Chapter

Management of *Pinus pinaster* Aiton for Wood and Resin Production: A Technical-Financial Feasibility Analysis

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Abstract

Maritime Pine sector is an important agent for promoting economy and sustainable development in Portugal. Among the products explored in these forests are wood and resin. The objective of this work was to evaluate the technical and financial viability from the creation of three simulated exploration scenarios: Wood Exploration (W), Resin (R) and Wood + Resin (WR), for this it was defined a loss of 16% of wood volume in resined forest stands and created operational models that defined the costs, investments and revenues that made it possible to prepare cash flow for each scenario and apply the Internal Rate of Return (IRR) feasibility analysis indicators, Net Current Value (VAL), Net Profitability Index (NPI) and Discounted Pay Back (DPB). Scenario R presented the best indicators, however, with absolute values that were not attractive and that the W and WR scenario presented viability but with a DPB at 10 years of age. The loss of wood was not compensated by resin production. The indicators of the WR scenario fell short of those observed in scenario R. Increased market price of resin and scale gain can overcome wood loss and ensure added value in the joint exploration of wood and resin.

Keywords: internal rate return, net current value, net profitability index, discounted pay back, forestry, scenarios

1. Introduction

Maritime pine (*Pinus pinaster* Aiton) is a large, rustic pioneer species that can reach up to 25 m in height and 60 cm in diameter at 60–70 years [1], is undemanding about the soil, but tolerates little soils of heavy texture and soggy [2]. Studies indicate that there were two subspecies of maritime pine in Portuguese territory. The subspecies *P. pinaster atlantica* EH del Vilar occurs along the coast from the North Alentejo and Extremadura, extending north through the coastal dune systems, while the subspecies *P. pinaster escarena* (RISSO) K. Richter has a Mediterranean continental occurrence [3].

The maritime pine wood has multiple applications. In general, the use of wood is associated with the characteristics of the tree, notably the diameter of the logs.

Larger-diameter logs (above 35 cm) are used for unrolling or producing sheets for application in furniture, interior decoration, and carpentry. Logs with an intermediate diameter (between 20 and 35 cm) are, as a rule, used for sawing for construction and furniture, while logs that are between 14 and 20 cm are used for sawing for the production of boards for boxing, pallets, among others. The wood of smaller diameter (less than 14 cm) has its most notable use for milling for the pulp and energy. In addition to wood, the bark of the trees is used for the production of substrate for use in agriculture and the resin for the chemical industry [2].

Every approach that is taken to maritime pine stands, in order to justify the investment in resources and efforts in the study of this species, it must be preceded by a recovery of its benefits and applications in the economy and its impact and importance on the society in which it operates. Data from the Portuguese National Forest Inventory (IFN6) shows that maritime pine is the third most common species in terms of land area, with 713,000 ha [4].

The large representation of maritime pine in Portugal translates into relevant economic results for Portuguese society. The report 'The Pine Row in 2019' [5] informs those maritime pinewoods constitute the largest carbon reservoir in the national forest in Portugal and generate 57,843 jobs in 8516 companies that enabled the generation of 1225 million euros in Gross Added Value and a turnover of 4384 million euros with an export value of 1876 million euros. Despite the strong numbers, the maritime pine forest area [4] and the productivity of the stands have decreased in the last decades [5] and thus justify the relevance of the approach of technical and scientific players in the production and dissemination of knowledge that allows the sustainable perpetuation of this important row.

Although the *P. pinaster* wood sector is well established in Portugal, like any product that falls under the laws of the free market, it has its own dynamics motivated by the quantities offered and demanded. It is important for the sustainability of the chain and its continuity, that there is a favorable balance of the income generated in relation to the expenses or production costs. In a generic analysis, it is possible to glimpse this relationship from indicator systems such as the Simplified System of Forest Product Quotations [6] of the Institute for the Conservation of Nature and Forests (ICNF), which presents the market prices of the cubic meter with bark of wood of various species, including maritime pine in public areas managed by ICNF. In the same value quotation line, the costs of timber harvest operations can be found in the Monitoring Committee of DGADR's forestry operations—Directorate General for Agriculture and Rural Development [7].

According to the aforementioned platforms, the average prices practiced by the maritime pine wood market for final cut (standing wood) in Portugal in 2020 was 34.56 euros for uncertified wood and 39.55(a) euros for FSC-certified wood [6]. As for the exploration costs, considering the mechanized process in the cut-to-length system where the felling and processing are done by the harvester equipment and the forwarder is fed back, the average cost indicated is 15.45(b) euros, and for transport the cost average to consider a distance of less than 30 km is 11.50(c) euros [7]. Ultimately, the final cost of the wood delivered to the consumer under the conditions presented should be close to 66.50(a + b + c) euros for uncertified round wood, plus the profits along the chain, capital costs, fees and taxes for the final cost.

In addition to wood, resin is another product that is explored in this species and adds important value to maritime pine economy. The application of the resin, as a product, is vast, but it can be summarized in two broad groups: turpentine, from which products such as pine oil, vitamins, dyes, flavorings and products for the cosmetic industry are made; and the rosin which is the basis for the production of glues, soaps, rubbers, lubricants, paints and various products for the chemical and pharmaceutical industry [8]. Beyond of economics benefits, the resin exploration has an important social gain, because its exploration induces the community nearby take care of the forest, what results in a more resilient forest since it is more guarded [9].

