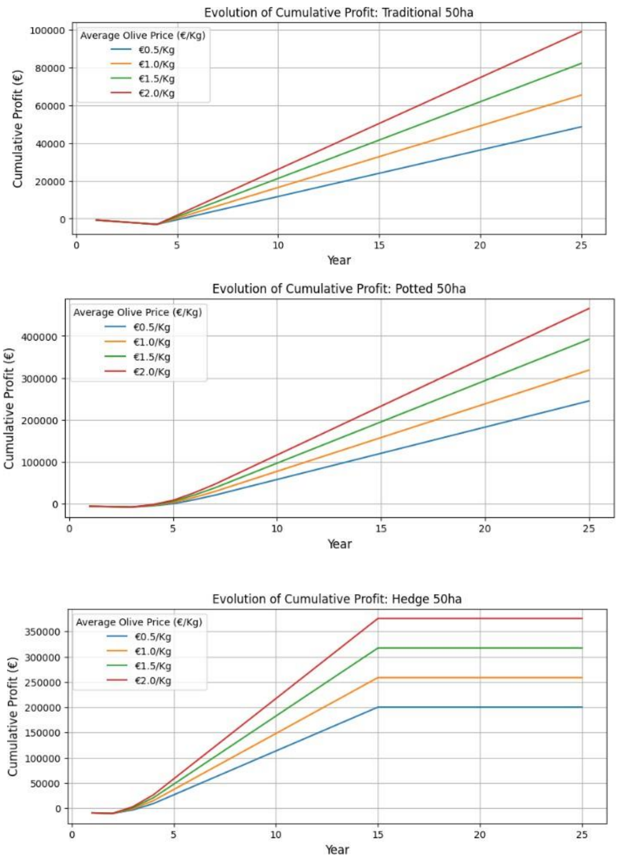


Figure 8.13 - Evolution of cumulative profit through 25-year period for 50 hectares

5.6.2 Multivariate Analysis

In the multivariate analysis, only the type of olive grove and cultivated area were variable, however the average olive price was fixed, as the univariate analysis demonstrated a consistent linear relationship between olive price and profit. This choice simplified the analysis to focus on understanding the impact of grove type and scale on cumulative profits.

The potted olive grove consistently emerges as the most profitable option, because it achieves the highest cumulative profit across all cultivated areas. For 15ha the profit is approximately €313,000 increasing sightly to €318,000 for 50ha and €321,000 for 100ha, these values demonstrate that potted system not only provides the greatest overall profitability but also scales effectively with increasing cultivated area.

The hedge olive grove ranks second in profitability, with cumulative profits of approximately €254,000 for 15ha, €258,000 for 50ha, and €260,000 for 100ha. This system doesn't match the performance of the potted system but offers a moderate profit and remains scalable as the cultivation area expands, so it provides a viable alternative for scenarios where high-density mechanized systems are preferred.

On the other hand, traditional olive grove consistently yields the lowest profits across all cultivated areas; with cumulative profits €64,000 for 15ha, €65,000 for 50ha, and €66,000 for 100ha, despite being the system with lower operational costs. However, the traditional grove limited production capacity and delayed returns make it the least economically competitive, even when cultivated area is bigger. Despite that, this system is suitable in situations where the input dependency is lower and long-term sustainability is prioritized over profitability.

This analysis, observed in Figure 8.14, demonstrates the differences of profitability between the three types of olive grove, standing out the potted system in terms of cumulative profit for 25 years. In the case of Municipality of Mação, the preference expressed is for the installation of a potted olive grove in all AIGPs, with the aim of balancing profitability and sustainability throughout the production cycle.

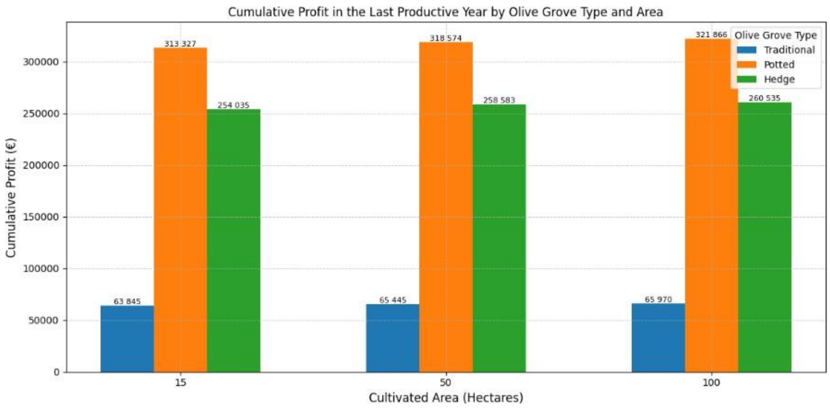


Figure 8.14 - Cumulative Profit in the last productive year (25-year period for Traditional and Potted, and 15 for Hedge)

5.7 Conclusion - Recommendations

5.7.1 Potted Olive Grove

The potted olive grove is the ideal option for Mação if the municipality's primary objectives are to balance longevity and sustainability, because this system delivers the highest cumulative profit over its 25-year productive lifespan. Furthermore, the potted grove scales effectively across different cultivated areas, which shows stable profitability even when the area increases.

Additionally, the moderate inputs requirements and long-term economic viability is ideal for producers who value sustainability alongside profitability, aligned with Mação's goals to foster productive and resource-efficient agricultural practices while maintaining economic returns.

5.7.2 Hedge Olive grove with replacement

Mação could adopt a hedge olive grove system with replacement after its lifespan of 15-year, if the main purpose be based on profit's maximization. In this scenario, a new grove is replanted, resulting in a cumulative profit of approximately €514,000 over the same 25-year timeframe, exceeding profits of both potted (€318,000) and traditional (€65,000) systems. The hedge system's mechanized and high-density planting yields rapid production and high profitability during each cycle, however, requires a larger initial investment and careful management for replanting after 15 years. Thus, this approach is best suited for producers who can accommodate higher operational demands and aim to achieve maximum financial returns.

5.8 Limitations

Despite the model's practical utility, it has some limitations that arise from the assumptions made during the model's development and the scope of data used, so addressing these issues in future versions could improve the model's accuracy and usefulness.

One notable limitation is that the model is based on general data for all Portugal regions, overlooking specifics like Mação's microclimate, soil conditions, and farming practices, which results in a reduced accuracy when assessing localized scenarios.

The model excludes key factors such as agriculture subsidies, government incentives, and policy impacts, that could significantly vary the costs, and in turn profitability, which limits the model's ability to assess economic viability in regions influenced by policy-driven factors.

Lastly, the model assumes a uniform price for olive oil, disregarding the differences arising from the characteristics and costs associated with the different cultivation systems.

