MULTITRACES

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A study case made by national students for rural business in Greece

TITLE OF THE PROJECT

POTENTIAL OF WOOD WASTE SUPPLY FOR PELLET PRODUCTION IN GREECE WITH REFERENCE TO ALFAWOOD GROUP COMPANY

Athanasios Fallias

Email:_afall@outlook.com.gr_

Nina Gavriilidou

Email: _gabriilidoun@gmail.com_

MENTORS:

INTERNATIONAL HELLENIC UNIVERSITY:
Vassiliki KAZANA, Dimitris RAPTIS

ALFA WOOD group S.A.

Dimitris Lazos

Presentation of the
ALFA WOOD GROUP S.A Company

Students:

Athanasios FALLIAS afall@outlook.com.gr

Nina GAVRIILIDOU gabriilidoun@gmail.com

The ALFA WOOD group is a family-run business offering unique services that respect both man and the environment, while adopting a more personal and emotional business approach.

The company was founded in Larissa in 1981 by Antonios Adamopoulos and Christos Agorastos and since then it has been shown a continuous upturn, making it the largest Wood Processing Industry in Greece and one of the most significant in the Balkans.

The ALFA WOOD group according the testimony of its owners has based the continuous successful running of the business in the Greek and international markets, on important core values, such as dynamism, loyalty, sense of responsibility and reliance.

The ALFA WOOD group has formed a network of 40 partners around the world. Their main export target is the markets of Europe, the Balkans, the Middle East and North Africa. The company's participation in the international market place is considered highly supportive to the Greek economy through the promotion of Greek products and services.

Figure 1 International Activity of ALFA WOOD group Company

The ALFA WOOD group company places much attention to the protection of the environment by reducing the environmental impact of the production processes while raising awareness about all the relevant to the company's environmental issues of all its employees.

The ALFA WOOD group company has established modern production practices and methods which, in combination of its state-of-the-art equipment and industrial facilities, are fully harmonized with both national and international environmental standards through the respective certifications.

The ALFA WOOD administration and staff are proud of the environmental role the company plays throughout the timber supply chain, in the production of wood-based fiberboard and alternative solid fuels based on forest biomass. The reuse of wood residues for wood and energy production leads to a saving of raw materials and a reduction in the intensity and extent of logging in forests. This results in cost-effective production with the lowest possible environmental impact. They ensure minimal impact on land, water and air, reducing carbon dioxide (CO2) emissions, as the thermal energy and much of the electricity they use is generated only from wood residues. They promote and accelerate the recycling of wood waste from other producers to the maximum extent, providing effective management solutions while protecting nature from the unnecessary deposition of wood by-products in streams and undefined areas. The ALFA WOOD group company is one of the first licensed units in the field of wood waste processing in Greece.

The company, with respect to sustainability and sustainable development, invests in new equipment, taking an active role in trying to improve environmental applications. They process residues from their production process, as well as all kinds of wood residues, including: wood, plant tissue residues, wooden packaging and other materials, which they then use to produce alternative fuels.

The ALFA WOOD group company supports forest management in Greece and other parts of the world. They use timber and forest biomass as raw materials for the production of industrial products and renewable energy towards sustainable development. This is why they place priority on the use of timber from fully managed and certified forests. In this context, the company implements the forest certification program (FSC) from the Forest Stewardship Council, which guarantees that any human intervention in the environment is done in a balance way by ensuring the relationship between the exploitation of natural resources and the evolution of ecosystems for the future generations.

The protection of the environment, as well as the care of providing the primary raw material, which is wood, is based on a turnover that is governed by the sustainable management of the forest environment. To this end,

- The wood industry obtains the timber it uses for the production of panels, exclusively from suppliers who are verified by the certified government agencies (Forestry divisions/forestry inspectorates) as well as international organizations such as FSC®. During the production process, they opt for internationally certified management systems such as quality management, low formaldehyde emission, fire and water resistance. ISO 9001: 2015, CE, FSC, CARB, E0, FIRE RETARDANT AND WATER RETARDANT.
- Their products reach the consumers in full transparency, according to the Environmental Product Declaration (EPD), which provides important information on the environmental and health aspects of the manufacturing process for each of the products.
- All wood processing by-products resulting from the production process, as well as those not suitable for sale, are re-processed and are used either for new wood panel production or for biomass energy production, depending on their origin.
- At the same time, biomass, through the combustion process, generates heat as well as “green electricity”
- .

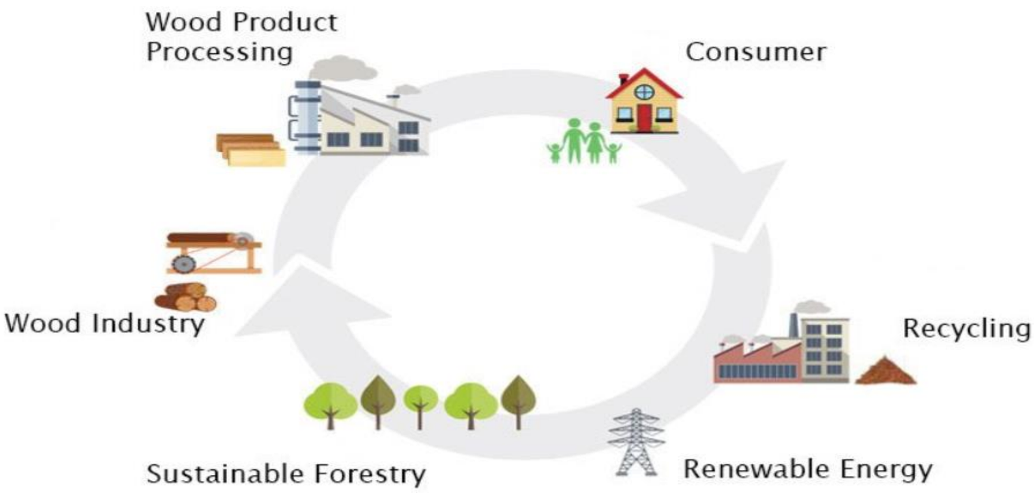

Figure 2 The production process of the ALFA WOOD group Company towards sustainable development

The ALFA WOOD group company focuses on recycling biomass waste, from its production process, as well as all its waste, such as, forest biomass, plant tissue waste, wooden packaging and other materials arising from wood's processing. The company uses these as raw material for the production of electricity and "green energy", aiming at enhancing and extending biomass' life cycle, by creating added value to it.

The biomass to be recycled, after being collected, is sent to the company's factories and is being subjected to a specific treatment, in order to be used for the production of green energy (heat and electricity) and eco- friendly products from renewable raw material resources. The ALFA WOOD group company proudly states that 75,000 tons of biomass wastes are being recycled every year and 200,000 tons of carbon dioxide (CO^2) are being saved every year.

All wood processing by-products, resulting from the production process, as well as those that are not suitable for sale / essentially at the end of their life cycle, are used to produce energy from biomass, depending on their origin, thus saving energy resources while contributing to sustainability at the same time.

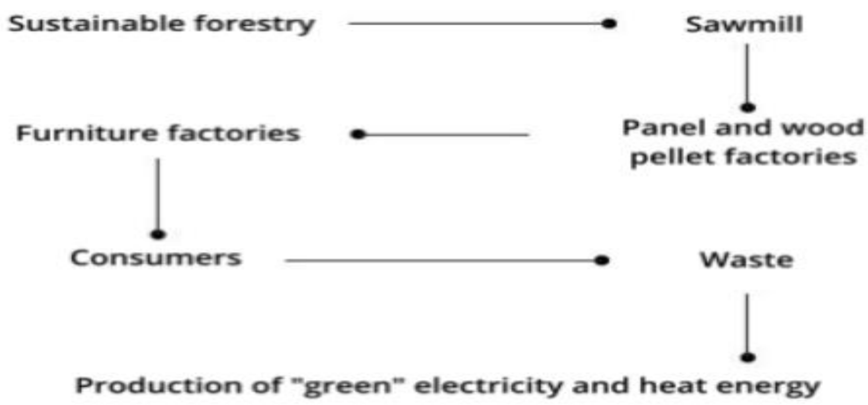

Figure 3 The production cycle of the ALFA WOOD Group Company

In 2011, the Company launched the new state-of-the-art pellet and briquette production plant in Kato Nevrokopi, Drama and in 2017 a power plant, which generates 1MWH of biomass power.

The facilities at Kato Nevrokopi are spread over an area of 228,000m^2 of which 15,300m^2 are factory premises. The Kato Nevrokopi unit is active in the production of bio-fuels and green energy. The products manufactured at this factory are:

• Wood Pelletts

• Wood briquettes

• Wood garden chips

• 1MWH power output using biomass

The ALFA WOOD group (Pellet and Briquette Industry) with a total of 65,000 tons pellet production per year is listed among the best wood pellet and briquette industries in Europe. The production launched in November 2010 and the increased stock availability, played the biggest part in its overall development. It is the only Greek factory that was certified according to the high quality European standard, ENplus.

The company employs over 40 local employees and many more in the supply chain. It is the definition of “GREEN GROWTH”, even though it operates in a remote area. In addition to the domestic market, it exports significant quantities, mainly to Italy, but also Cyprus, Bulgaria, Albania, Lebanon, thus contributing significantly to the country’s economy.

Figure 4 ALFA WOOD group (Pellet and Briquette Industry) at Kato Nevrokopi

Pellets are a form of biofuel with widespread use and a large number of applications. They consist of aggregates or compacts of biomass forming a type of natural biological fuel in woody form, also known as wood pellets. For their production, pine and spruce forest products are used as raw material. The aggregates (pellets) are standardized cylindrical biofuel 40 mm long and 6 mm in diameter with quality specifications for the preparation of which no glues, chemical additives or other substances are used – only high pressure and steam, which makes them completely environmentally friendly.