The values paid per kg of resin in Portugal are around 18 euros, which makes the activity attractive, and can result in gains of 50–500 euros per year per hectare [10]. Despite its attractiveness, it is important to reflect on the physiological aspect of the tree in resin production, as for resin exudation there is a physiological process stimulated by a wound that supposedly diverts resources to be used in the secondary growth of the plant [11] raising the question about a possible loss of wood productivity in tapped individuals.

Regarding the loss of wood biomass in forests submitted to resining was verified 20% reductions in the volume of *P. pinaster* in France [12]. In Portugal, there was a loss of 14% [13] in the diameter at breast height (d) and 16% in the total volume of trees [14] in *P. pinaster* stands. In India, decreases of 17.64% were verified in the diameter of *Pinus roxburghii* trees [15] while in *P. pinaster* stands in Spain, the diameter loss reached 33% [14]. In Germany, experiments conducted on *Pinus sylvestris* did not verify loss of dimensions of diameter, height or volume [16]. **Table 1** summarizes the references regarding the loss of dimensions of tapped trees.

It must be considered that although the resin exploration promotes some reduction in the production of biomass (wood), the economic results of the production of wood x resin might be viable. The viability of the business for *Pinus elliotti* in Brazil even with a loss of 9% of wood volume due to resin coating [18]. Regarding the financial performance of tapped *Pinus elliottii* stands in Brazil, in relation to non-resined and extraction costs and business profitability, it was found that extraction operations cost less than US$0.50 (0.42 euros[1]) per tree in forests that produce at least 2.5 kg of resin per tree per year, are profitable (have financial viability), which represented a result of 504.00 dollars (423.36 Euros[1]) per hectare of resinous forest and a gain of 17.76%, although there was a significant loss of wood volume for veneer and sawmill in the resinous forest [18].

References	Country	Species	Age (years)	diameter (%)	Height (%)	Volume (%)
Figueiredo apud Gomes [15]	Portugal	*Pinus pinaster*	—	—	—	16.0%
Figueiredo apud Maginni [15]	Italy	*P. pinaster*	—	8.0%	6.0%	—
Lemoine & Decourt [12]	France	*P. pinaster*	30	—	—	20.0%
Verma & Pant [17]	India	*Pinus roxburghii*	—	17.6%	—	—
Figueiredo [15]	Brazil	*Pinus elliottii*	23	6.0 a 14.9%	12%	14.9%
Figueiredo [18]	Brazil	*P. elliottii*	23	—	—	9.0%
Ferreira [13]	Portugal	*P. pinaster*	—	14.0%	—	—
Gènova et al. [14]	Spain	*P. pinaster*	93–109	33.0%	—	—
Van der Maaten et al. [16]	Germany	*Pinus Silvestrys*	115–140	0%	0%	0%

Table 1.
Selected articles for definition of volume loss with indication of country of origin, species, age and loss of dimensions (diameter, height and volume) due to the influence of resin.

[1] Quotation on September 7, 2021.

Planning the harvest of forest stands is a complex task due to the large number of production factors and the interactions between these factors, which makes each question that must be answered by planning assuming characteristics of 'perverse problems' or 'Wicked Problems', a situation in which the dynamics of the interaction between the factors of production is so complex that the answers are multiple and changeable according to the scenario presented at the time [19].

In order to mitigate the difficulties in the elaboration of scenarios imposed by the 'Wicked Problems', it is necessary to consider the analysis of a set of factors, which, when interacting, are responsible for the behavior of a variable that one wants to verify [19].

In a forest, factors such as climate, relief, soil type, species genetics, degree of anthropization, form and intensity of exploitation affect the potential productivity of wood and resin, as well as their interactions, hence the objective overview of this chapter will be to analyze among the possible production scenarios of a forest stand, for standard site conditions, which one offers the most sustainable results and the best balance between cost and benefit of integrated production of wood and resin, based not only on production potential, but also on the results of financial viability indicators based on investments and planned cash flow.

The objective of this work is to evaluate the technical and financial feasibility of different management goals in maritime pine stands considering managing the stands for wood and/or resin. The specific objectives of the chapter are addressed into two distinct stages. At first, a timber harvesting model will be defined in a maritime pine stand, using the Modispinaster simulator [20, 21]. Afterwards, it will be defined an average coefficient of loss of productivity of wood as a function of the resin extraction process, namely the relationship between dendrological variables (diameter, age, stand density) and wood production. In a second stage, after defining the integrated wood x resin productivity balance, based on market prices and considering the full commercialization of the products, the investments, operational costs and financial results will be verified based on the indicators of internal rate of return, net profitability index, net present value and payback time. The best exploitation scenario will be indicated according to the resin extraction intensity and always considering the cycles and interventions indicated by the previous phase simulated in Modispinaster. In this way, it is intended to answer the question: How do the financial viability indicators respond considering the joint exploration of wood and resin? Considering the exploitation of only wood, only resin and wood with resin, which scenario is more attractive?