5.9 Future Work

A future direction is the development of a regionalized data model tailored to Mação, this model would integrate the region's characteristics, such as its microclimate, soil composition, and traditional growing system, improving accuracy of economic assessments for olive cultivation.

The process would involve collecting localized data through contact with farmers, cooperatives, and institutions in Mação. Some examples of tools that provide detailed inputs are surveys, climatic data, soil analysis, and remote sensing technologies. These efforts would refine cost structures, capture variations in productivity, and account for specific challenges, such as irrigation and logistic costs.

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Appendix

Appendix II - Mação

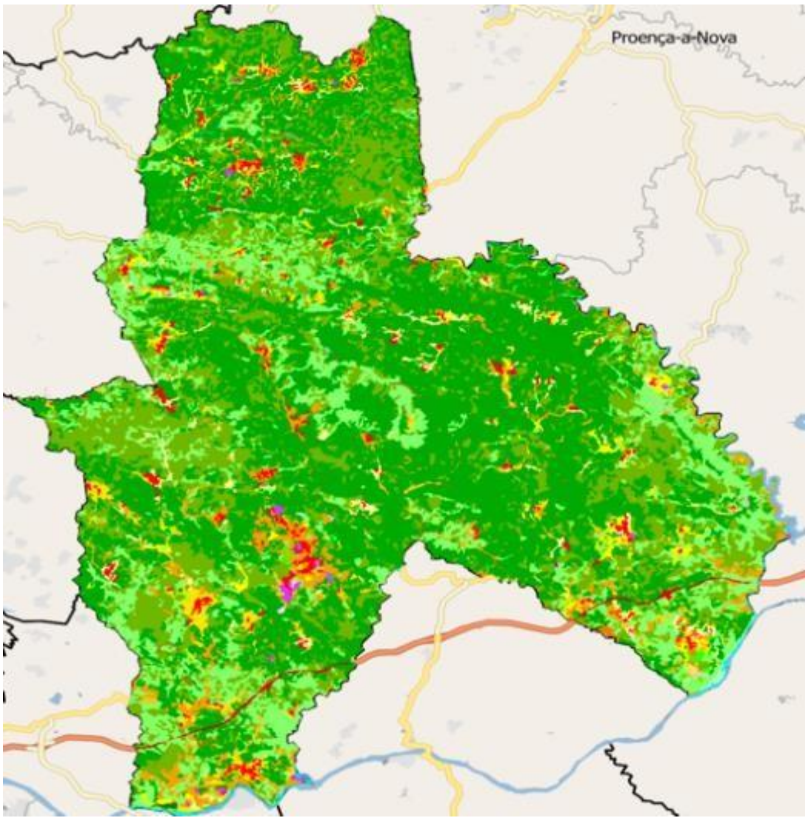

Figure II.1: COS Map | Source: Matias 2023

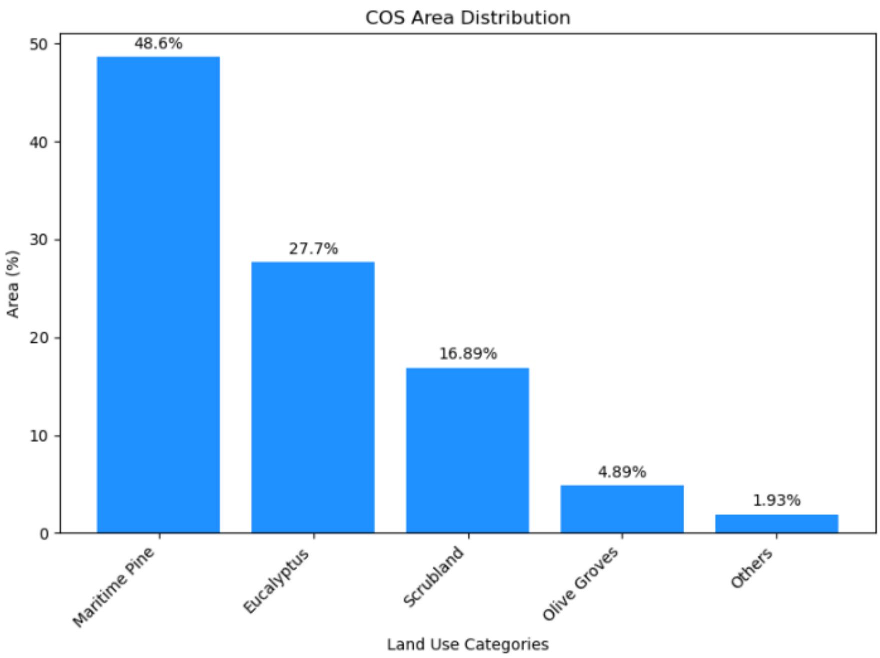

Figure II.2: COS Area distribution

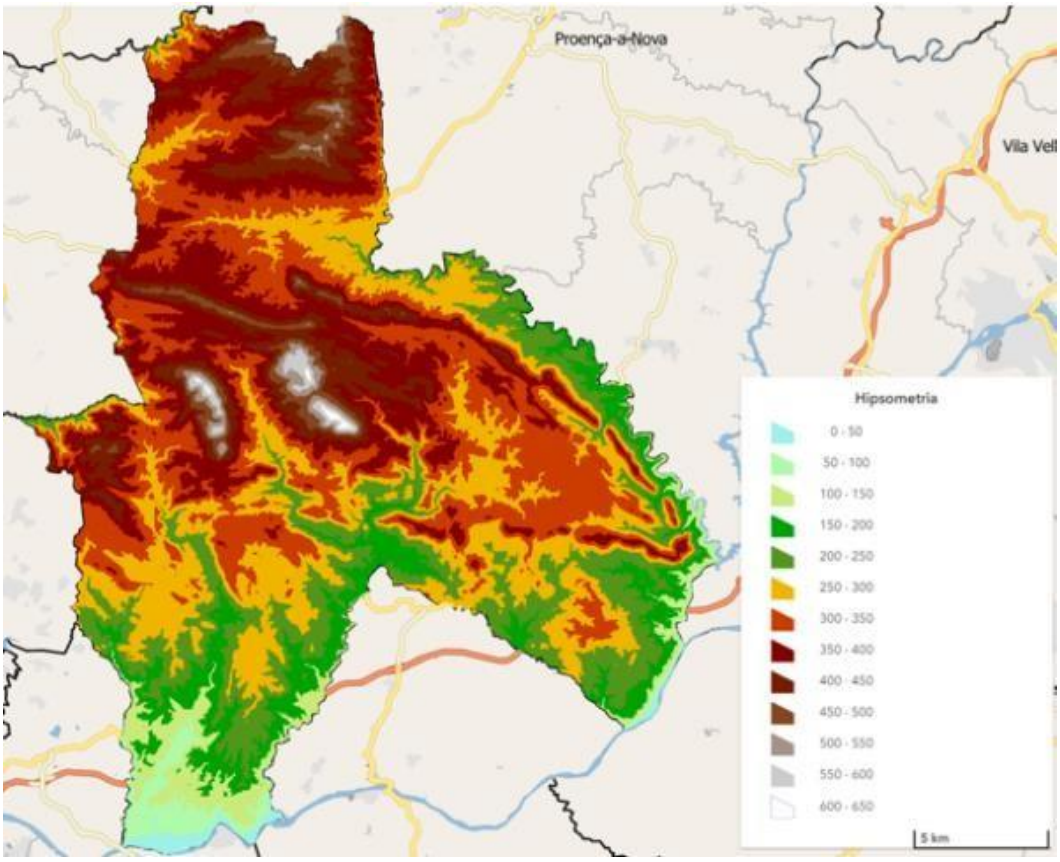

Figure II.3: Hypsometry in Mação

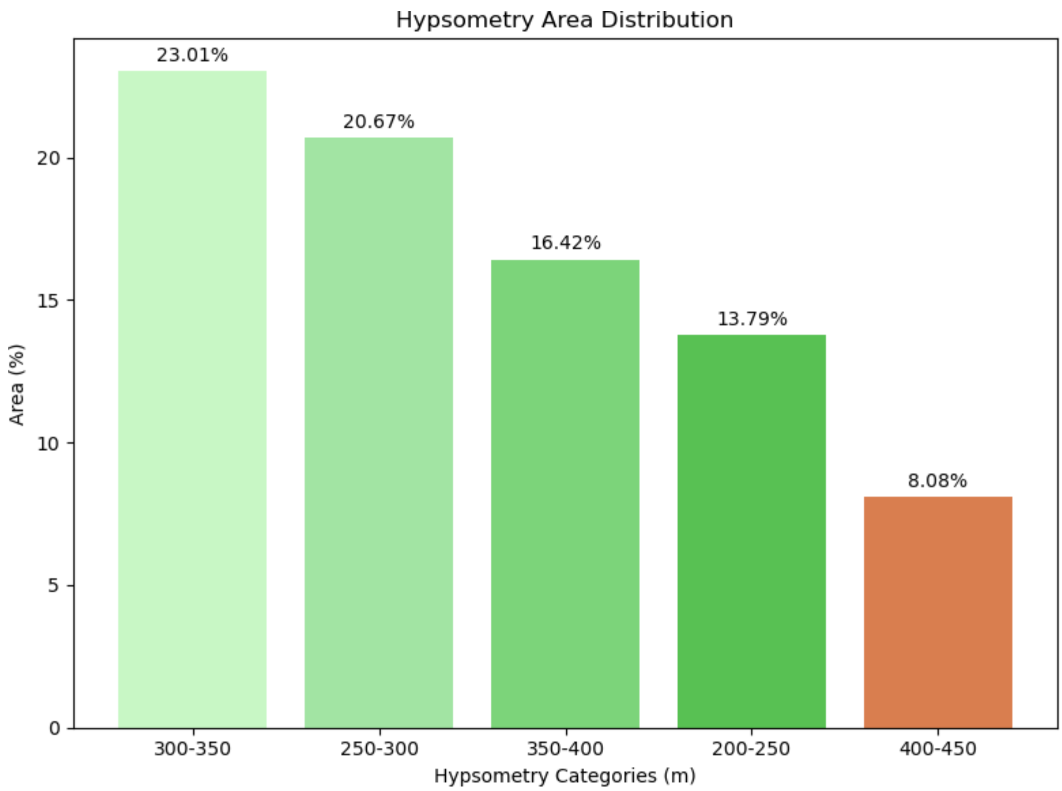

Figure II.4: Map Hypsometry in Mação | Source: Matias 2023

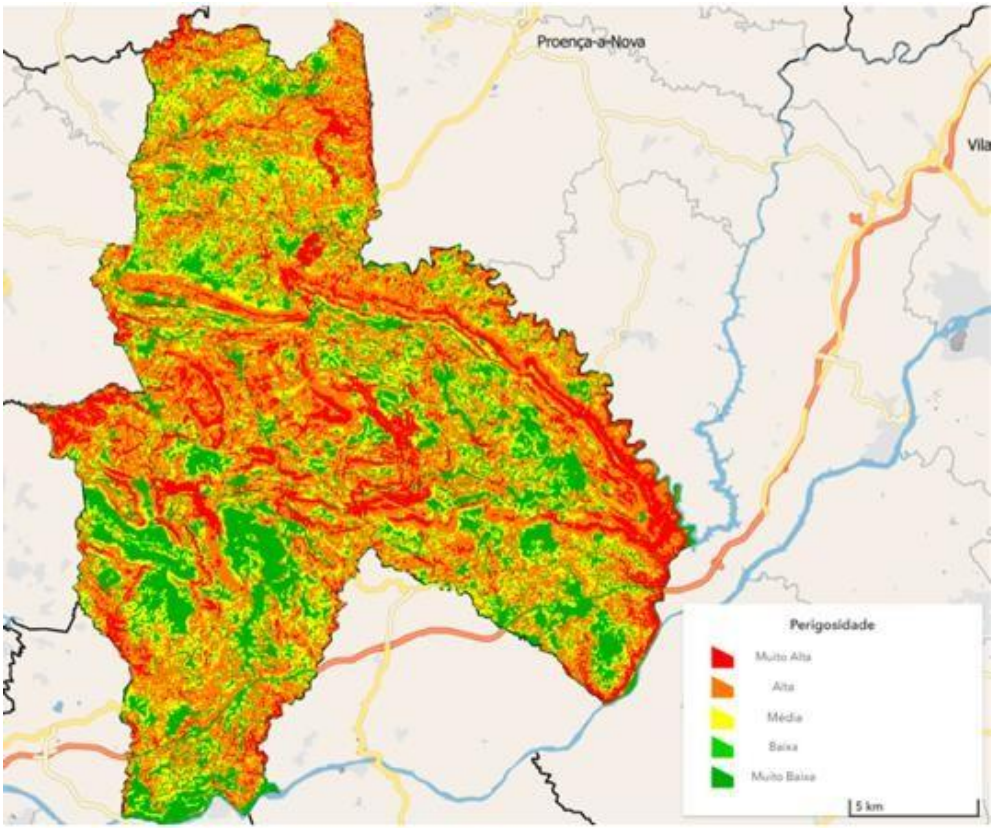

Figure II.5: COS Hypsometry in Mação

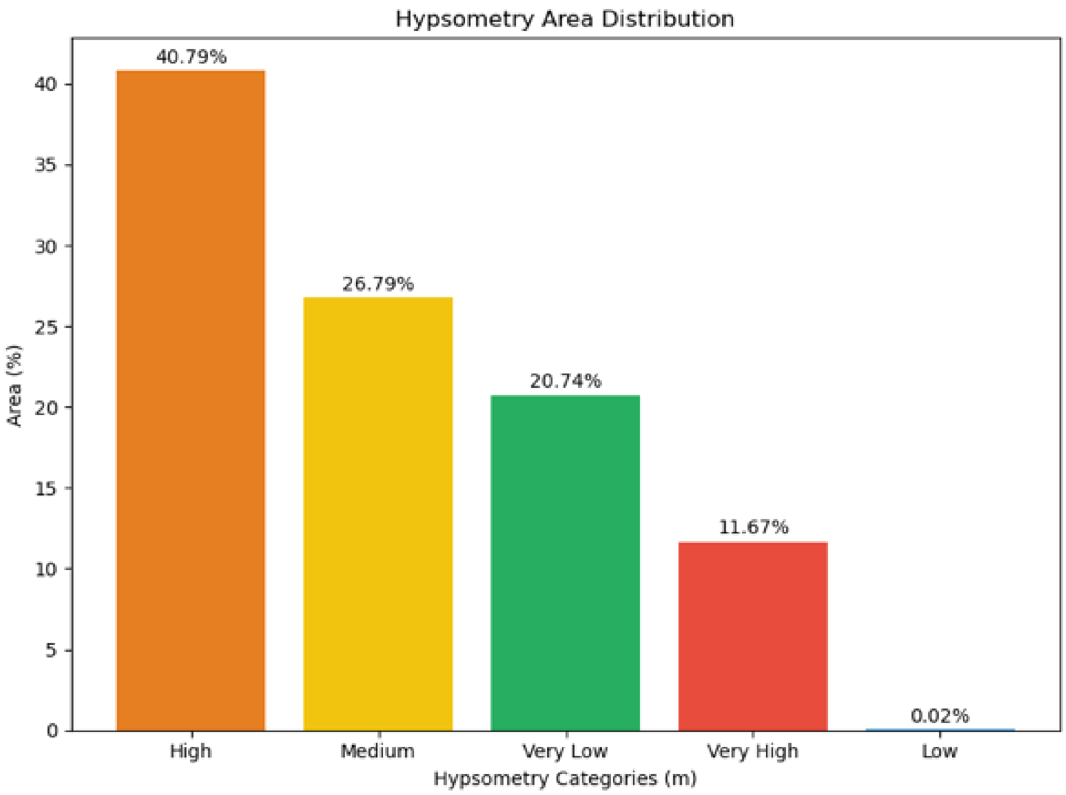

Figure II.6: COS Map Mação | Source: Matias 2023