Wood briquettes are compressed biomass briquettes, 100% natural material, environmentally friendly solid fuel produced from natural wood, made by high compression machines and they do not contain harmful substances and chemical additives. For their production, pine and spruce forest products are used as raw material. Wood briquettes are standardized cylindrical bio-fuel with quality specifications, for the preparation of which no chemicals are used, which makes them also completely environmentally friendly.

The production of pellets and briquettes has high demands in the field of technology, which should be combined with economy and ecology. A key requirement is that in the briquette and pellet production industry, the energy from the combustion of discarded, as not suitable for pelletizing, logging residues and derivatives of the wood industry is used as energy for drying the wood chips.

As a raw material for production, 100% of debarked coniferous tree trunks are used exclusively from pine and fir forests. The high quality raw material can ensure excellent characteristics of the final product, such as the highest calorific value, very small combustion residues, high mechanical strength and high density per m^3. In the ALFA WOOD Company they advocate that the best ones are those made from soft wood. One of the main reasons for choosing coniferous pellets is their extremely high caloric content. The melting temperature reaches 800 degrees Celsius in the boiler. In addition, their residual ash is much smaller than hardwood pellets. The amount of harmful emissions is minimized when fir or pine is used to produce pellets.

From the administrative point of view the Alfa Wood Nevrokopi is located in the Municipality of Kato Nevrokopi, which forms part of the Regional Unit of Drama in the northwestern part of the country. The Regional Unit of Drama belongs to the Region of Eastern Macedonia and Thrace. It borders Bulgaria to the north, the Regional Unit of Kavala to the south, the Regional Unit of Rhodope to the east and the Regional Unit of Serres to the west.

The surface area of the territory is 3466km^2, with its majority dominated by big mountains massifs (about 70%). The southern part of the Regional Unit of Drama is shaped by big contiguous plains extending over 431km^2. The Regional Unit of Drama consists of five municipalities, Prosotsani, Doxato, Paranesti, Drama (which is where the capital of the Unit by the same name of the municipality is located), and Kato Nevrokopi. The population of the Regional Unit of Drama is 98287 people according to the 2011 national census.

The land uses of the Regional Unit of Drama are agriculture and forestry covering 74% of its territory. The forests of Drama area are composed by several deciduous and coniferous species, in pure and mixed forms, being of great attraction to a wood treatment company, such as ALFA WOOD, which uses as main raw materials coniferous wood products. The forests of Drama area are managed by the National Forest Service mainly for wood production, based on selective loggings in order to protect the forest soil properties. The productive forests of Drama occupy approximately 173303 ha or about 49.97% of the total area.

The agricultural land in Drama regional Unit is approximately 67,557 ha. The main agricultural crops include cereals, cotton, tomatoes, tobacco, vineyards, fruits and vegetables. The agricultural sector provides significant revenue to the region, contributing about 0.5% to the national GDP and about 1.5% to the total country’s agricultural production.

The forestry sector as a primary sector of production is also significant in the Regional Unit of Drama. Despite the fact that the forest area of Drama represents only 2.6% of the country’s total forest area, it contributes approximately 11% to the total produced wood at national level. According to the Forest Service of Drama the total woody volume of the 173,303 ha Drama forest land is estimated to 16,061,470m^3.

A great economic asset with high economic potential also in the Regional Unit of Drama is the marble exploitation, which is carried out through the extended quarries’ network of the area. About 80% of the total marble exports at national level are originated from the 80 active quarries of the Regional Unit of Drama, which comprise about 40% of the country’s active quarries.

The secondary sector of the area's economy includes mainly industries of small-medium size and fewer big ones established in the area during the past few years, in the fields of marble processing, metal and wood processing, as well as food and beverage production.

The tertiary sector of the area's economy includes mainly businesses operating in the fields of transportation, storage, communication, social activities, wholesale and retail trade, catering services and financial services. Tourism is not well developed in the area although the alternative tourism potential has been well recognized by all the concerned stakeholders of the area.

Potential of wood waste supply for pellet production in Greece with reference to Alfawood Group company

Mentors:

International Hellenic University:

Vassiliki KAZANA,

Dimitrios RAPTIS,

Antonios PAPADOPOULOS

ALFAWOOD GROUP

Dimitrios LAZOS

Students:

International Hellenic University:

Athanasios FALLIAS

afall@outlook.com.gr

Nina GAVRIILIDOU

gabriilidoun@gmail.com

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Executive Summary

The Alfawood Group Company according to its working plan uses significant amounts of woody residuals or low quality wood as primary raw material for pellet and briquette production, through a complex process of high precision equipment. The most preferred by the Company wood types are of coniferous origin (softwood), because they provide significant advantages as compared to those of hardwood origin in the production processing stage. A significant source of raw material in demand by the Company could be sought directly in the forests, where dead woody residuals of different dimensions remain on the forest floor following the typical wood logging processes. However, in the frame of the current silvicultural practice in Greece, the logging residues are intently left to undergo a decomposition phase in order to maintain soil fertility and to reduce nutrient loss from the forest ecosystem.

A resent research on the soil effects of the exploitation of logging residues for energy purposes in fir (*Abies borisii regis*) and beech (*Fagus sylvatica*) dominated forest ecosystems, confirmed that the extraction of relatively thick woody branches (>2 cm) results in minimum nutrient loss and they can be used as raw material for energy demands. This suggestion could possibly lead to notably changes in logging residuals extraction, since it can cover a significant portion of wood demands for heating or other potential energy uses in a frame of an emerging energy crisis. However, the accurate estimation of the available woody biomass that can be extracted from forests in the form of logging residuals remains under question, since it is difficult to quantify the specific natural source in terms of dry weight. In addition, the estimation of the wood availability for extraction is a critical issue for companies of wood exploitation for energy purposes, such as the Alfawood Company.

The basic aim of the current study is to quantify the total amounts composed by logging residuals of relatively large dimensions (>2 cm), that can be extracted without compromising any potentiality of soil degradation or nutrient loss from the forest ecosystem. The quantification approach is based on a combination of biomass modelling and field measurements, properly mounted on a GIS (Geographical Information System) basis. The Alfawood Company location in Northern Greece was selected as the central point for the applied scenario of biomass extraction and economic profitability analysis was performed.

1. Project Overview

1.1 Introduction

The Alfawood Group Company according to its working plan uses significant amounts of woody residuals or low quality wood as primary raw material for pellet and briquette production, through a complex process of high precision equipment. The most preferred by the Company wood types are of coniferous origin (softwood), because they provide significant advantages as compared to those of hardwood origin in the production processing stage. Therefore, a significant source of the raw material needed by the

Company is sought directly in the forests, where dead woody residuals of different dimensions remain on the forest floor following the typical wood logging processes. However, in the frame of the current silvicultural practice in Greece, the logging residues are intently left on the forest floor allowing no market supply possibilities to companies such Alfa Wood, thus depriving a typical renewable natural resource of the rural areas, that is the woody biomass logging residuals to be valorized in the context of circular economy and contribute to rural sustainable development.

Following thorough discussions with Forest District Officials as well as representatives of Forest Cooperatives, who are the main stakeholders involved in this process of woody biomass logging residues valorization, several reasons appear to account for this problem. The first main reason is of biological nature and it concerns the lack of accurate estimations of the woody biomass logging residue quantities that could be safely become available to potential consumers, that wish to use it as raw material such as, for example, Alfa Wood. Also, tools in the form of reliable models, which could provide forecasts for future availability of this type of woody biomass are also lacking. The second reason accrues from the forest policy management sustained yield restrictions, which urge forest managers to intently leave the logging residues on the forest floor to undergo a decomposition phase in order to maintain soil fertility and to reduce nutrient loss from the forest ecosystem, despite they can hardly justify that all the logging residue quantities should remain in the forests. The third important reason concerns the attitude of forest cooperative contractors, who are not willing to extract and sell the wood waste, because they believe that this process is not profitable enough.

This problem has generated many difficulties to Alfa Wood Company and other companies operating in the same production sector as regards the company’s need to safeguard procurement of the required raw material quantities at a reasonable cost. The situation is becoming even harder with the current energy crisis and the increase of transportation cost, since the company is forced to long distance travelling up to 500 km away from its premises in the order to purchase the required quantities of woody biomass for its production.

This problem has stimulated our efforts through the current project to investigate whether availability of wood logging residues would be possible and profitable in sufficient proximity from the company’s premises at Kato Nevrokopi- Drama, taking into consideration the forest management sustained yield restrictions in order to promote the valorization of a renewable type of natural resource, namely the wood logging waste in the frame of circular economy.

1.2 State –of- the- art

1.2.1 Historical framework of the context

Forests have the capacity to provide a large amount of litter, branches, foliage, etc. Furthermore, it is typical through the forest management practice, such as harvesting, logging or resin harvesting to generate a natural floor of residual products, which enrich the soil with nutrients and create a layer of subsoil. In the frame of Circular Economy these leftover wood products can be utilized, although such valorization does not at this stage applies to any Greek forest. This is also a typical situation in many other European forests, mainly because of barriers due to forest management sustainability or other forest policy restrictions. However, in the frame of Circular Economy, public discussion has already begun with regard to the need of valorization of natural resource wastes, such as the wood logging residues (Camia 2021).

Recent research has shown that small branches with diameter less than 2 cm and foliage and needles provide the soil with more nitrogen than twigs with over 2 cm diameter, which provide limited nutrients. Therefore, theoretically, residual wood with over than 2 cm diameters could be removed, as this does not contribute a large amount of nutrients to soil enrichment. In any case, to avoid sustained yield violation, Filippou et al. 2019 stated that all the residual biomass, small twigs, needles, foliage and branches with less than 2 cm, should remain in the forest and they should be utilized for ecological purposes.