2. Methodology

This study is based on scenario creation and simulations; therefore, there is no real physical area for data collection. The data listed here were obtained through interviews conducted in 2021 with companies operating in the forestry market, notably with the exploration of maritime pine and are based on records of these companies and on the common sense existing in the market. Some characteristics of the hypothetical simulated study area were predefined, such as forest size, terrain characteristics, fuel consumption and wages and charges and others, such as the type of equipment used and the exploration system were considered as adjustable variables for obtaining the lowest-cost scenarios.

2.1 Methodology for determining the wood productivity adjustment factor due to the impact of resin coating

The impact of resin on tree growth and, consequently, on wood productivity was assessed in scientific literature for *Pinus* genus in countries where it is natural or cultivated (**Table 1**).

Some references (see **Table 1**) did not indicate the impact on volume variation due to tapping, but rather on the stem diameter and eventually on height. To obtain a measure of impact on volume and therefore, to measure the volume loss as a function of diameter reduction, the volume model (Eq. 1) developed for the species *P. pinaster* [22] was used. The equation allows to estimate the total stem volume (v, m^3) of a tree based on the diameter measured over bark at 1.30 m height above the soil level (d, cm). The equation was applied for each diameter class central value, starting at 10 cm, and then the process was repeated for the diameter class centre until 65 cm, with the reduction in percentage pointed out by the references in **Table 1** [13–15].

$$v = -0.073243082 + 0.005815280 \times e^{d^{0.458656754}} \quad (1)$$

The comparison of the volumes obtained for each operation was used as a proxy of the loss of volume.

In this way, with the variation of the inserted diameters, the volume variation was achieved. The density of green (wet) wood over bark of *P. pinaster* with an average age of 33 years is close to 0.8 g.cm^{-1} [23], therefore considering that the stand of this study has an average age of 40 years, and that with increasing age, there is also an increase in wood density [24], it was considered in this study that the density of *P. pinaster* wood at the time of felling is equal to 1 g/cm^3, so the conversion of volume to biomass is direct and equal to 1, that is, 1 m^3 is equivalent to 1 ton, so the loss of volume (m^3) is equivalent to the loss of mass (t). This is accepted to be a simplification, but it does not alter the objectives pursued.

2.2 Definition of the premises for the study

It was assumed that the harvest will be done by the producer-owner of the forest and that the entire field operation will be its own.

Regarding the exploration model, scenarios of exploration of wood, resin and wood integrated with resin were considered. The scenario analysis period will be 10 years, considering year 1 (t1 = 35 years) and year 10 (t10 = 45 years). The initial age of 35 years was considered because at this age the simulated scenario indicated the predominance of trees with a diameter above 20 cm, a legal and favorable condition for resining.

The exploration model considers the premise that the forest did not undergo resining prior to the study period. In scenarios where there is logging, a thinning occurs every 5 years, which means that there are two thinnings during the simulation: at t5 (40 years) and at t10 (45 years). The trees to be removed in the thinning from below were those with the lower dimensions, both in height and diameter.

The characteristics of the target forest stand for the study are based on the average pattern of *P. pinaster* forests found in northern Portugal, where the relief is moderately sloping, with the presence of some rockiness. The stands, in general, have irregular spacing as they result from natural regeneration. It was assumed that spontaneous vegetation in the understory is low. The wood volumes are considered over bark.

The model of timber harvest adopted was that of services performed by the owner himself, since the removal of timber will be occasional. It was considered that the sale value of standing wood will support all forest maintenance costs, such as controlling spontaneous vegetation, maintenance of roads and firebreaks, inventory and combating pests and diseases, and will be deducted from its value by 30% considered as profit and taxes of the producer, with the remaining 70% added to the investment value for the production of wood delivered to the consumer.

In relation to exploration and transport operations, average utilization rates were always above 70%, high base productivities of machines and equipment when not impacted by the experience of the operator (which was adopted as 'experienced', which considers the potential to reach 100% of the expected productivity) and operating conditions, which was considered good for this study (low slope, few rocks, dry weather and non-aligned trees) because was considered that these conditions will not to influence the operating income. Income and operating cost were adjusted in accordance with the practice of a leading company in the Portuguese forestry market, through a personal report from its forestry engineer.

Regarding the costs related to the machines, the market acquisition values were considered for amortization in 60 months [25] at a residual value of 10%. Fuel consumption and other inputs, as well as maintenance and administrative costs, were obtained from personal information obtained from the field coordination of the company in question.

The description of the operating process for the production of resin, its costs and investments were collected through personal information provided by a technician specialized in the area.

Market values for standing wood delivered to the consumer and the market price of the resin and the rental price of the spouts were also obtained from the aforementioned company.

2.3 Methodology for defining biomass (t) and characteristics of available wood

To determine which interventions should occur in the forest stands and thus create the operational scenario for the harvest of the forest, the Modispinaster simulator [21, 26] available on the CAPSIS platform [27] was used. The simulator requires, as input data, information on basal area (G) of the stand, mean quadratic diameter (dg), dominant height (hdom), stand age and stand density (trees ha^{-1}). The simulator returns the output data (outputs) that refer to the forestry model that should be applied to the stand. The variable values needed to initializate the simulator were taken from Production Tables [20, 28]. A medium quality station (SI35 = 16 m) was assumed [29]. At the starting point, the pine stand was 15 years old and had a density of N = 2200 trees ha^{-1}, G = 12.8 m^2ha^{-1} and dg = 8.6 cm.