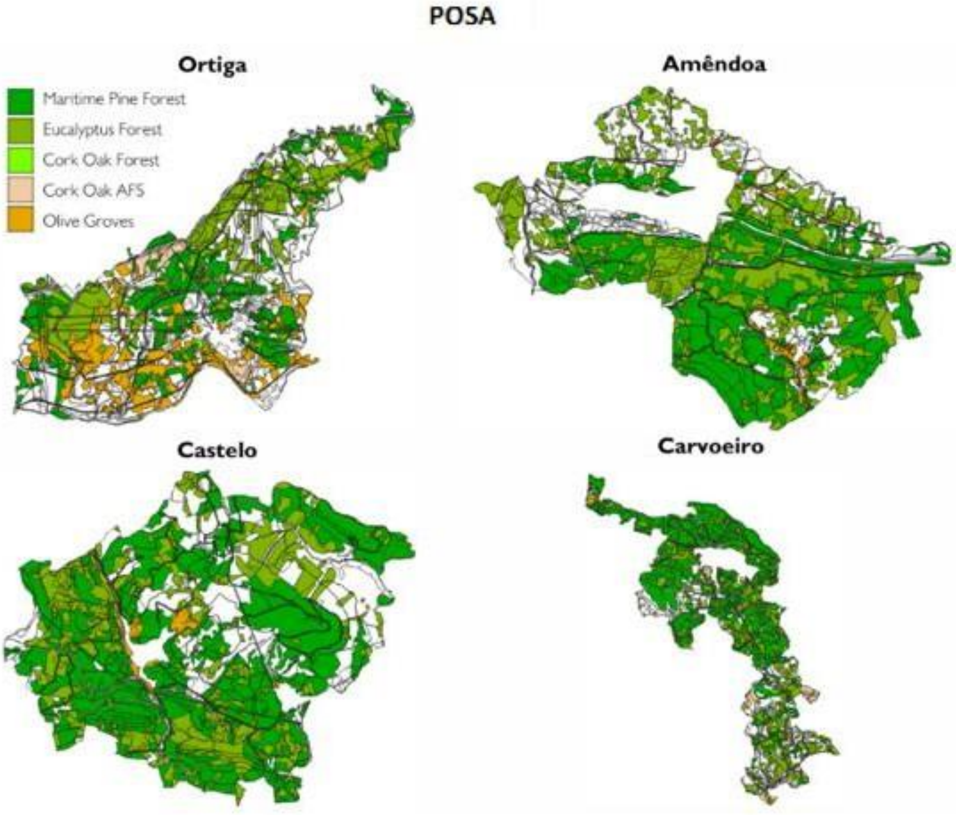

Figure II.7: Current Land Use Map in four specific AIGPS

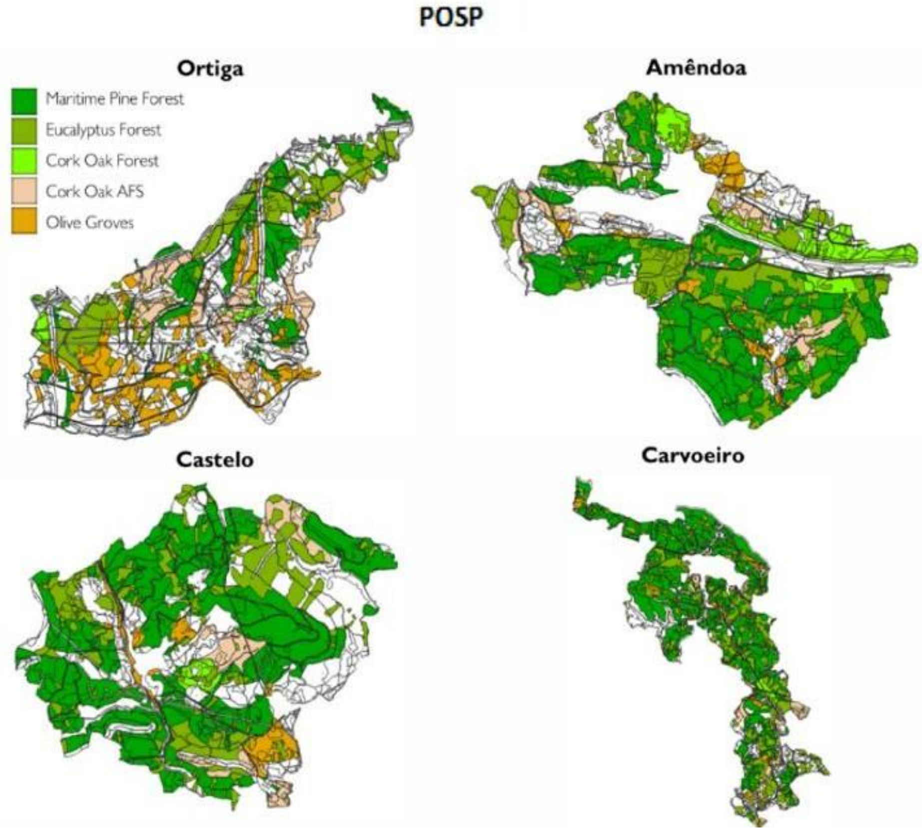

Figure II.8: Proposed Land Use Map in four specific AIGPs

Appendix IV – StandsSIM

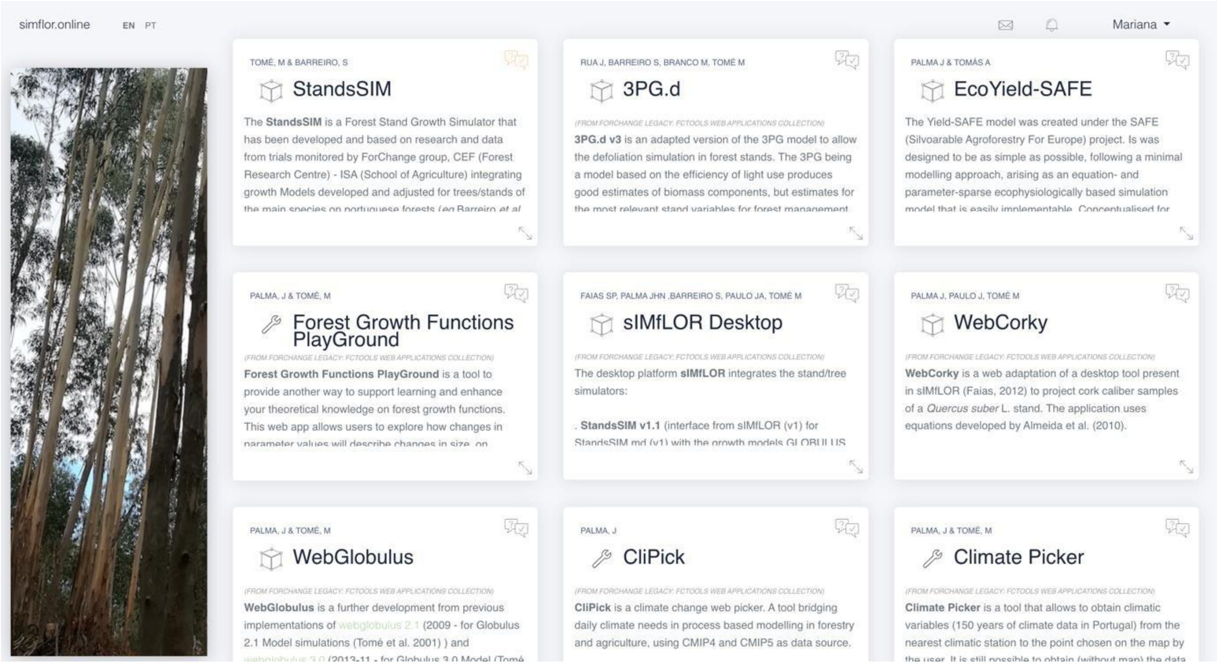

Figure IV.1 – Online Simflor Interface

id_stand	id_presc	year	Thinning	Debark	t	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
MACAO_5	ID1	2024	0	0	0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2025	0	0	1.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2026	0	0	2.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2027	0	0	3.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2028	0	0	4.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2029	0	0	5.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2030	0	0	6.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2031	0	0	7.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2032	0	0	8.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2033	0	0	9.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2034	0	0	10.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2035	0	0	11.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2036	0	0	12.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2037	0	0	13.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2038	0	0	14.