Although several researchers argue that biomass removal can affect the nutrient balance, recent studies have shown that this effect varies according to the forest species, the rotation period applied in forest management, the site quality, and the amount of biomass, as well as the overall forest ecosystem management. These studies have been conducted in forest ecosystems managed under short rotation periods, intensive silviculture and clear-cutting harvesting methods. Furthermore, studies were carried out on the effects of whole-tree harvesting on soil productivity (Raison et.al. 2002, Jensen et. al 2008). Bouriaud et.al. (2013) published an extensive literature review on this topic emphasizing that, there is a need for further research to develop and establish specific guidelines for the harvesting and removal of logging residues to ensure sustainable forest production. Such studies are yet scarce worldwide and are almost completely lacking in Greece. Nowadays, the need for further research on the specific issues related to the biomass residual value and exploitation in relation to sustainability and under the lenses of circular economy still remains.

Removal of the natural floor that remains in the forest should also be regulated legally because the retention of biomass in forest ecosystems also entails risks, the biggest of which is fire ignition. This danger is also intensified by the fact that rural and mountain areas have been depopulated due to urbanization and migration that started a few decades ago, thus allowing biomass accumulation to continuously increase on the forest floor. The removal of biomass therefore would be beneficial in terms of reducing wildfires.

From the economic point of view another problem of importance exists, which is particularly related to the cost of biomass removal (Baker et. al. 2018). It has been assessed in economic terms that for pellet production to be profitable, the raw material should be available at low procurement costs. However, due to the claimed high logging residue costs, forest cooperatives are not willing to harvest the residual biomass. It has to be noted at this point that forest exploitation according to the Greek Forest Law and the Law 4423/2016 about forest cooperatives (Government Gazette 182/A/27-9-2016) is commissioned to the forest cooperatives on terms of agreements between the Forest

Authorities, who have the legal responsibility to supervise the whole harvesting process according to the approved forest management plans. The common practice to date is that forest cooperatives do not enter into agreements with the Forest Authorities to harvest and collect the logging residues due to claimed low profitability. However, no reliable economic studies exist on this issue too. Moreover, in Greece the use of specific equipment, such as the special crushers that are being used in some European countries (Camia et al. 2021) for harvesting logging residues and transporting these directly at the forest road wood collection sites has not been tested, neither studied yet. The latter should certainly take into account the possibilities this equipment to be used in the Greek forests, where the land relief and inclination may pose several difficulties for efficient use.

In any case it appears that supplies of raw materials such as those used by Alfa Wood Company for the production of pellets, briquettes and bioenergy, that is the wood biomass logging residues can become available through development of a market for this renewable type of natural resource in rural areas with the lenses of circular economy. It is also important to note that the valorization of this natural resource does not appear to reduce or eliminate forest management sustainability.

1.2.2 Existing solutions

In almost all the productive forests in Greece, the biomass waste and particularly the wood logging residues, which are required as raw material for the production of pellets, briquettes and bioenergy, that is the products produced by the Alfa Wood Group Company are currently out of market with limited procurement possibilities. In other words, there is availability of raw material a short distance from the company's premises and its valorization is prohibited. This results in long-distance search for the company reaching up to 500 km away from its premises to purchase the required biomass for its production process. This inevitably increases highly the raw material procurement cost for the company with negative effects on the final selling price of its products and therefore to the competitiveness status of the company and its production process.

Pellet production is not usually made from good quality and therefore, other sources of raw material that could be used are the residues of wood panel plants, recycled wood products, such as wooden constructions, frames, residues of agricultural products and the production of energy crops, for example rape, cane, etc. However, Alfa Wood can use at this stage such types of raw materials because of restrictions imposed on the quality of its products due to the quality product specification standards that the company has adopted.

Other solutions Alfa Wood set into consideration involved imports of raw materials from Bulgaria that is in proximity with the company's premises at Kato Nevrokopi-Drama and Ukraine. The Ukraine market however collapsed due to the Russian-Ukraine war, while certain regulations posed several barriers to raw material procurement possibilities from Bulgaria too.

Procurement of wood biomass residues therefore needs to be secured from the internal market facing all the existing barriers as these have been described in the previous section. Lifting of the main barrier, that is the raw material availability through changes in logging residues extraction can be pursed based on the recent study by Filippou et. al. 2019 on soil effects of the logging residues exploitation for energy purposes in fir (Abies borisii regis) and beech (Fagus sylvatica) dominated forest ecosystems. The study confirmed that the extraction of relatively thick woody branches (>2 cm) results in minimum nutrient loss and therefore this renewable natural resource can be used as raw material for energy demands without jeopardizing forest management sustainability constraints. However, this solution still requires the accurate estimation of the available woody biomass that can be extracted from forests in the form of logging residuals, because it is difficult to quantify the specific natural source in terms of dry weight. In addition, this solution requires a profitability analysis of the wood logging residuals extraction cost, in order to be possible to enter into the forest exploitation agreements between the Forest Authorities and the Forest Cooperatives.

1.3 Description of the chosen solution

1.3.1 SWOT Analysis

In order to facilitate the Alfa Wood Group Company solve the problem of securing its wood biomass raw material demands for its production process this project attempts to estimate through biomass modeling the available woody biomass that can be extracted from forests in the form of logging residuals in terms of dry weight within a distance of 300 km away from the company's premises at Kato Nevrokopi- Drama. This project focuses on the quantification of the total amounts of logging residuals with relatively large diameters (>2 cm), that can be extracted without compromising any potential soil degradation or nutrient loss from the forest ecosystem. The quantification approach is based on a combination of biomass modeling and field measurements, properly mounted on a GIS (Geographical Information System) base. In addition, profitability analysis is conducted based on the total estimated available wood biomass. The results of this project can be used to promote valorization of wood biomass waste, that is, an abundant natural resource in rural areas, such as the logging residuals, which is highly compatible with promotion of circular economy, while at the same time safeguarding forest management sustainability. The resulting information can be communicated to the basic stakeholders for forest exploitation, that is the Forest Authorities and the Forest Cooperatives towards building agreements that include the valorization of this type of renewable natural resource.

The strengths, weaknesses, opportunities and threats of valorizing the wood logging residues of the Greek forests with reference to the raw material procurement needs of the Alfa Wood Company are presented in the following SWOT Analysis table.

SWOT Analysis for valorization of forest wood logging residues of the Greek forests for the ALFA WOOD Company

INTERNAL ENVIRONMENT

Strengths

Weaknesses

1. Forest policy restrictions
2. Loss of valuable raw material to businesses due to non-valorization of logging residues
3. Lack of accurate quantification of logging residues
4. Lack of accurate economic profitability studies for valorization of logging residues
5. Lack of coordination and communication between interested stakeholders

1.4 Conclusions

The Alfa Wood Group Company is facing a serious problem securing its procurement needs of wood biomass raw material. The main barriers of this problem involve the non-valorization of an abundant renewable natural resource of rural areas, the wood logging residues. These barriers are mainly due to lack of reliable information on the available quantities of wood biomass waste that can be extracted from the forests within the forest management sustainability restrictions and the economic aspects of the extraction costs of this natural resource. This information is necessary for Forest Authorities and Forest Cooperatives, who are the main stakeholders involved in the process of forest exploitation. Valorization of the wood logging waste can fully promote circular economy in rural areas.

In this context, the current project focuses on two issues: i) the quantification of the total amounts of logging residuals with relatively large diameters (>2 cm), that can be extracted without compromising any potential soil degradation or nutrient loss from the forest ecosystem, by using biomass modeling, field measurements and Geographical Information Systems (GIS) technology and ii) profitability analysis based on the total estimated available wood biomass.

The project results are useful for the Forest Authorities and the Forest Cooperatives towards building agreements that include the valorization of this type of renewable natural resource and promote circular economy.

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2. Biomass modeling of wood logging residues from the Greek forests for use as raw materials for the Alfa Wood industry

2.1 Input data of the project

The methodology to obtain the input data for the available forest biomass quantification is presented in the following figure (5).

