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Environmental and Economic Assessment of Wood Pellet Production from Trees in Greece

Chrysanthos Golonis, Rigou Aikaterini, Charaklias Konstantinos, Zeibekis Konstantinos, Georgantzeli Polixeni, Piteros Andreas

Agricultural University of Athens, Athens, Greece
Email: crisgoloni@gmail.com

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Abstract

Biomass is a renewable, economic and readily available resource of energy that has potential to substitute fossil fuels in many applications such as heat, electricity and biofuels. The increased use of the agricultural biomass can help the agricultural based societies in achieving energy security and creating employment without causing environmental degradation. However, the viability and feasibility of electricity generation from agricultural biomass depends upon the availability of biomass supply at a competitive cost. The present study investigates the availability of agricultural biomass for distributed power generation in Greece (Kozani). The study concludes with a discussion on significance and challenges of decentralized electricity generation for rural energy supply, including brief description about economical, social, environmental and technical aspects of bioelectricity. With the application of the life cycle analysis applied, the environmental and economic impacts that will occur in the region of Kozani in Greece, where a biomass wood pellets production workshop is operating, have been assessed. The total annual emission of CO 657.9 gr, HC 22.36 gr, PM 67.94 and NOx 8.832,2 gr was calculated. The economic evaluation estimated the payback period for the investment in this plant to be approximately 3 years.

Keywords

Biomass, Wood Pellets, Energy, Emission, Life Cycle Assessment

1. Introduction

Energy is one of the most important concerns for the future and development of humanity, as the economic activity is strongly related to the availability of energy. The production of electricity is mainly based on fossil fuels. It is known that fossil fuels reserve (which are actually the main source of energy) are declining, which arises the need of finding other sources of energy production. The increase of concentration of CO_2 in the atmosphere that comes from the combustion of fossil fuels is the main reason of global warming and makes it more urgent the search of "clean" energy production like renewable energy. The combustion of fossil fuels leads to the inevitable production of carbon dioxide (CO_2), while most of the times harmful emissions are produced, such as carbon monoxide (CO), nitrogen oxides (NOX), sulfur oxides (SOX), unburned hydrocarbons (HC), and solid particles [1] [2].

On the other hand, renewable energy technologies do not require any fossil fuel during normal operation. Their operation is based on the exploitation of natural resources, such as the sun and wind, having relatively lower operating costs, although they still require some maintenance.

As a result, global energy production promotes policies that focus on energy production from renewable energy sources combined with the increase in the price of fossil energy from the crisis of the war between Russia and Ukraine. Some of the electricity generation technologies are solar, wind, geothermal, hydrodynamic, biomass and wave energy [3].

Renewable power generating capacity saw its largest annual increase ever in 2016 and 2020 (**Figure 1**), with an estimated 171 gigawatts (GW) of capacity added. Total global capacity was up nearly 9% compared to 2015. The world continued to add more renewable power capacity annually than it added (net) capacity from all fossil fuels combined. In 2020, one is accounted for an estimated nearly 62% of net additions to global power generating capacity [4].

Renewable energy systems are increasingly being used for electricity generation, either at small-scale decentralized systems with capacity in the kW scale or even medium-scale systems (often called utility-scale) with capacity of a few MW. Particularly important are the quantities of electricity production from the sun. The improvement of the quality of the cells from the photovoltaics as well

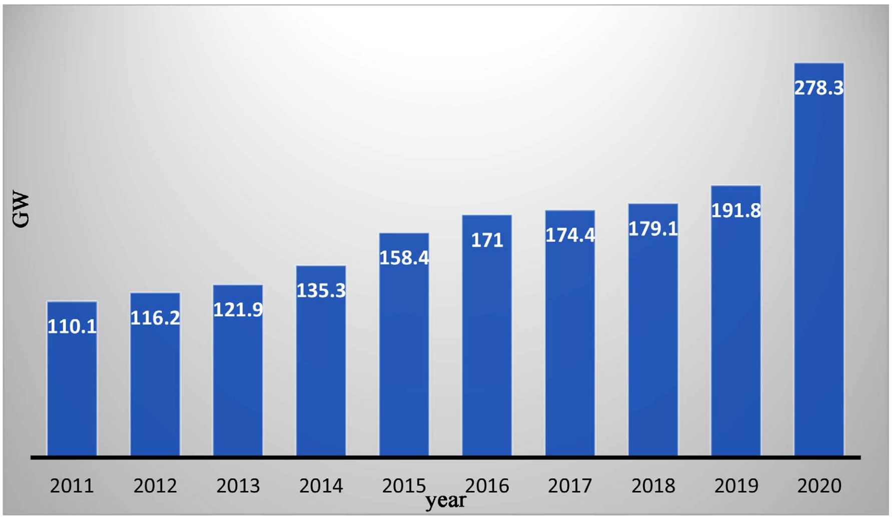

Figure 1. Net global renewable energy in Giga Watt (GW) capacity additions by year [63].

as the combined technologies of production of electricity and heat from the photovoltaics contributed significantly to this [5].

The aim of this study is to apply the life cycle analysis method to assess the environmental and economic impacts that will occur in the area of Kozani in Greece, where a biomass pellet production laboratory operates. Biomass energy is a promising alternative to such limited fossil fuel reserves in world economy as oil, natural gas and coal [6] [7].