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2039	0	0	15.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2040	0	0	16.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2041	0	0	17.0	0.	1470.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2042	0	0	18.0	0.	1390.	80.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2043	0	0	19.0	0.	1390.	80.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2044	0	0	20.0	0.	1040.	430.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2045	0	0	21.0	0.	710.	760.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2046	0	0	22.0	0.	180.	1290.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2047	0	0	23.0	0.	0.	1470.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2048	0	0	24.0	0.	0.	1470.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2049	0	0	25.0	0.	0.	1470.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2050	0	0	26.0	0.	0.	1470.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2051	0	0	27.0	0.	0.	1390.	80.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2052	0	0	28.0	0.	0.	1390.	80.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2053	0	0	29.0	0.	0.	1290.	180.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2054	0	0	30.0	0.	0.	1110.	360.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2055	0	0	31.0	0.	0.	980.	490.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2056	0	0	32.0	0.	0.	840.	630.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2057	0	0	33.0	0.	0.	710.	760.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2058	0	0	34.0	0.	0.	560.	910.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2059	0	0	35.0	0.	0.	180.	1290.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2060	0	0	36.0	0.	0.	180.	1210.	80.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2061	0	0	37.0	0.	0.	0.	1390.	80.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2061	1	0	37.0	0.	0.	0.	1010.	80.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2062	0	0	38.0	0.	0.	0.	1010.	80.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2063	0	0	39.0	0.	0.	0.	960.	130.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2064	0	0	40.0	0.	0.	0.	910.	180.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2065	0	0	41.0	0.	0.	0.	840.	250.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2066	0	0	42.0	0.	0.	0.	730.	360.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2067	0	0	43.0	0.	0.	0.	660.	430.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2068	0	0	44.0	0.	0.	0.	600.	490.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MACAO_5	ID1	2069	0	0	45.0	0.	0.	0.	600.	410.	80.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