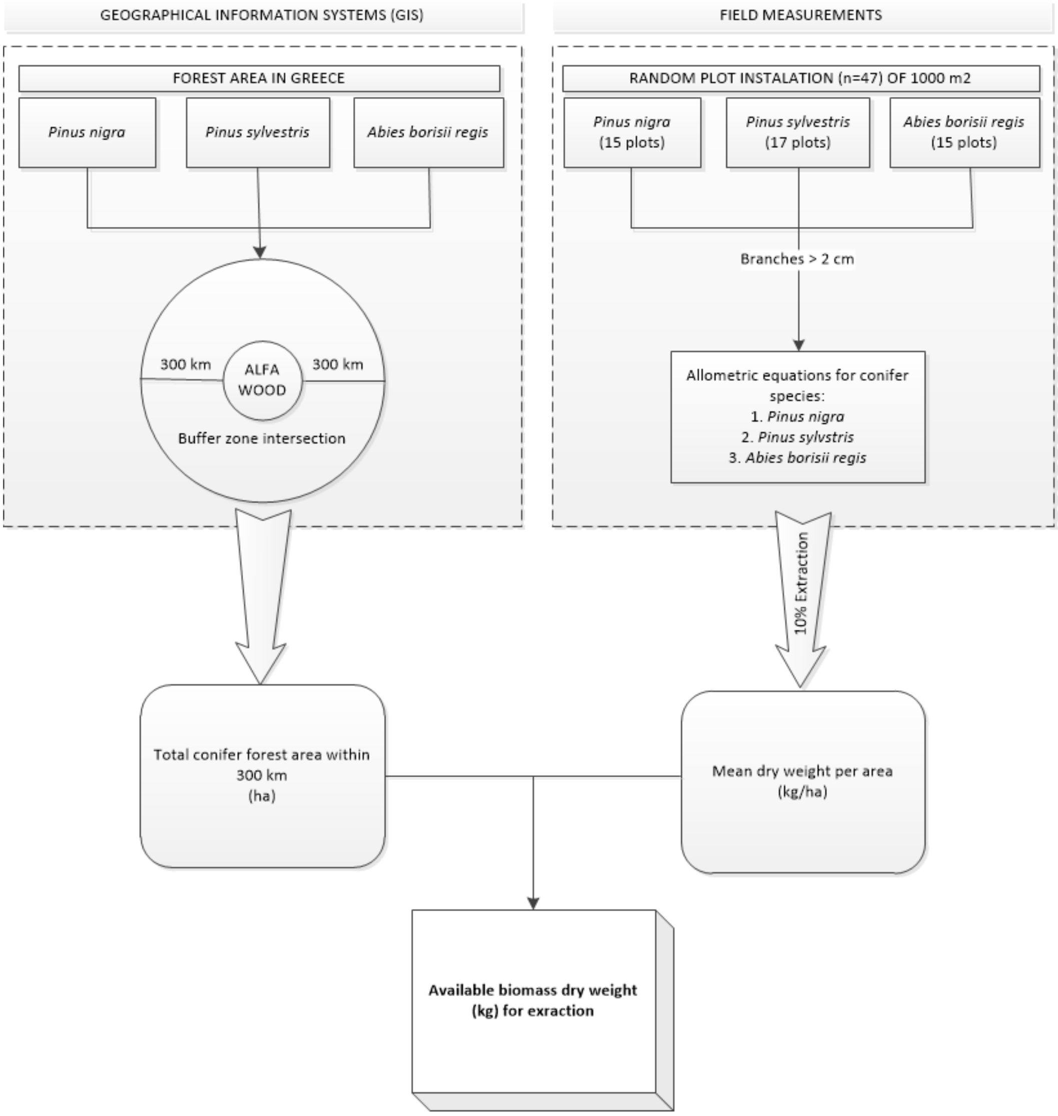

Figure 5 The flowchart of the followed methodology

2.1.1 Spatial analysis - Location

For the needs of the current report, a detailed geo-database of the forests distribution in Greece was used as the primary information for the total biomass estimation (Kazana et al. 2020). The vector-file format was georeferenced in Greek Grid (EGSA 87), and the pine along with fir - dominated forests were spatially selected and extracted (figure 6). The pine forests in the lower zone (Pinus halepensis and Pinus brutia) were excluded from the analysis because they are currently managed for wildfire protection, presenting low commercial value. Hence, three main species of high quality wood production were selected the King Boris Fir (Abies borisii regis), the Black Pine (Pinus nigra) and the Scots Pine (Pinus sylvestris).

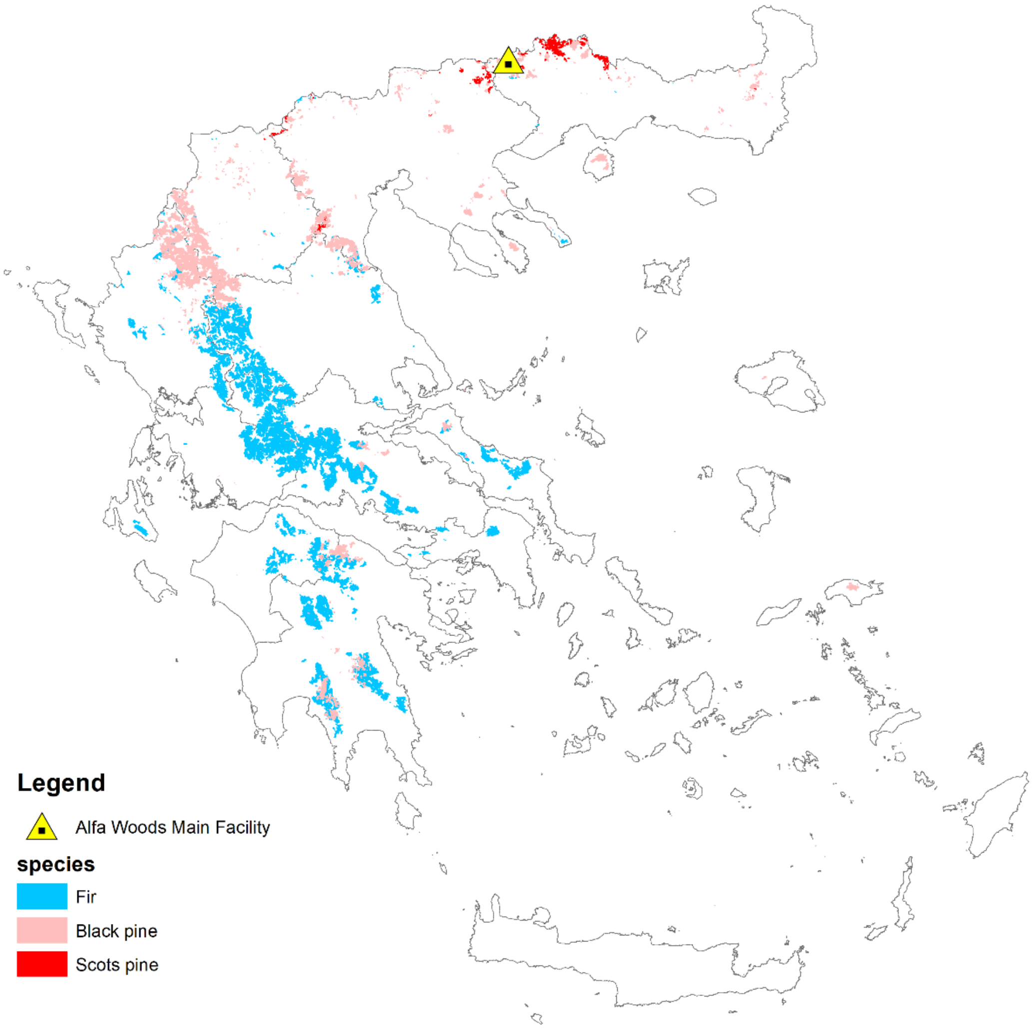

Figure 6 The selected species distribution in Greece

According to the Alfawood Company policy, the wood delivery could exceed the 250 km at horizontal distance from the Northern facility (figure 2), reaching the 300 km in many cases. Following this simple spatial rule, a buffer zone of 300 km around the main facility was created and the intersected forest area was selected as a primary source of raw woody material. It should be noted that mixed forests composed by both coniferous (evergreen) and deciduous tree species were also excluded from the analysis.

2.1.2 Field measurements – Numerical data

One of the most significant steps for the total biomass availability estimation is to quantify the dry biomass of certain dimensions per hectare for each of the three conifer species, in the frame of the current management framework. For this to happen, a representative area composed by the specific species in pure form was selected and a plot network was installed for sampling purposes. The total sample included 47 circular non-permanent sample plots in total. Each sample plot covered a total area of about 1000 m^2 (0.1 ha) at horizontal projection. For the plot installation the "*create random points*" module of the ArcGis 10.2.2 software was used in order to ensure randomness at spatial basis. Within each plot, the diameter at breast height of all standing trees (in cm) was measured using a digital caliper. In addition, the forest species were recorded and several attributes were estimated at plot level (stem density, basal area).

2.1.3 Biomass modeling

Biomass equations (models) are available in the world literature for different species and regions. This kind of equations are mainly used for the estimation of the total carbon stock at tree level or for the calculation of the available fuel load during wildfire ignition and spread. In the current case, models for the estimation of the total dry weight of tree branches with diameter larger than 2 cm are needed, separately for the Black pine, the Scots pine and the King Boris Fir. The latest is a taxon endemic to the southern Balkan Peninsula, described as a hybrid between the Silver fir (*Abies alba*) and the Greek fir (*Abies cephalonica*) according to Bella et al. (2014). Since no available models can be found in the world literature, it was decided to apply biomass equations for the widespread Silver fir. Hence, the following allometric relationships were selected for the estimation of the medium and the thick branches at tree level as they have been proposed by Ruiz-Peinado et al (2011):

For the King Boris fir:

$$\boldsymbol{W_b = W_{mb} + W_{tb} = 0.0584dbh^2} \quad \textbf{(1)}$$

For the Black pine:

$$\boldsymbol{W_{mb} = 0.0521dbh^2} \quad \textbf{(2)}$$

and

$$\boldsymbol{W_{tb} = 0.028(dbh - 32.5)^2, when\ dbh \geq 32.5\ cm} \quad \textbf{(3)}$$

For the Scots pine:

$$\boldsymbol{W_{mb} = 0.0295dbh^{2.742}h^{-0.899}} \quad \textbf{(4)}$$

and

$$\boldsymbol{W_{tb} = [0.540(dbh - 37.5)^2 - 0.0119(dbh - 37.5)^2], when\ dbh \geq 32.5\ cm} \quad \textbf{(5)}$$

where *dbh* is the diameter at breast height (cm), W_{md} is the dry weight of medium branch (diameter between 2 and 7 cm) fraction in kg, W_{tb} is the dry weight of the thick branch (diameter larger than 7 cm) fraction in kg, and *h* is the total height of the tree in m.

As it can be seen from the equation (4), the total height (*h*) is a basic regressor for the estimation of the medium branch dry weight. However, the total height is particularly difficult to be measured in field conditions and it was missing from the obtained field data. In order to overcome this shortage, a separate sample of 100 random Scots pine trees were measured within the area and a 2-parameter nonlinear function was fitted for height prediction. The mathematical form of the model is explained below (Meyer 1940, Raptis et al. 2021):

$$\boldsymbol{h = 1.3 + \beta_0(1 - exp(-\beta_1 dbh))}+\varepsilon \qquad \textbf{(6)}$$

Where β_0, β_1 are the parameters that need to be estimated and ε is the error term, normally and randomly distributed across the fitted values.