Projection of growth was simulated over a 50-year period, subject to thinning from below. The density regulation was based on specifying the proportion of trees removed periodically over time. The intervention regime adopted considers a total of six thinnings, one every 5 years, starting at age 20 and ending at 45 years of age. The proportion of trees removed varies from 20–30%, with the following sequence: 20% (t = 20 yr), 30% (t = 25 yr), 30% (t = 30 yr), 25% (t = 35 yr)), 25% (t = 40 yr) and 25% (t = 45 yr).

According to this model of density regulation, the stand reaches a value of 20 cm at 31 years old. Of the entire growth projection period, this case study focuses, as mentioned, on the range of 35–45 years. At 35 years of age, after performing a thinning, the trees are distributed in diameter classes (5 cm range) of 20 cm or greater.

2.4 Methodology for simulation of optimized wood production scenarios

The determination of the optimized scenario for the exploitation of wood by Modispinaster indicated the volume to be extracted per hectare so that production has is sustainable. Based on this volume value, operational scenarios for the harvest of wood were established. A programmed Excel sheet was used to generate monthly costs per ton in the exploration and transport of wood according to pre-established parameters. The sheet is not prepared to include the investment and cash flow values in the generation of costs, only for the calculation of operating costs. The payroll is programmed from seven cost sub-groups, namely:

- Equipment costs: this cost group includes the acquisition value of new equipment for use in forestry harvest, such as Harvester, Feller-Buncher, Skidder, Forwarder, Crane, Tractor-Grapple, Self-loading Tractor, Shutter, Chainsaw and Support vehicles (Pick up and light vehicles). In this same group, there is also a certain period of depreciation/amortization of the acquisition values (predefined for 60 months), which can be changed according to the intensity and mode of use of the equipment. It can also be defined a residual value for goods, which is set to zero, and insurance for machinery and vehicles.

- Maintenance costs: The costs of tools, collective protection equipment and maintenance equipment for the establishment of a workshop (fixed or field), costs with spare parts, wearing material and preventive/predictive maintenance are included in this field.

- Fuel and input costs: The updated prices of fuels (diesel and gasoline) and inputs (hydraulic oil) are allocated in this field. Low consumption inputs such as coolants or anti-freeze, chain oils and lubricating grease were not allocated in this field, as these costs are considered to be already present in the amount allocated to maintenance costs.

- Personnel costs: This group of costs includes the expected salary to be paid to employees (machine operators, mechanics, assistants, administrative assistants and managers). Also in this group are the values with food, lodging, labour exams, insurance, extra benefits, payments for production, uniforms and personal protection equipment.

- Costs with contributions and taxes on labour: This sheet includes amounts related to compulsory fees and contributions, provisions for extra wages, leaves and charges related to work. The allocated amounts are linked to the personnel cost group and automatically feed it.

- Administrative costs: The costs necessary for the management of the business are represented here, such as costs with fees and taxes related to the license and operation of the project, training and training, food, travel and accommodation for the management, extra vehicles, Information Technology and office material, costs of renting rooms and their expenses, technical consultancy.

- Project profit margin: It is previously established as 20% for outsourced projects, where the calculation of profit occurs on the provision of services and 0% for own projects where the calculation of profit occurs on the sale of the product (wood).

Assumptions and parameters were included, such as hypothetical project area (see justification below), volume to be harvested per hectare, slope, occurrence of rocky outcrops and stones, density of the under storey spontaneous vegetation, density of trees per hectare in the forest, average volume of trees, weather conditions, price of standing wood, distance and average transport speed. The entry of these data into the excel sheet enabled the next step, which was the entry of variable data that enabled the creation of the lowest operating cost scenario.

Variable data for creating of scenarios was: Exploration system and machines as well as their productivities, mechanical availability, operational efficiency, employees' salaries, costs of acquisition of vehicles and machines, work shift used (number of days in the month, hours a day and number of shifts per day), support and maintenance structure (personnel and equipment) and type of operation (own or outsourced). Each of these variables was adjusted in the model, until the lowest possible cost per cubic meter/ton of wood was found.

It should be noted that there were assumptions for the generation of the operational scenario, and any modification in one of these will alter the results presented. In brief, the operational scenario is based on the following characteristics:

a. Exploration area: the area chosen as the starting point is 100 ha, as this will gain some scale and remain coherent with the characteristic of northern Portugal where small properties predominate. The oscillation of this area will be addressed in the discussions that follow.

b. Terrain slope: Moderate or gentle undulating slope with a declivity of 3–8% was taken by default [30], since in the north of Portugal forests are always located in areas with some slope.

c. Spatial arrangement: A configuration with irregular tree spatial distribution was adopted as it is the most common situation and poses greater operational challenges.

d. Machine operator experience: It is assumed that the operators of the machines and equipment selected have experience and practice and have already gone through the entire learning curve in order to find themselves at the peak of productivity.

e. Weather: It is related to weather conditions; it is considered that the entire operation takes place in dry weather, without rain.

For the final analysis, considering the lower-cost scenario, it was assumed that the value of standing wood already includes all previous costs such as opening and maintaining roads, clearing vegetation of the land, planting, combating trees' pests and diseases, inventories and others. The sum of the cost of standing wood, plus the cost of exploration and transport, results in the final cost of the wood (delivered to the consumer).