Figure IV.2 – StandsSIM output file: output_dd

id_stand	id_presc	ttotal	S	NPV	EAA	0.030	0.040	0.050	0.000	0.000	maiV	Vharv	Vuharv
MACAO_5	ID1	36	15.4	-716.6	-38.4	-20.0	-38.4	-57.4	0.0	0.0	11.2	160.2	129.5
MACAO_med	ID1	36	20.7	1603.0	85.9	110.1	85.9	61.1	0.0	0.0	20.9	311.9	256.6
MACAO_95	ID1	36	25.9	5211.4	279.2	312.9	279.2	245.1	0.0	0.0	36.2	550.9	458.2

Figure IV.3 – StandsSIM output file: output_npv

id_stand	S	AreaUG	id_presc	FMA	opt	year	ttotal	t	rot	FinalCut	Thinning	Debark	hdom	Nst	N	Ndead	N_ing	Fw	G	dg	Vu_st	Vb_st	Vst	V	V_as1	V_as2	V_as3	V_as4	V_as5	Vu_as1	Vu_as2	Vu_as3	Vu_as4	Vu_as5	Vharv	Vuharv	Vtot	maiV	iV	Ww	Wb
MACAO_5	15.44	1.00	ID1	4	1	2024	0	0.0	1	0	0	0	0.0	1250.	1250.	0.	0.	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0
MACAO_5	15.44	1.00	ID1	4	1	2025	1	1.0	1	0	0	0	4.1	1250.	1250.	0.	0.	0.68	0.1	1.1	0.2	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.1	0.0
MACAO_5	15.44	1.00	ID1	4	1	2026	2	2.0	1	0	0	0	7.2	1250.	1250.	0.	0.	0.39	0.7	2.7	1.8	0.5	0.1	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	1.2	2.2	0.7	0.1
MACAO_5	15.44	1.00	ID1	4	1	2027	3	3.0	1	0	0	0	9.3	1250.	1250.	0.	0.	0.30	1.7	4.1	5.3	1.4	0.2	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0	2.3	4.6	2.4	0.3
MACAO_5	15.44	1.00	ID1	4	1	2028	4	4.0	1	0	0	0	10.8	1233.	1233.	17.	0.	0.26	2.8	5.3	10.1	2.6	0.3	13.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.0	3.3	6.1	4.7	0.6
MACAO_5	15.44	1.00	ID1	4	1	2029	5	5.0	1	0	0	0	12.0	1217.	1217.	16.	0.	0.24	3.9	6.4	15.6	3.9	0.5	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.0	4.0	7.0	7.4	0.9
MACAO_5	15.44	1.00	ID1	4	1	2030	6	6.0	1	0	0	0	12.9	1201.	1201.	16.	0.	0.22	4.9	7.2	21.5	5.3	0.6	27.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.4	4.6	7.4	10.5	1.3
MACAO_5	15.44	1.00	ID1	4	1	2031	7	7.0	1	0	0	0	13.7	1185.	1185.	16.	0.	0.21	6.0	8.0	27.5	6.7	0.7	35.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	35.0	5.0	7.6	13.7	1.7
MACAO_5	15.44	1.00	ID1	4	1	2032	8	8.0	1	0	0	0	14.4	1169.	1169.	16.	0.	0.20	7.0	8.7	33.6	8.1	0.8	42.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	42.5	5.3	7.6	17.0	2.2
MACAO_5	15.44	1.00	ID1	4	1	2033	9	9.0	1	0	0	0	14.9	1153.	1153.	16.	0.	0.20	7.9	9.4	39.5	9.5	1.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	5.6	7.4	20.2	2.6
MACAO_5	15.44	1.00	ID1	4	1	2034	10	10.0	1	0	0	0	15.4	1138.	1138.	15.	0.	0.19	8.8	9.9	45.4	10.8	1.1	57.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	57.3	5.7	7.3	23.5	3.0
MACAO_5	15.44	1.00	ID1	4	1	2035	11	11.0	1	0	0	0	15.9	1123.	1123.	15.	0.	0.19	9.7	10.5	51.1	12.1	1.2	64.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	64.3	5.8	7.1	26.6	3.5
MACAO_5	15.44	1.00	ID1	4	1	2036	12	12.0	1	0	0	0	16.3	1108.	1108.	15.	0.	0.18	10.5	11.0	56.5	13.3	1.3	71.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	71.2	5.9	6.8	29.7	3.9
MACAO_5	15.44	1.00	ID1	4	1	2037	13	13.0	1	1	0	0	16.7	1093.	1093.	15.	0.	0.18	11.3	11.4	61.9	14.5	1.4	77.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	71.9	58.2	77.8	6.0	6.6	32.7	4.3
MACAO_5	15.44	1.00	ID1	4	1	2037	13	0.0	1	0	0	0	0.0	0.	0.	0.	0.	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0
MACAO_5	15.44	1.00	ID1	4	1	2038	14	1.0	2	0	0	0	4.1	875.	4019.	0.	0.	0.38	0.1	0.7	0.2	0.1	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	78.0	5.6	0.3	0.1	0.0
MACAO_5	15.44	1.00	ID1	4	1	2039	15	2.0	2	0	0	0	7.2	875.	4019.	0.	0.	0.22	1.3	2.1	3.3	0.9	0.1	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	82.1	5.5	4.1	1.4	0.2
MACAO_5	15.44	1.00	ID1	4	1	2039	15	2.0	2	0	1	0	7.2	875.	1050.	0.	0.	0.43	0.6	2.7	1.4	0.4	0.1	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	82.1	5.5	4.1	0.6	0.1
MACAO_5	15.44	1.00	ID1	4	1	2040	16	3.0	2	0	0	0	9.3	875.	1050.	0.	0.	0.33	1.3	4.0	4.2	1.1	0.2	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	85.6	5.4	3.6	1.8	0.2
MACAO_5	15.44	1.00	ID1	4	1	2041	17	4.0	2	0	0	0	10.8	864.	1039.	11.	0.	0.29	2.2	5.2	8.0	2.0	0.3	10.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	90.5	5.3	4.8	3.6	0.4
MACAO_5	15.44	1.00	ID1	4	1	2042	18	5.0	2	0	0	0	12.0	854.	1028.	11.	0.	0.26	3.1	6.1	12.4	3.1	0.4	15.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	96.1	5.3	5.6	5.8	0.7