According to the current management practice in Greece, the amount of the extracted wood in conifer forests corresponds to about 10% of the total standing volume, or to approximately 30% of the volume increment within a period of 10 year rotation cutting. Assuming that the mentioned percentage is similar to all forests in Northern Greece, and the percentage is approximately similar in weight terms, the estimated dry weight per hectare was converted for all forest area per species as it was calculated during the spatial analysis. Since the proposed methodology is based on field measurements, accurate biomass models and a detailed spatial geodatabase, the results are expected to provide critical information about the current status of the Greek forests potentialities.

2.2Results

2.2.1 Forest area available for exploitation

In figure 7 the total forest area covered by conifer species within the proximity of the Alfawood Company is presented, on a spatial basis.

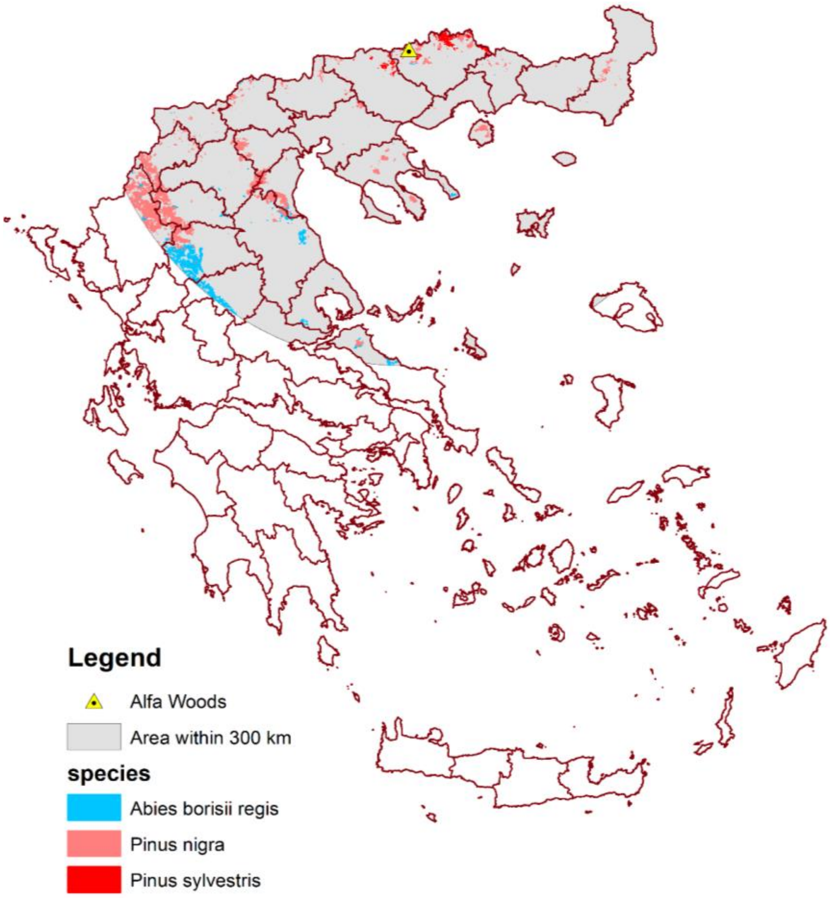

Figure 7 Forest area within 300 km from the Alfa Woods North facility

The estimated forest area per species is described in the following table (1).

Table 1 Total area of conifer species within 300 km from the Alfa Wood Company

Species	Total area within 300 km (ha)
King Boris (*Abies borisii regis*)	66773
Black pine (*Pinus nigra*)	176849
Scots pine (*Pinus sylvestris*)	19132.2

2.2.2 Field data

In figure 8, the installed sample plot network is presented. The total sample size included 15 plots within fir ecosystems, 15 in Black pine forests and 17 in Scots pine.

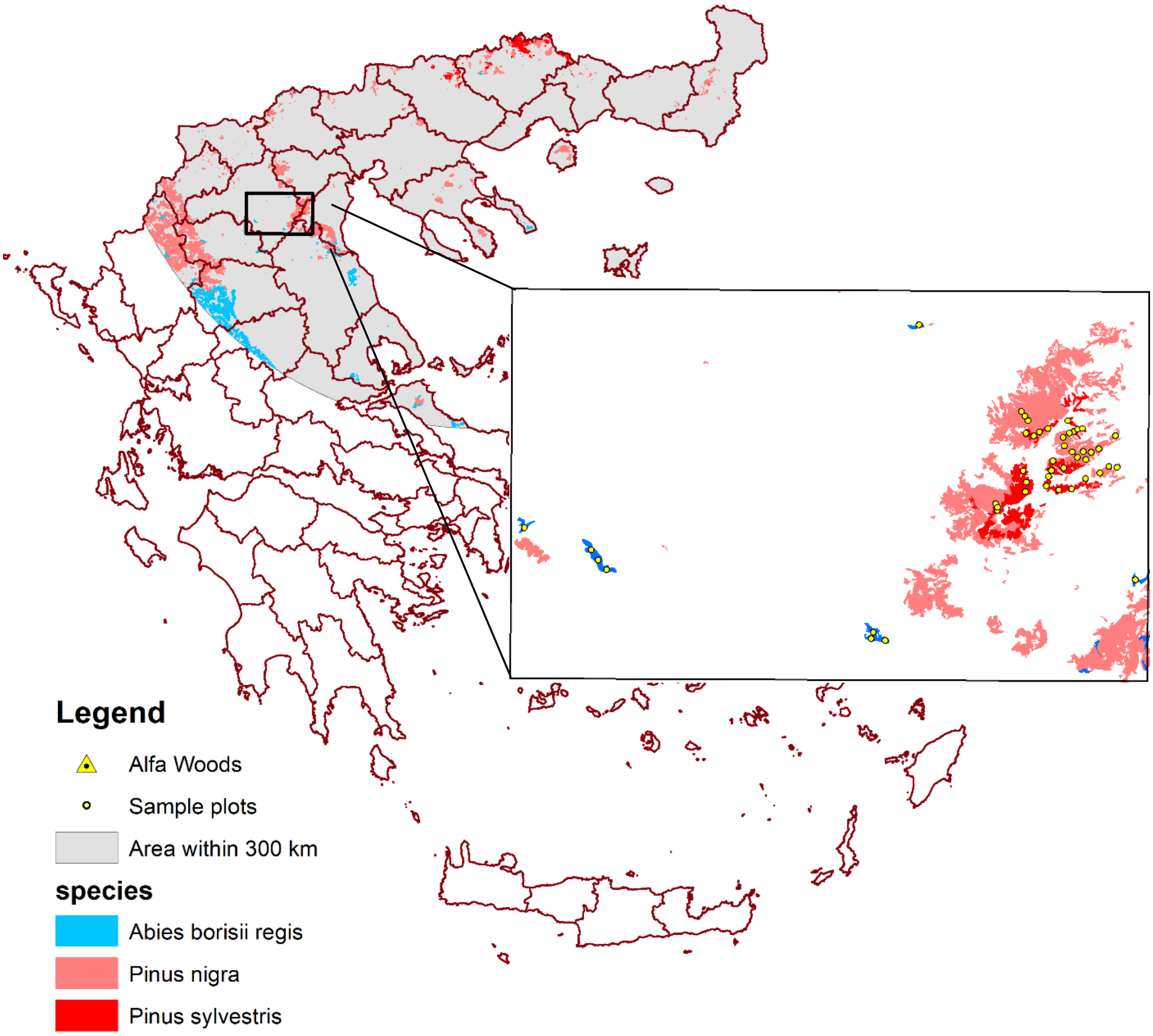

Figure 8 Distribution of the sample plots

For the needs of the current project a total sample of N=2393 trees was measured in field conditions. The descriptive statistics of the field measurements are presented in the following table (2).

Table 2 Descriptive statistics of the total sample (N=2393) at tree level

Species	Diameter breast height (*dbh*) in cm			
	Min	Max	Mean	St. Dev.
King Boris (*Abies borisii regis*) n=651	10	72	24.36	13.45
Black pine (*Pinus nigra*) n=1038	10	72	30.86	17.04
Scots pine (*Pinus sylvestris*) n=704	10	90	34.37	17.34

The diameter distribution of the total sample is presented in the following histogram (figure 9).

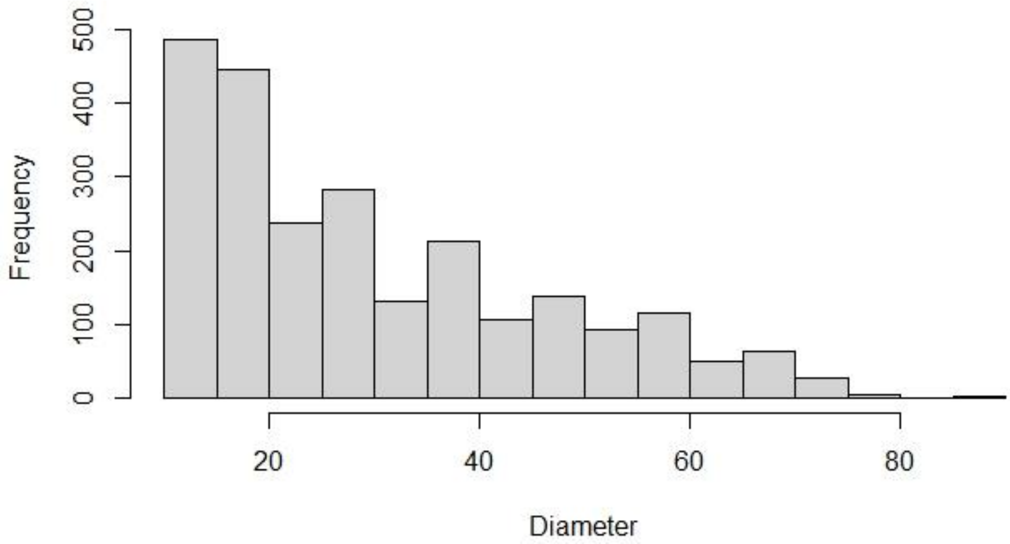

Figure 9 Diameter distribution of the total sample

As it can be concluded from figure 5, the forest structure in the research area can be characterized as uneven-aged, with 3 well distinguished age groups (three-aged). Hence, the applied silvicultural treatments are assumed to be similar in most of the cases, leading to a consistent extraction rate within the total area.