By comparing the final cost of the wood with the value (price) paid by the market, the profit margin of the complete wood exploration process was obtained. From the scenario chosen for logging adjusted in the excel sheet, resin production revenues and expenses were generated for 0% (Scenario 1-W) and 100% of trees above 20 cm in diameter breast height (Scenario 2-MR) and after that, a third scenario was created to consider only resin production (Scenario 3-R). To define the amount of wood harvested, it was considered that there was a reduction in the volume of wood obtained in each scenario as a function of resin. Afterwards, this reduction was applied in the annual increment of the forest according to the percentage of tapped trees. It was considered that in the study area there is no history of resin tapping.

Table 2 specifies the verified exploration scenarios.

The creation of each exploration scenario allowed obtaining the unit cost for wood (€/t) and resin (€/kg), and by multiplying this cost by the quantity produced, the values of capital outflows from the cash flow were estimated. The multiplication of the quantities produced by the unit market value indicates capital inflows into the cash flow, essential elements for the financial feasibility analysis below.

Scenarios	Products	% of tapped trees (d > 20 cm)
Scenario 1 (W)	Wood	—
Scenario 2 (WR)	Wood + Resin	100%
Scenario 3 (R)	Resin	100%

Table 2.
Scenarios of wood and resin exploration in a Pinus pinaster forest.

2.5 Methodology for the analysis of financial feasibility

The financial feasibility analysis was developed based on four classic indicators for this type of analysis: The Internal Rate of Return (IRR), Net Present Value (NPV), Net Profitability Index or Return on Investment (NPI) and the period of recovery or time of return on investment (Payback) obtained through an Excel spreadsheet.

The selected indicators are the most frequently used for financial viability analyses. The internal rate of return (IRR) is the maximum rate that an investor can invest so that there is no capital loss. The net present value (NPV) is based on comparing the project's cash flows with the initial investment, and the project is said to be profitable when its value is positive, and the net profitability index (NPI) returns the effective return per unit of capital invested in the project while the recovery period or Payback indicates whether the invested capital is recovered in a shorter period than the projected time [31].

A viable project from a financial point of view is one that allows the return of the invested capital to the investor in a period of time shorter than the period of analysis (Payback), which is established in this study in 10 years, as it is compatible with long-term projects common in the forestry area. Profitability index above 1, which means that for each invested unit, one unit returns to the investor plus the percentage above 1 represented by the decimal places of the indicator.

The internal rate of return must be greater than the opportunity cost, which means that the project remunerates the invested capital above other possible investments considered, for this project the value of 5% per year was considered. The net present value must be positive, if we retroact the values considered in the cash flow (investment + inflows +outflows) to the present time, the value must be positive because values below zero indicate that there was a financial loss [31]. **Table 3** defines the parameters that will be considered for the final analysis.

To calculate the indicators, it was previously necessary to raise the investments and build the cash flow (CF).

For the investments, all costs of acquisition of vehicles, machinery and equipment provided for in the excel sheets were used for the preparation of the scenarios, plus the value of 3 months of personnel costs and consumable materials

Indicator	Reference Value	Interpretation
IRR	>5%	The bigger the better
NPV	>0	The bigger the better
NPI	>1	The bigger the better
Payback	<10 years	The smaller the better

Table 3.
Parameters for financial analysis.

Parameters	Description
Expected rate of return (K)	5%
Market price per ton of standing wood	€ 20.00
Cost per ton of standing wood (investment for production after thinning)	€14.00
Price per ton of pulping wood delivered to the final consumer (industry)	€ 40.00
Wood and resin exploration system	Own (acquisition of equipment and execution of services by the forest owner), free of taxes and profit.
Average distance of wood transport	10 km (forest/industry)
Price per kg of resin paid by the processing industry	€ 2.00
Resin production by spout	2 kg

Table 4.
Parameters adopted for analysis of financial feasibility.

as working capital. The definition of a working capital of 3 months considers that the project will have 1 month of preparation/mobilization, 1 month of production and 1 month of bureaucratic procedures for the first entry to occur capital (payment).

The cash flow is composed of capital inflows and outflows. The value of the entries was obtained by the annual quantity of wood for wood chips (the most representative product in the market) and/or resin produced, multiplied by the price paid by the market. Wood for veneer and sawmill may suffer loss of value due to stretch marks (wood damage) [32]; however, for this study, this loss was not considered because it was decided to simulate scenarios only of wood for cellulosic pulp and energy.

The output value was calculated by the amount of wood/resin produced multiplied by the cost (indicated by the companies) of production indicated by each scenario.

The assumptions used for the project feasibility analysis are shown in **Table 4**.

3. Results and discussion

3.1 Determination of wood productivity adjustment factor due to the impact of resin

The analysis of **Table 1** indicates potential diameter loss ranging between 8 and 33%, for heights losses between 6 and 12% and for volume losses between 0 and 20% for trees ranging in age from 23 to 140 years old. After excluding the values of the aforementioned articles incompatible with the study [16, 14], the stem volumes and the volume losses were estimated according to the methodology described in Section 2.1. The volume loss ranged between 0 and 20%, and the average value for the sequence of studies of 16% biomass reduction was adopted. The estimated rate of volume loss is in agreement with the value mentioned in literature for maritime pine in Portugal [15]. The differences found with other studies [16, 14] are expected because the losses of dimensions in the trees can be conditioned for genetics factors and environmental variables that change in different sites.