MACAO_5	15.44	1.00	ID1	4	1	2043	19	6.0	2	0	0	0	12.9	843.	1018.	11.	0.	0.24	3.9	7.0	17.2	4.2	0.5	21.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	102.1	5.4	6.0	8.3	1.0
MACAO_5	15.44	1.00	ID1	4	1	2044	20	7.0	2	0	0	0	13.7	833.	1007.	10.	0.	0.23	4.8	7.8	22.1	5.4	0.6	28.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	108.2	5.4	6.2	10.9	1.3
MACAO_5	15.44	1.00	ID1	4	1	2045	21	8.0	2	0	0	0	14.4	823.	997.	10.	0.	0.22	5.6	8.5	27.1	6.5	0.7	34.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	114.5	5.5	6.3	13.5	1.7
MACAO_5	15.44	1.00	ID1	4	1	2046	22	9.0	2	0	0	0	14.9	813.	986.	10.	0.	0.21	6.4	9.1	32.1	7.7	0.8	40.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	120.7	5.5	6.2	16.2	2.0
MACAO_5	15.44	1.00	ID1	4	1	2047	23	10.0	2	0	0	0	15.4	803.	976.	10.	0.	0.21	7.2	9.7	37.0	8.8	0.9	46.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	126.9	5.5	6.1	18.9	2.4
MACAO_5	15.44	1.00	ID1	4	1	2048	24	11.0	2	1	0	0	15.9	793.	966.	10.	0.	0.20	7.9	10.2	41.8	9.9	1.0	52.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	46.3	37.4	132.9	5.5	6.0	21.5	2.7
MACAO_5	15.44	1.00	ID1	4	1	2048	24	0.0	2	0	0	0	0.0	0.	0.	0.	0.	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0
MACAO_5	15.44	1.00	ID1	4	1	2049	25	1.0	3	0	0	0	4.1	635.	2995.	0.	0.	0.44	0.1	0.7	0.2	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	133.1	5.3	0.2	0.1	0.0
MACAO_5	15.44	1.00	ID1	4	1	2050	26	2.0	3	0	0	0	7.2	635.	2995.	0.	0.	0.25	1.1	2.1	2.6	0.7	0.1	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	136.3	5.2	3.2	1.1	0.1
MACAO_5	15.44	1.00	ID1	4	1	2050	26	2.0	3	0	1	0	7.2	635.	762.	0.	0.	0.50	0.5	2.9	1.3	0.4	0.1	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	136.3	5.2	3.2	0.5	0.1
MACAO_5	15.44	1.00	ID1	4	1	2051	27	3.0	3	0	0	0	9.3	635.	762.	0.	0.	0.39	1.1	4.3	3.6	1.0	0.1	4.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	139.3	5.2	3.1	1.6	0.2
MACAO_5	15.44	1.00	ID1	4	1	2052	28	4.0	3	0	0	0	10.8	627.	754.	7.	0.	0.34	1.9	5.6	6.9	1.8	0.2	8.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	143.5	5.1	4.1	3.1	0.4
MACAO_5	15.44	1.00	ID1	4	1	2053	29	5.0	3	0	0	0	12.0	619.	747.	7.	0.	0.31	2.6	6.7	10.7	2.7	0.3	13.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	148.3	5.1	4.8	5.0	0.6
MACAO_5	15.44	1.00	ID1	4	1	2054	30	6.0	3	0	0	0	12.9	612.	740.	7.	0.	0.28	3.4	7.6	14.8	3.7	0.4	18.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	153.5	5.1	5.2	7.1	0.9
MACAO_5	15.44	1.00	ID1	4	1	2055	31	7.0	3	0	0	0	13.7	604.	733.	7.	0.	0.27	4.1	8.5	19.1	4.7	0.5	24.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	159.0	5.1	5.4	9.3	1.1
MACAO_5	15.44	1.00	ID1	4	1	2056	32	8.0	3	0	0	0	14.4	597.	726.	7.	0.	0.26	4.8	9.2	23.5	5.7	0.6	29.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	164.5	5.1	5.5	11.7	1.4
MACAO_5	15.44	1.00	ID1	4	1	2057	33	9.0	3	0	0	0	14.9	590.	719.	7.	0.	0.25	5.5	9.9	27.9	6.8	0.7	35.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	170.0	5.2	5.5	14.0	1.7
MACAO_5	15.44	1.00	ID1	4	1	2058	34	10.0	3	0	0	0	15.4	583.	712.	7.	0.	0.24	6.2	10.6	32.3	7.8	0.8	40.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	175.5	5.2	5.5	16.4	2.0
MACAO_5	15.44	1.00	ID1	4	1	2059	35	11.0	3	1	0	0	15.9	576.	705.	7.	0.	0.24	6.9	11.1	36.6	8.8	0.8	46.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	42.0	33.9	180.9	5.2	5.4	18.7	2.4
MACAO_5	15.44	1.00	ID1	4	1	2059	35	0.0	3	0	0	0	0.0	0.	0.	0.	0.	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0
MACAO_med	20.69	1.00	ID1	4	1	2024	0	0.0	1	0	0	0	0.0	1250.	1250.	0.	0.	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0
MACAO_med	20.69	1.00	ID1	4	1	2025	1	1.0	1	0	0	0	10.2	1250.	1250.	0.	0.	0.28	0.4	1.9	1.3	0.3	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	1.6	1.6	0.5	0.1
MACAO_med	20.69	1.00	ID1	4	1	2026	2	2.0	1	0	0	0	13.8	1250.	1250.	0.	0.	0.21	1.7	4.1	7.9	1.8	0.2	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	5.0	8.4	3.7	0.4
MACAO_med	20.69	1.00	ID1	4	1	2027	3	3.0	1	0	0	0	15.8	1250.	1250.	0.	0.	0.18	3.3	5.8	17.9	4.0	0.4	22.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.4	7.5	12.4	8.8	1.0
MACAO_med	20.69	1.00	ID1	4	1	2028	4	4.0	1	0	0	0	17.1	1233.	1233.	17.	0.	0.17	5.0	7.2	28.9	6.4	0.7	36.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	36.0	9.0	13.7	14.7	1.6