The descriptive statistics of the separate sample that was used for the height (h) modeling of Scots pine trees is presented in the table (3).

Table 3 Descriptive statistics of the Scots pine trees for height modelling

Species	dbh (cm)		h (m)	
	Mean	St. Dev.	Mean	St. Dev.
Scots pine (*Pinus sylvestris*) n=100	32.95	15.97	21.10	6.18

The fitting statistics of the nonlinear function using Ordinary Least Squares (OLS) modeling procedure are presented in the following table (4).

Table 4 Fitting statistics of the height-diameter model for the Scots pine trees

Model	**β_1 (s.e.)**	**β_2 (s.e.)**	**R^2**	**RMSE**	**Bias**
Meyer 1940	30.1168 (1.4205)	0.0372 (0.0037)	0.763	2.997	0.069

Hence, the final model for the height prediction of Scots pine trees was:

$$\boldsymbol{h = 1.3 + 30.1168(1 - exp(-0.0372dbh))} \quad \textbf{(7)}$$

The graphical representation of the model is presented in the figure (10):

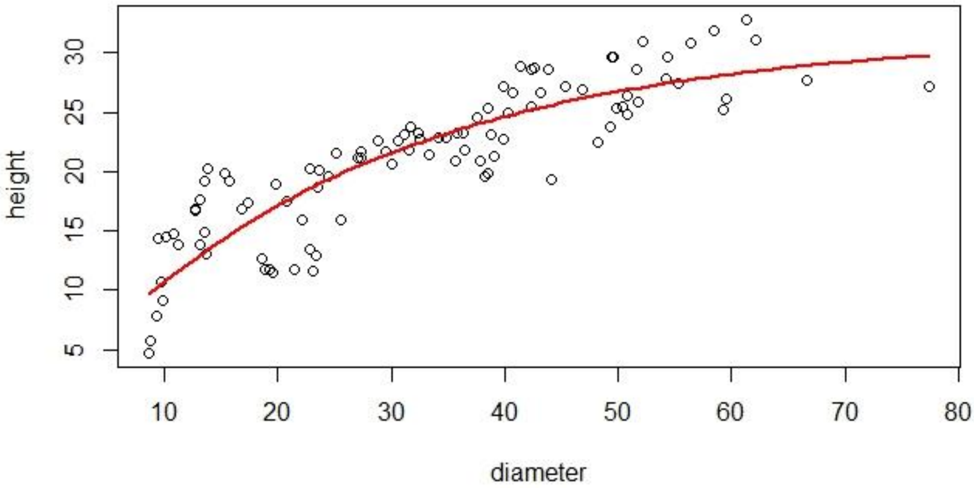

Figure 10 Graphical representation of the Scots pine height model

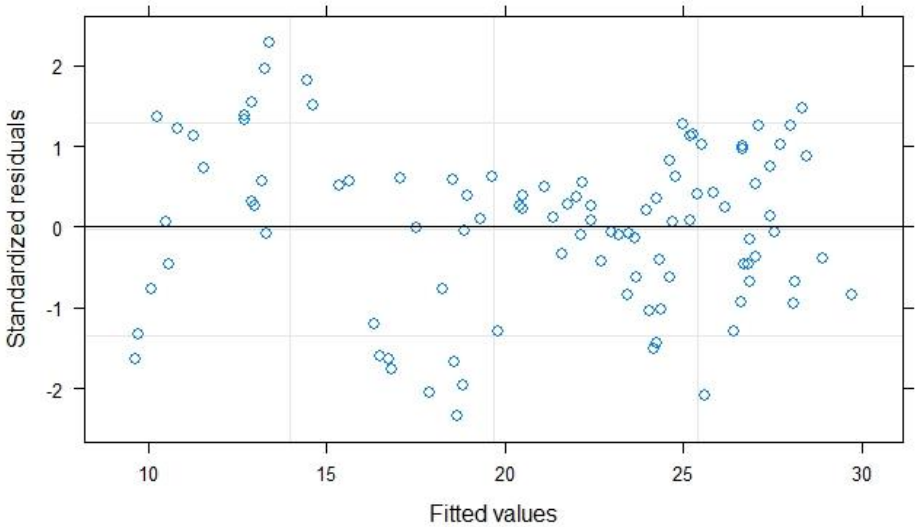

Figure 11 Residual distribution of the Meyer's model

According to table 4 and figure 11, all the parameter estimates were significantly different than zero, and the residuals presented no evidences of heteroscedasticity. Hence, the model can be used for the estimation of the available biomass for the Scots pine tree species.

The combination of the equations (**1**), (**2**), (**3**), (**4**), (**5**) and (**7**) leaded to the estimation of the total branch biomass quantity per sample plot and dominant tree species (table 5).

Table 5 Descriptive statistics of the results for the total sample at plot level

Plot	Dominant Tree Species	N /ha	Basal area (m^2/ha)	Total dry weight (kg/ha)
1	*Pinus sylvestris*	350	64.3	75380
2	*Pinus sylvestris*	1380	67.0	47560
3	*Pinus sylvestris*	260	81.4	137270
4	*Pinus sylvestris*	270	79.8	118750
5	*Pinus sylvestris*	270	94.4	164980
6	*Pinus nigra*	660	96.7	99590
7	*Pinus nigra*	910	147.7	165430
8	*Pinus sylvestris*	310	32.8	14230
9	*Pinus nigra*	720	65.0	71170
10	*Pinus nigra*	310	33.2	30860
11	*Pinus nigra*	290	42.0	40630
12	*Abies borisii regis*	340	31.7	24300
13	*Pinus sylvestris*	100	12.8	12370
14	*Pinus sylvestris*	330	19.5	9280
15	*Pinus sylvestris*	420	33.1	34840
16	*Abies borisii regis*	640	57.8	43010
17	*Abies borisii regis*	100	14.2	10590
18	*Pinus sylvestris*	620	46.6	19580
19	*Abies borisii regis*	100	7.9	5840
20	*Abies borisii regis*	760	24.5	18240
21	*Pinus sylvestris*	651	50.7	49400
22	*Abies borisii regis*	340	32.7	28600
23	*Abies borisii regis*	260	29.6	22000
24	*Pinus nigra*	600	22.9	17010
25	*Pinus nigra*	1130	182.1	202860
26	*Pinus nigra*	910	130.7	139730
27	*Pinus nigra*	380	65.8	75620
28	*Pinus nigra*	740	104.2	118900
29	*Pinus sylvestris*	480	28.2	10080
30	*Pinus sylvestris*	520	33.0	12630
31	*Pinus sylvestris*	440	46.2	21140
32	*Abies borisii regis*	630	24.4	18150
33	*Abies borisii regis*	220	19.0	14140
34	*Pinus nigra*	2000	86.8	64540
35	*Pinus sylvestris*	800	32.3	16860
36	*Pinus nigra*	1430	43.5	31720
37	*Abies borisii regis*	400	34.5	29350
38	*Pinus nigra*	230	18.1	14900
39	*Pinus nigra*	1850	67.1	44520
40	*Pinus sylvestris*	770	66.9	40090
41	*Abies borisii regis*	140	4.0	3000
42	*Abies borisii regis*	80	14.3	10640
43	*Abies borisii regis*	80	2.0	1520
44	*Pinus sylvestris*	100	4.9	2380
45	*Pinus nigra*	820	16.2	10750
46	*Abies borisii regis*	140	10.5	7780
47	*Abies borisii regis*	200	4.5	3370

Assuming that about 10% of the standing volume is extracted through selective harvesting, the mean available biomass per species composed by tree branches is presented in table 6:

Table 6 Mean available biomass rate per species

Species	Available dry branch biomass (kg/ha)
King Boris (*Abies borisii regis*)	1603.6
Black pine (*Pinus nigra*)	7521.5
Scots pine (*Pinus sylvestris*)	4628.3

By combining table 1 and table 6, the total available dry branch biomass for exploitation are presented in table 7.

Table 7 Mean available biomass rate per species

Species	Total available dry branch biomass (kg)
King Boris (*Abies borisii regis*)	107077
Black pine (*Pinus nigra*)	1330170
Scots pine (*Pinus sylvestris*)	88550
Total dry biomass	1525797

Hence, the total available dry biomass in the form of woody residuals is estimated to about 1525797 kg or 1526 metric tons.