3.2 Definition of volume and characteristics of available wood

After processing the input data and simulating the growth of the stands and periodical silvicultural practices, the Modispinaster simulator returned the results that were taken as the initial parameters in establishing a model for the scenario feasibility analyses. **Figure 1a** and **b** represent the diameter distribution of the stand before and after thinning at 40 years of age. This moment represents the centre of the analyzed period (t5 = 40 years). At 40 years, the diameters at breast height are above 20 cm and the most represented class is that of 25 cm. The quadratic mean diameter changes from 25.9 cm before thinning to 27.0 cm after thinning with this variation being associated with the thinning from below.

In order to delimit the analysis scenario, it was decided to work with fixed values of the number of trees with breast height diameter above 20 cm before and after the intermediate thinning; therefore, no entry, neither loss of individuals was considered in the 5 years preceding and in the following thinning. For the pre-thinning scenario (t1–t5), the defined scenario indicates that the number of is 645 treesha^{-1}, and in the post-thinning scenario, it is 485 treesha^{-1}. These numbers will be used to define the mass of resin produced in each period.

Finally, the theoretical wood biomass to be extracted from the forest in the two-thinning scheduled to occur at 40 years (t = 5 years) and at the end of the analysis cycle, at 45 years (t = 10 years), are 37 tha^{-1} and 45 tha^{-1}, respectively.

3.3 Simulation of optimized wood and resin production scenarios

As already mentioned, there are three management scenarios to be analyzed: the exploration of wood (W), resin (R) and the integration of wood and resin (WR) exploration in the same area (**Table 2**). Initially, the wood and resin exploration scenarios will be analyzed separately, and later the integration of both products was carried out in order to consider the loss of 16% of wood due to resin coating.

3.3.1 Logging

The analysis system adopted initially indicated the lowest cost per ton of wood for a mechanized logging system (7.19€ha^{-1} of wood stacked on the road). However,

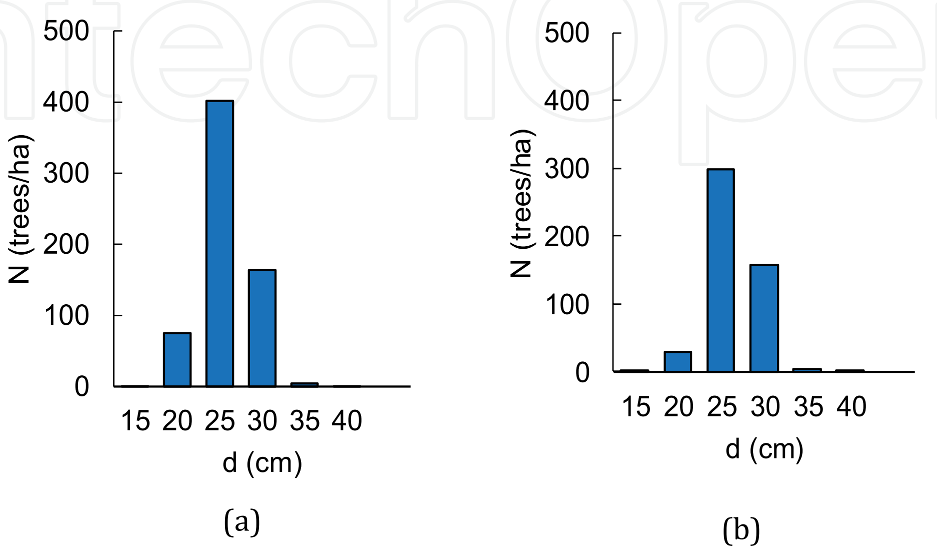

Figure 1.
Diameter distribution before (a) and after (b) thinning at 40 years old.

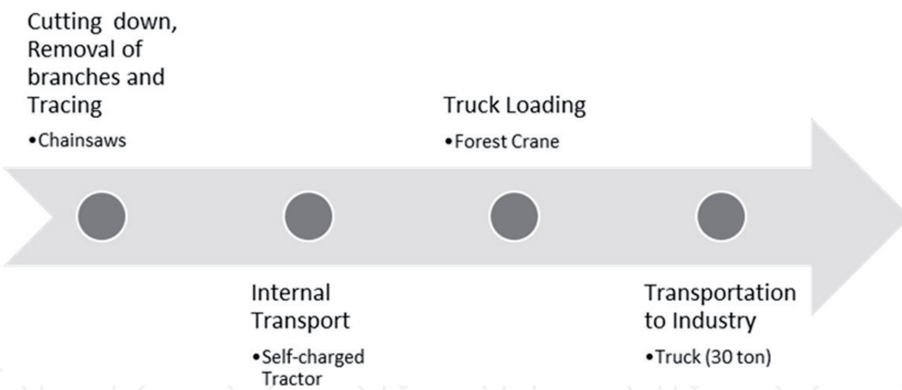

Figure 2.
Logging system (scenario W).

when analyzing the scenario from the perspective of the technical component, it should be considered that because it is a natural regenerated forest, the access to a trail by the equipment can be impossible due to the arrangement and density of trees on the ground. Therefore, the system was conservatively adjusted for the use of chainsaws, and the system was then designed as indicated in flowchart below (**Figure 2**)

The final cost for logging was 12.27 €ha^{-1} for harvesting and delivery operations and 5.64 €$ha^{-1}$of wood for transporting the forest to the consumer (industry). These costs are very different and sensibly smaller than the costs indicated for [7] that indicates generic values that were not adjusted for any particular case, therefore is important in deeper analysis to calculate the costs, using the [7] only for cases that do not require precision.