Figure IV.4 – StandsSIM output file: output_yieldtabl

Appendix V – The Case of Olive Tree

Appendix V.1 – Inputs of the Developed Model

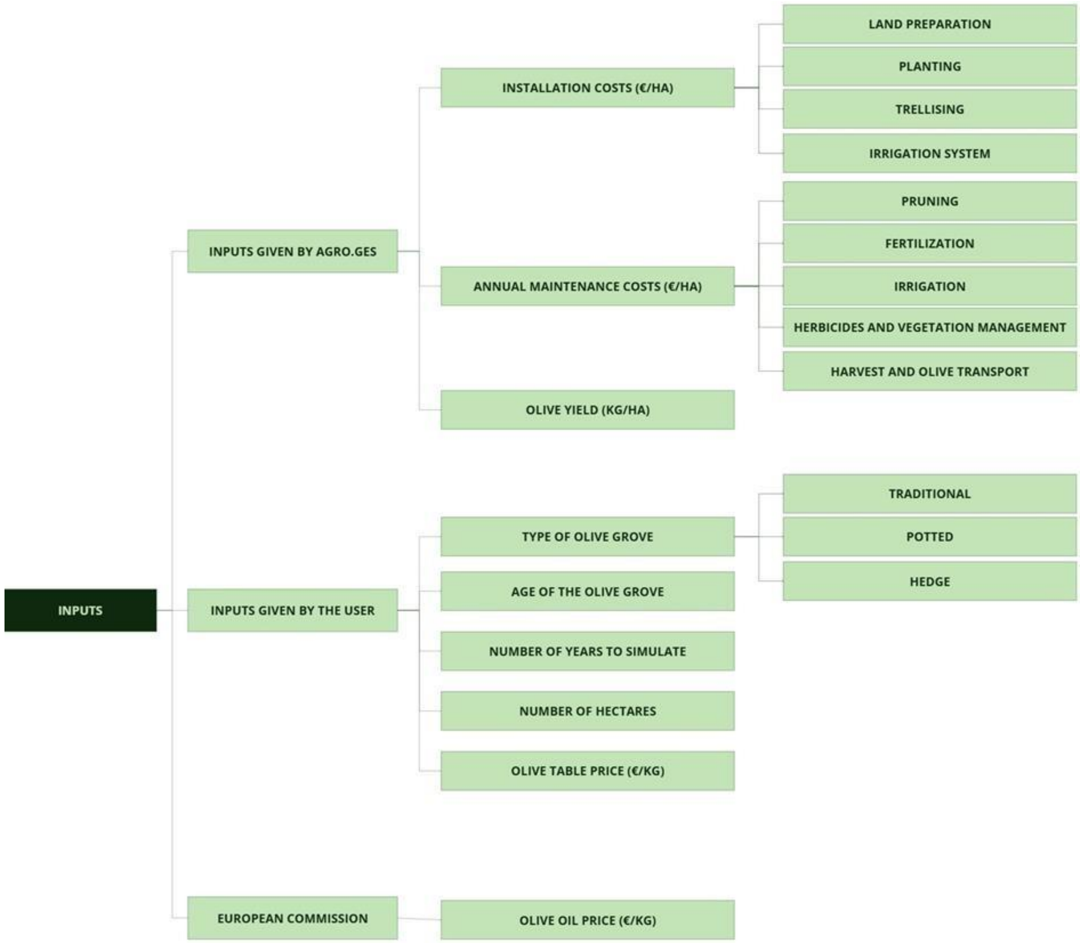

Figure VIII.1 – Inputs of the developed model's structure

Appendix V.2 – Simulation of the Developed Model

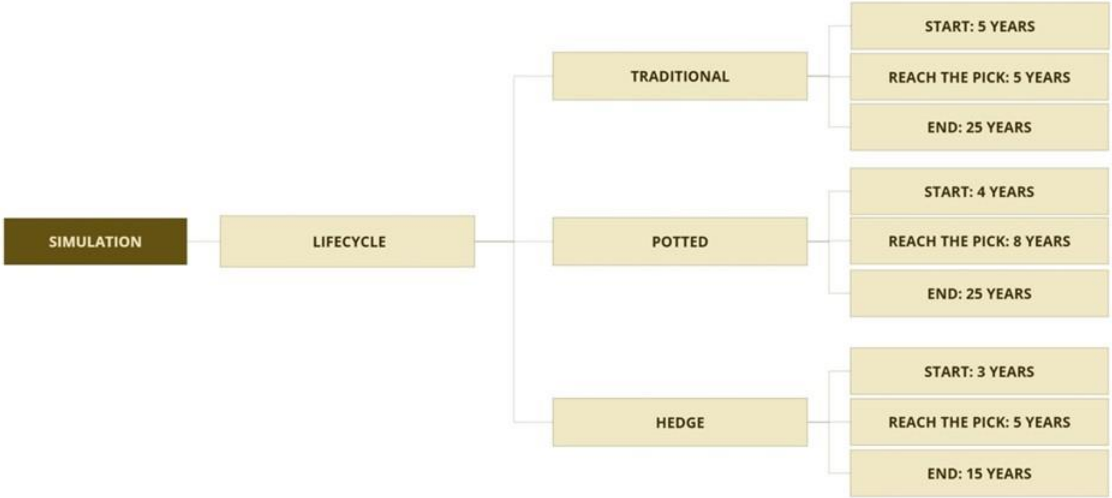

Figure VIII.2 – Simulation Structure

Appendix V.3 – Outputs of the Developed Model

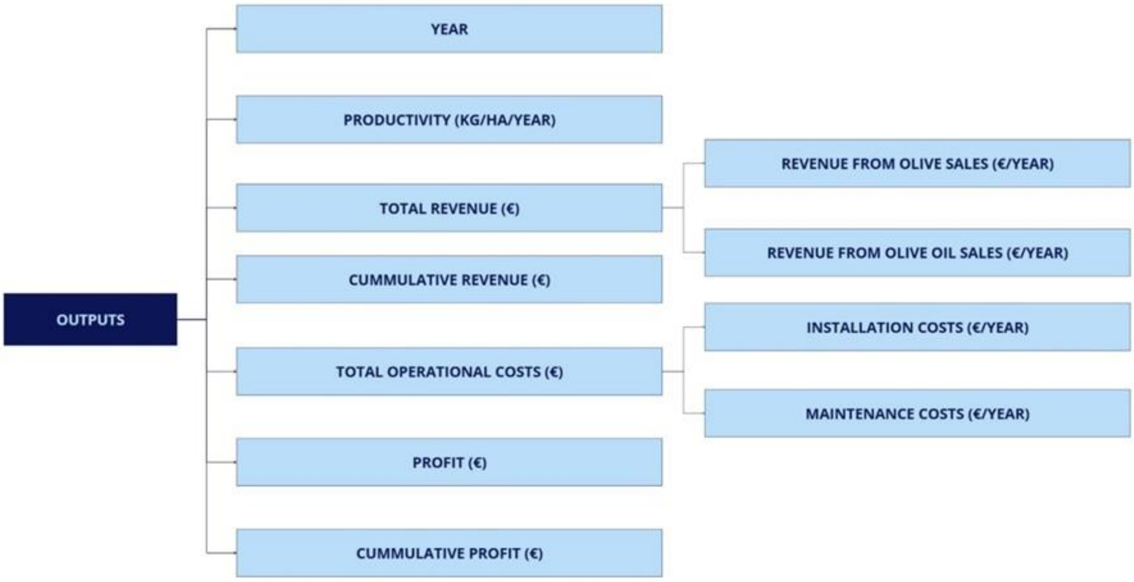

Figure VIII.3 – Outputs of the developed model's structure