2.3 Benefits of the solution from point of view of Circular Economy

2.3.1 Outcomes overview

The main outcomes of the wood biomass modeling process can be summarized as follows:

1. A georeferenced map of three selected species, King Boris fir, Black pine and Scots pine distribution in Greece in GIS vector-file format
2. A georeferenced map of the forest area within 300 km from the Alfa Wood Group Company facilities at Kato Nevrokopi- Drama
3. Field data of Scots Pine tree breast-height diameters and heights from 8 sample plots
4. Allometric biomass models for the estimation of the medium and the thick branches at tree level for King Boris fir species
5. Allometric biomass models for the estimation of the medium and the thick branches at tree level for Black pine species
6. Allometric biomass models for the estimation of the medium and the thick branches at tree level for Scots pine species

7. Estimation of the total available dry branch biomass for extraction
8. Estimation of the total woody residuals dry biomass

2.3.2 Impact on the environment

The current project contributes to the valorization of a renewable natural resource, the wood logging residues, which although abundant in rural areas, remains completely unused, as it is intentionally left in the forests, thus creating problems to the coverage of the raw material procurement needs of companies, such as Alfa Wood. Through the current project it is shown that the company's needs can be covered fully within a distance of 300 km of its premises at Kato Nevrokopi – Drama by fully taken into consideration the forest management sustainability constraints. In this context the proposed solution does have a positive impact on the environmental footprint.

In addition, the project was based on the recent study by Filippou et. al. 2019 on soil effects of the logging residues exploitation for energy purposes in fir (*Abies borisii regis*) and beech (*Fagus sylvatica*) dominated forest ecosystems. The study confirmed that the extraction of relatively thick woody branches (>2 cm) results in minimum nutrient loss and therefore this resource can be used as raw material for energy demands without jeopardizing forest management sustainability constraints. Finally, but equally important the proposed solution for valorization of wood wastes will reduce the wildfire danger, which is very high in most of the Greek forests.

2.3 References

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3 PROFITABILITY ANALYSIS

The required quantity of conifer raw material for the ALFAWOOD company can be derived from forests within 300km from the company facilities at Kato Nevrokopi Dramas, where according to our estimation based on the analysis of section 2 of the current report the available quantity amounts approximately to 200000 tons per year Indeed the company's annual procurement need is about 120000 tons corresponding to its 60000 tons of final annual production or in other words to about 62% of the total available quantity within this area.

3.1 Costs and Benefits

The more detailed profitability analysis is as follows:

COSTS AND BENEFITS				
COSTS				
TYPE OF COST	**Unit**	**Unit Value (€)**	**Available quantity**	**Value**
Harvesting (dbh> 7cm)	m^3	6,31	48000	302880
Harvesting (dbh<7cm)	χκμ	5,77	112500	649125
Hauling and transport to roadside (dbh>7cm)	m^3	7,86	48000	377280
Hauling and transport to roadside (dbh<7cm)	m^3	5,61	144000	807840
Unloading, Grading and Stacking	χκμ	1,44	112500	162000
Loading at road side (dbh>7cm)	m^3	2,49	48000	119520
Loading at road side (dbh<7cm)	χκμ	1,43	112500	160875
Transportation (straight line 300 km from facility)	tn	30	120000	3600000
TOTAL DIRECT COST				6179520
TOTAL INDIRECT COST				2471808
TOTAL COST				**8651328**
BENEFITS				
TYPE OF BENEFIT				
Products	kg	0,4	60000000	24000000
TOTAL BENEFITS				**24000000**

3.2 Profitability indicators- Net Present Value, Internal Rate of Return, Payback Period

In order to calculate the profitability indicators we assumed 2 different scenarios, one with discount rate 4% and another one with 10%. For each scenario sensitivity analysis was performed by increasing the cost 2%, 10% and 15% and by decreasing benefits 2%, 10% and 15%. The detailed calculations are presented in the following tables.

Scenario 1 (Discount rate 4%)

Cash flow of the proposed solution			
Year	**Benefits (B)**	**Costs (C)**	**Net cash flow (B-C)**
0	0	**8651328**	-8651328
1	24000000	**8651328**	15348672
2	24000000	**8651328**	15348672
3	24000000	**8651328**	15348672
4	24000000	**8651328**	15348672
5	24000000	**8651328**	15348672
Total	**120000000**	**51907968**	**68092032**

Discounted cash flow (r=4%)			
Year	**Benefits (B)**	**Costs (C)**	**Net cash flow (B-C)**
0	0	8651328	-8651328
1	23076923	8318585	14758338
2	22189349	7998639	14190710
3	21335913	7690999	13644914
4	20515301	7395191	13120109
5	19726251	7110761	12615490
Total	**106843736**	**47165503**	**NPV= 59678233**

IRR	**166%**
B/C	**2,27**

Payback period

Year	**Cumulative Benefits (ΣB)**	**Cumulative Costs (ΣC)**	**Cumulative Net Cash Flow (Σ(B-C))**
0	0	8651328	-8651328

1	23076923	16969913	6107010
2	45266272	24968552	20297721
3	66602185	32659551	33942634
4	87117485	40054742	47062743
5	106843736	47165503	59678233

Sensitivity Analysis

Cost=+2%

Cash flow of the proposed solution (Increased Cost by 2%)			
Year	**Benefits (B)**	**Costs (C)**	**Net cash flow (B-C)**
0	0	8824354,56	-8824354,56
1	24000000	8824354,56	15175645,44
2	24000000	8824354,56	15175645,44
3	24000000	8824354,56	15175645,44
4	24000000	8824354,56	15175645,44
5	24000000	8824354,56	15175645,44
Total	**120000000,0**	**52946127,36**	**67053872,64**

Discounted cash flow (r=4%)			
Year	**Benefits (B)**	**Costs (C)**	**Net cash flow (B-C)**
0	0,0	8824354,6	-8824354,6
1	23076923,1	8484956,3	14591966,8
2	22189349,1	8158611,8	14030737,3
3	21335912,6	7844819,1	13491093,5
4	20515300,6	7543095,3	12972205,3
5	19726250,6	7252976,2	12473274,3
Total	**106843735,9**	**48108813,2**	**NPV= 67053872,6**

IRR	**171%**
B/C	**2,22**

Cost=+10%

Cash flow of the proposed solution (Increased Cost by 10%)			
Year	**Benefits (B)**	**Costs (C)**	**Net cash flow (B-C)**
0	0	9516460,8	-9516460,8
1	24000000	9516460,8	14483539,2
2	24000000	9516460,8	14483539,2
3	24000000	9516460,8	14483539,2

4	24000000	9516460,8	14483539,2
5	24000000	9516460,8	14483539,2
Total	**120000000,0**	**57098764,8**	**62901235,2**

Discounted cash flow (r=4%)			
Year	**Benefits (B)**	**Costs (C)**	**Net cash flow (B-C)**
0	0,0	9516460,8	-9516460,8
1	23076923,1	9150443,1	13926480,0
2	22189349,1	8798503,0	13390846,2
3	21335912,6	8460099,0	12875813,6
4	20515300,6	8134710,6	12380590,0
5	19726250,6	7821837,1	11904413,5
Total	**106843735,9**	**51882053,5**	**NPV= 62901235,2**

IRR	**151%**
B/C	**2,06**

Cost = +15%

Cash flow of the proposed solution (Increased Cost by 15%)			
Year	**Benefits (B)**	**Costs (C)**	**Net cash flow (B-C)**
0	0	9949027,2	-9949027,2
1	24000000	9949027,2	14050972,8
2	24000000	9949027,2	14050972,8
3	24000000	9949027,2	14050972,8
4	24000000	9949027,2	14050972,8
5	24000000	9949027,2	14050972,8
Total	**120000000,0**	**59694163,2**	**60305836,8**

Discounted cash flow (r=4%)			
Year	**Benefits (B)**	**Costs (C)**	**Net cash flow (B-C)**
0	0,0	9949027,2	-9949027,2
1	23076923,1	9566372,3	13510550,8
2	22189349,1	9198434,9	12990914,2
3	21335912,6	8844649,0	12491263,7
4	20515300,6	8504470,1	12010830,4
5	19726250,6	8177375,1	11548875,4
Total	**106843735,9**	**54240328,7**	**NPV= 60305836,8**

IRR	**139%**

B/C	**1,97**

Benefits=-2%

Cash flow of the proposed solution (Decreased Benefits by 2%)			
Year	**Benefits (B)**	**Costs (C)**	**Net cash flow (B-C)**
0	0,0	**8651328**	-8651328,0
1	23520000,0	**8651328**	14868672,0
2	23520000,0	**8651328**	14868672,0
3	23520000,0	**8651328**	14868672,0
4	23520000,0	**8651328**	14868672,0
5	23520000,0	**8651328**	14868672,0
Total	**117600000,0**	**51907968,0**	**65692032,0**

Discounted cash flow (r=4%)			
Year	**Benefits (B)**	**Costs (C)**	**Net cash flow (B-C)**
0	0,0	8651328,0	-8651328,0
1	22615384,6	8318584,6	14296800,0
2	21745562,1	7998639,1	13746923,1
3	20909194,4	7690999,1	13218195,3
4	20104994,6	7395191,4	12709803,1
5	19331725,6	7110761,0	12220964,6
Total	**104706861,2**	**47165503,2**	**NPV= 65692032,0**

IRR	**171%**
B/C	**2,22**

Benefits=-10%

Cash flow of the proposed solution (Decreased Benefits by 10%)			
Year	**Benefits (B)**	**Costs (C)**	**Net cash flow (B-C)**
0	0,0	**8651328**	-8651328,0
1	21600000,0	**8651328**	12948672,0
2	21600000,0	**8651328**	12948672,0
3	21600000,0	**8651328**	12948672,0
4	21600000,0	**8651328**	12948672,0
5	21600000,0	**8651328**	12948672,0
Total	**108000000,0**	**51907968,0**	**56092032,0**

Discounted cash flow (r=4%)			
Year	Benefits (B)	Costs (C)	Net cash flow (B-C)
0	0,0	8651328,0	-8651328,0
1	20769230,8	8318584,6	12450646,2
2	19970414,2	7998639,1	11971775,1
3	19202321,3	7690999,1	11511322,3
4	18463770,5	7395191,4	11068579,1
5	17753625,5	7110761,0	10642864,5
Total	**96159362,3**	**47165503,2**	**NPV= 56092032,0**