3.3.2 Resin exploration

The resin exploration system followed the traditional model adopted in Portugal, which occurs with essentially manual operation, where the worker in the field opens streaks that lead and converge the resin flow to a central point below the wounds, determining the so-called 'spout', where there is a container to collect the resin to be later transported to the storage area before going to the transformation industry.

The system was designed as shown in **Figure 3**.

In the resin production in Portugal, the producer finishes his actions when he delivers the resin in a stock location, and from there the buyer (industry) collects

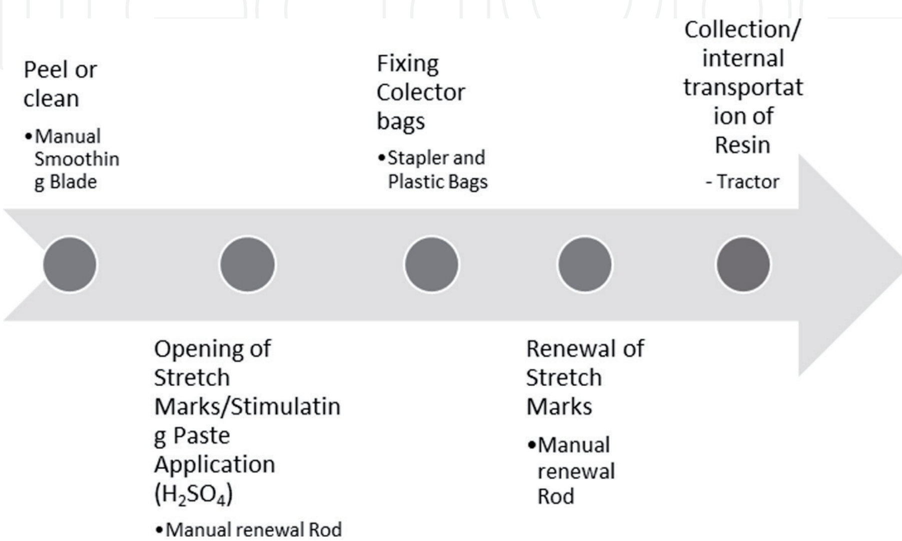

Figure 3.
Resin exploration system (R).

the resin and performs all the logistics to the plant, so actions such as stockpiling, truck loading, transportation and delivery are not indicated in the flow of the resin above.

In the model conceived in light of the characteristics of the forest and the operation in the field, the spreadsheet in Excel returned the cost of the resin at 1.06 €kg^{-1}, and this cost will be multiplied by the quantity produced for the composition of the outputs or expenses of this activity and, in turn, will participate in the formation of the cash flow.

3.3.3 Integrated wood and resin exploration

When resin production occurs in conjunction with resin production, that is, both products are explored in the same stand, it is expected that beneficial synergies to the process will occur, resulting in optimized operational and financial indicators. For example, a single manager can monitor both processes, and so there is a reduction in personnel involved and consequently their costs. Among the most likely synergies in this type of systems integration are the optimization of the operational workforce, the administrative system (management and control) and the use of machines and equipment. The mentioned synergy aforementioned was defined by [33], which explains when there is a production increase, using the same resources, occurs a dilution of fixed costs and the variable costs remain equal, so the final cost decreases.

For the subsequent analyses, in the WR scenario, such synergies or gains arising from the joint exploration of wood and resin were not considered, because, in the case of a simulation, the possible results of this exercise would be too broad and subjective. The number of scenarios that can be simulated is considerably large, and despite there were evidence that tapped trees can present anatomic differences from non-tapped trees [34], the WR scenario was designed in a simplified way by the sum of investments, costs and revenues of scenarios M and R separately. There are studies that confirm wood and resin exploration are viable, as [35] indicates this exploration as a way to recover the loss with thinning of small volume trees. The benefits from joined production of wood, resin and carbon may extend the optimal rotation age of Pine plantations [36].

3.4 Financial feasibility analysis

The values used to compose the cash flows resulting from the values simulated in each of the scenarios and that allowed the analysis of financial feasibility are presented in **Table 5** for 100 ha.

Table 6 shows the results obtained from the cash flow analysis for each indicator defined for the financial feasibility analysis.

The analysis of **Table 6** clearly indicates that the three scenarios, respecting the defined technical and operational conditions, are financially viable.

The Internal Rate of Return (IRR) is always greater than the predetermined rate of return of 5%. Scenario R presents the highest rate of return on invested capital (20.5%) followed by scenario W and WR, respectively, with similar rates of 12% and 11.9%. The excellent performance of the IRR indicator in the R scenario is due to the fact that in this situation, despite the absolute return values on the cash flow, the investment is very small when compared to scenario W and therefore to scenario WR. Scenario R has an excellent return; however, for larger gains in absolute values, a much larger scale of exploration (number of trees and area) is needed than the one fixed in the study. The advantage of scenario R was verified too in *Pinus elliotti* in Brasil, using a similar methodology, where the exploration of resin indicates a superior IRR than timber or timber and resin [37].