IRR	**148%**
B/C	**2,04**

Benefits=-15%

Cash flow of the proposed solution (Decreased Benefits by 15%)			
Year	Benefits (B)	Costs (C)	Net cash flow (B-C)
0	0,0	**8651328**	-8651328,0
1	20400000,0	**8651328**	11748672,0
2	20400000,0	**8651328**	11748672,0
3	20400000,0	**8651328**	11748672,0
4	20400000,0	**8651328**	11748672,0
5	20400000,0	**8651328**	11748672,0
Total	**102000000,0**	**51907968,0**	**50092032,0**

Discounted cash flow (r=4%)			
Year	Benefits (B)	Costs (C)	Net cash flow (B-C)
0	0,0	8651328,0	-8651328,0
1	19615384,6	8318584,6	11296800,0
2	18860946,7	7998639,1	10862307,7
3	18135525,7	7690999,1	10444526,6
4	17438005,5	7395191,4	10042814,1
5	16767313,0	7110761,0	9656552,0
Total	**90817175,6**	**47165503,2**	**NPV= 50092032,0**

IRR	**134%**
B/C	**1,93**

Scenario 2 (Discount rate=10%)

Cash flow of the proposed solution

Year	Benefits (B)	Costs (C)	Net cash flow (B-C)
0	0	**8651328**	-8651328
1	24000000	**8651328**	15348672
2	24000000	**8651328**	15348672
3	24000000	**8651328**	15348672
4	24000000	**8651328**	15348672
5	24000000	**8651328**	15348672
Total	**120000000**	**51907968**	**68092032**

Discounted cash flow (r=10%)			
Year	**Benefits (B)**	**Costs (C)**	**Net cash flow (B-C)**
0	0	8651328	-8651328
1	21818182	7864844	13953338
2	19834711	7149858	12684853
3	18031555	6499871	11531684
4	16392323	5908973	10483349
5	14902112	5371794	9530318
Total	**90978882**	**41446668**	**NPV= 49532215**

IRR	**151%**
B/C	**2,20**

Year	Cumulative Benefits (ΣB)	Cumulative Costs (ΣC)	Cumulative Net Cash Flow (Σ(B-C))
0	0	8651328	-8651328
1	21818182	16516172	5302010
2	41652893	23666029	17986863
3	59684448	30165900	29518548
4	76076771	36074874	40001897
5	90978882	41446668	49532215

Sensitivity Analysis

Cost=+2%

Cash flow of the proposed solution (Increased Cost by 2%)			
Year	**Benefits (B)**	**Costs (C)**	**Net cash flow (B-C)**
0	0	8824354,56	-8824354,56

1	24000000	8824354,56	15175645,44
2	24000000	8824354,56	15175645,44
3	24000000	8824354,56	15175645,44
4	24000000	8824354,56	15175645,44
5	24000000	8824354,56	15175645,44
Total	**120000000,0**	**52946127,36**	**67053872,64**

Discounted cash flow (r=10%)			
Year	**Benefits (B)**	**Costs (C)**	**Net cash flow (B-C)**
0	0,0	8824354,6	-8824354,6
1	21818181,8	8022140,5	13796041,3
2	19834710,7	7292855,0	12541855,7
3	18031555,2	6629868,2	11401687,0
4	16392322,9	6027152,9	10365170,0
5	14902111,8	5479229,9	9422881,8
Total	**90978882,5**	**42275601,1**	**NPV= 67053872,6**

IRR	**171%**
B/C	**2,15**

Cost=+10%

Cash flow of the proposed solution (Increased Cost by 10%)			
Year	**Benefits (B)**	**Costs (C)**	**Net cash flow (B-C)**
0	0	9516460,8	-9516460,8
1	24000000	9516460,8	14483539,2
2	24000000	9516460,8	14483539,2
3	24000000	9516460,8	14483539,2
4	24000000	9516460,8	14483539,2
5	24000000	9516460,8	14483539,2
Total	**120000000,0**	**57098764,8**	**62901235,2**

Discounted cash flow (r=10%)			
Year	**Benefits (B)**	**Costs (C)**	**Net cash flow (B-C)**
0	0,0	9516460,8	-9516460,8
1	23076923,1	8651328,0	14425595,1
2	22189349,1	7864843,6	14324505,5
3	21335912,6	7149857,9	14186054,8
4	20515300,6	6499870,8	14015429,8
5	19726250,6	5908973,4	13817277,1

Total	**106843735,9**	**45591334,5**	**NPV= 62901235,2**

IRR	**151%**
B/C	**2,34**

Cost=+15%

Cash flow of the proposed solution (Increased Cost by 15%)			
Year	**Benefits (B)**	**Costs (C)**	**Net cash flow (B-C)**
0	0	9949027,2	-9949027,2
1	24000000	9949027,2	14050972,8
2	24000000	9949027,2	14050972,8
3	24000000	9949027,2	14050972,8
4	24000000	9949027,2	14050972,8
5	24000000	9949027,2	14050972,8
Total	**120000000,0**	**59694163,2**	**60305836,8**

Discounted cash flow (r=4%)			
Year	**Benefits (B)**	**Costs (C)**	**Net cash flow (B-C)**
0	0,0	9949027,2	-9949027,2
1	21818181,8	9044570,2	12773611,6
2	19834710,7	8222336,5	11612374,2
3	18031555,2	7474851,4	10556703,8
4	16392322,9	6795319,4	9597003,5
5	14902111,8	6177563,1	8724548,6
Total	**90978882,5**	**47663667,9**	**NPV= 60305836,8**

IRR	**139%**
B/C	**1,91**

Benefits=-2%

Cash flow of the proposed solution (Decreased Benefits by 2%)			
Year	**Benefits (B)**	**Costs (C)**	**Net cash flow (B-C)**
0	0,0	**8651328**	-8651328,0
1	23520000,0	**8651328**	14868672,0
2	23520000,0	**8651328**	14868672,0
3	23520000,0	**8651328**	14868672,0
4	23520000,0	**8651328**	14868672,0
5	23520000,0	**8651328**	14868672,0
Total	**117600000,0**	**51907968,0**	**65692032,0**

Discounted cash flow (r=10%)			
Year	**Benefits (B)**	**Costs (C)**	**Net cash flow (B-C)**
0	0,0	8651328,0	-8651328,0
1	21381818,2	7864843,6	13516974,5
2	19438016,5	7149857,9	12288158,7
3	17670924,1	6499870,8	11171053,3
4	16064476,5	5908973,4	10155503,0
5	14604069,5	5371794,0	9232275,5
Total	**89159304,8**	**41446667,7**	**NPV= 65692032,0**

IRR	**171%**
B/C	**2,15**

Benefits=-10%

Cash flow of the proposed solution (Decreased Benefits by 10%)			
Year	**Benefits (B)**	**Costs (C)**	**Net cash flow (B-C)**
0	0,0	**8651328**	-8651328,0
1	21600000,0	**8651328**	12948672,0
2	21600000,0	**8651328**	12948672,0
3	21600000,0	**8651328**	12948672,0
4	21600000,0	**8651328**	12948672,0
5	21600000,0	**8651328**	12948672,0
Total	**108000000,0**	**51907968,0**	**56092032,0**

Discounted cash flow (r=10%)			
Year	**Benefits (B)**	**Costs (C)**	**Net cash flow (B-C)**
0	0,0	8651328,0	-8651328,0
1	19636363,6	7864843,6	11771520,0
2	17851239,7	7149857,9	10701381,8
3	16228399,7	6499870,8	9728528,9
4	14753090,6	5908973,4	8844117,2
5	13411900,6	5371794,0	8040106,6
Total	**81880994,2**	**41446667,7**	**56092032,0**

IRR	**148%**
B/C	**1,98**

Benefits=-15%

Cash flow of the proposed solution (Decreased Benefits by 15%)			
Year	**Benefits (B)**	**Costs (C)**	**Net cash flow (B-C)**
0	0,0	**8651328**	-8651328,0
1	20400000,0	**8651328**	11748672,0
2	20400000,0	**8651328**	11748672,0
3	20400000,0	**8651328**	11748672,0
4	20400000,0	**8651328**	11748672,0
5	20400000,0	**8651328**	11748672,0
Σύνολο	**102000000,0**	**51907968,0**	**50092032,0**

Discounted cash flow (r=10%)			
Year	**Benefits (B)**	**Costs (C)**	**Net cash flow (B-C)**
0	0,0	8651328,0	-8651328,0
1	18545454,5	7864843,6	10680610,9
2	16859504,1	7149857,9	9709646,3
3	15326821,9	6499870,8	8826951,2
4	13933474,5	5908973,4	8024501,1
5	12666795,0	5371794,0	7295001,0
Σύνολο	**77332050,1**	**41446667,7**	**NPV=50092032,0**

IRR	**134%**
B/C	**1,87**

3.3 Conclusion

Both scenarios showed that the proposed procurement solution is profitable on the basis of all the calculated indicators, namely NVP, IRR and B/C. The payback period is just 1 year, which indicates that this procurement solution is of very low risk. The sensitivity analysis also showed that even when the costs increased by 15% or the benefits decreased by 15% the proposed procurement solution remains profitable, although as it was expected the actual NPV values appeared decreased.

3.4 References

Baker, J.S., Crouch, A., Cai, Y., Latta, G., Ohrel, S., Jones, J., Latane, A. 2018. Logging residue supply and costs for electricity generation: Potential variability and policy considerations, Energy Policy 116:397-409, doi:10.1016/j.enpol.2017.11.026