Cash flow	Stand Age (years)	W (€)	WR (€)	R (€)
Initial investment	35	−543,537.07	−566,604.22	−23,067.14
Cash Flow year 1	36	−20,000.00	−14,408.09	5591.91
Cash Flow year 2	37	−20,000.00	−14,408.09	5591.91
Cash Flow year 3	38	−20,000.00	−14,408.09	5591.91
Cash Flow year 4	39	−20,000.00	−14,408.09	5591.91
Cash Flow Year 5 (Roughing)	40	714,221.41	699,813.32	5591.91
Cash Flow year 6	41	−20,000.00	−16,877.40	5591.91
Cash Flow year 7	42	−20,000.00	−16,877.40	5591.91
Cash Flow year 8	43	−20,000.00	−16,877.40	5591.91
Cash Flow year 9	44	−20,000.00	−16,877.40	5591.91
Cash Flow Year 10 (Roughing)	45	723,556.63	746,679.23	5591.91

Table 5.
Cash flow in the three projects verified (values in euros, €/100 ha).

Indicator	W	WR	R
IRR	12.0%	11.9%	20.5%
NPV	317,894.46 €	325840.49 €	19,154.42 €
NPI	1585	1575	1830
DPB	FC 10	FC 10	FC5

Table 6.
Financial feasibility indicators for scenarios W, WR and R.

The Net Present Value (NPV) is positive for the three scenarios, and it is higher in the WR Scenario by an amount of 325840.49€, followed by the NPV of Scenario W of 317,894.46€ and finally a lower absolute value in Scenario R of 19,154.42€. The positive NPV is a good feasibility indicator only if we consider the isolated analysis of each scenario whether positive or negative. However, it should not be used as a comparative indicator, because it is a proportional number. That is, larger investments tend to generate higher NPV, as it is the case of scenarios W and WR which have investment values in the hundreds of thousands while scenario R has an investment in the tens of thousands of euros. The NPV was confirmed to be good indicator by [38], which indicates that exploration of timber and resin brings economics benefits to forest owners in United States. The same result was found for [36] in Java.

The Net Profitability Index (NPI) also indicates feasibility in the three scenarios and once again the NPI of Scenario R of 1.83 stands out, above the indicators of scenarios W, which presented an NPI of 1.585, slightly higher than the WR scenario, which presented an NPI of 1.575. Once again, in the same trend as the IRR, the low investment in Scenario R allows for a better performance of this indicator.

The Discounted Pay Back (DPB) or Recovery Period of invested capital is established at 5 years for the R scenario and 10 years for the W and WR scenarios. The best rates of return and net profitability index of scenario R, given the low investment, once again place this scenario with the best indicator.

4. Conclusions

Scenario R, where only resin is explored, has the best financial indicators and has less operational complexity; however, given the low absolute values of investment, the financial result also generates low absolute values, which means that for a businessman to bet a resin exploration project, it is necessary to gain scale (largest area and number of trees). Resin production can be scaled up by increasing the area, increasing productivity by spout or by increasing the number of trees harvested per hectare or by all both productions.

The integration between the wood and resin exploration that generates the WR scenario, which, despite being viable, generates the worst indicators of those presented, being very close, but still below the indicators of Scenario W. The reason for the worsening of the indicators is due to the fact that the 16% loss of wood volume/biomass that the resin imprints on the wood is not surpassed by the generation of resources from the resin.

The 10-year Payback of the scenarios where there is logging (W and WR) indicates that in the first thinning the producer does not recover his invested capital, which only happens in the second thinning at 10 years (corresponding to a stand age of 45 years, in the case study); however, with the gain of scale and use of the structure for projects that occur in parallel, this effect can be mitigated.

Increased productivity, increased sales price and gains in scale in the area significantly improve the scenarios presented. An increase of only 1 cent in the price per kg of resin already makes the WR scenario more attractive than the W scenario.

Finally, once this study was based on simulations, it is important that new studies may add precision in the results with a larger stand of data from field.

Acknowledgements

Thanks are due to the Pinus Competence Centre (CCPB), Pinus Centre (Centro Pinus), and International Union of Forest Research Organizations (IUFRO), namely Division 1 (Silviculture), unit 1.01.10 Ecology and Silviculture of Pine, for promoting fruitful discussions on the silviculture and management of pine forests that have contributed to the organization of this chapter. Thanks to Dr. José Lousada and to Forest Engineers Mr. Marcos Ribeiro and Mr. André Ferreira for their valuable contribution.

Funding

For the author integrated in the research centre Forest Research Centre (CEF), the research was financed by National Funds through the Portuguese funding agency, FCT (the Portuguese Foundation for Science and Technology), within project UIDB/00239/2020. For the author integrated in the MED research centre, this work is funded by National Funds through FCT—Foundation for Science and Technology under the Project UIDB/05183/2020. For the author integrated in the CITAB research centre, it was supported by National Funds by FCT—Portuguese Foundation for Science and Technology, under the project UIDB/04033/2020.

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