According to EUROSTAT (**Figure 2**) data among the EU Member States, more than 70% of electricity consumed in 2020 was generated from renewable sources in Austria (78.2%) and Sweden (74.5%). The consumption of electricity from renewable sources was also high in Denmark (65.3%), Portugal (58%) and Latvia (53.4%), accounting for more than half of electricity consumed. At the other end of the scale, the share of electricity from renewable sources was 15% or less in Malta (9.5%), Hungary (11.9%), Cyprus (12.0%), Luxembourg (13.9%) and Czech (14.8%). The EFTA countries Norway and Iceland produced more electricity from renewable sources than they consumed in 2020, therefore leading a share higher than 100%.

Eurostat estimates that in 2020, the year when COVID-19 containment measures were widely introduced by the EU Member States, carbon dioxide (CO_2) emissions from fossil fuel combustion (mainly oil and oil products, coal, peat and natural gas) significantly decreased by 10% in the EU compared with the previous year. CO_2 emissions from energy use are a major contributor to global warming and account for some 75% of all man-made EU greenhouse gas emissions. They are influenced by factors such as climate conditions (e.g. cold and

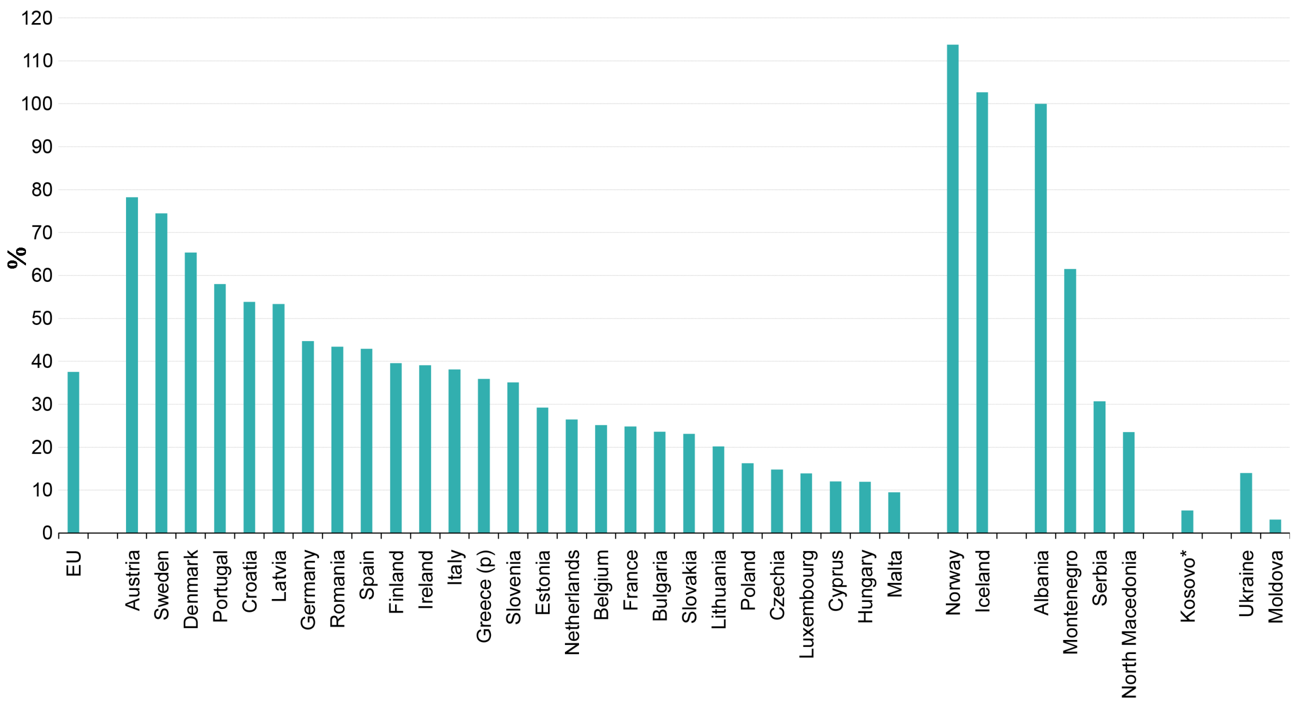

Figure 2. Share of electricity from renewable sources 2020 [63].

long winter or hot summer), economic growth and size of the population, transport and industrial activities.

The fact contributed to it a clear drop in fossil fuel consumption (hard coal, lignite, shale oil and oil sands, oil and oil products and natural gas) was observed in all countries. The largest decreases were seen for all types of coals. The consumption of oil and oil products also decreased in almost all Member States, while natural gas consumption decreased only in fifteen Member States and increased or stayed at the same level in the twelve others. In contrast, the share of ones be (especially wind, hydro and solar) in electricity (details in **Figure 3**) generation grew considerably (>80 Terawatt hours more electricity generation).

2. Energy Use of Biomass

Biomass refers to the organic carbon-containing materials produced through photosynthesis by the use of water, air, land. Biomass is available in many forms, comprising products as well as residues from forestry, agroindustry and agriculture.

It is characterized by renewability, less pollution, wide distribution and abundant resources. During growth of the plants, trees and crops, CO_2 is withdrawn from the atmosphere and stored in the biomass as chemical energy. The CO_2 cycle is closed again when CO_2 is released during conversion of the biomass and the derived products. The renewable and CO_2—neutral nature of biomass is the major motivation to use the material for the energy generation. It is still the fourth world-wide energy resource (following natural gas, oil and coal) but the energy use of the organic substances is limited by their low energy density, complexity of the supply chain (often in competition with the main uses of organic

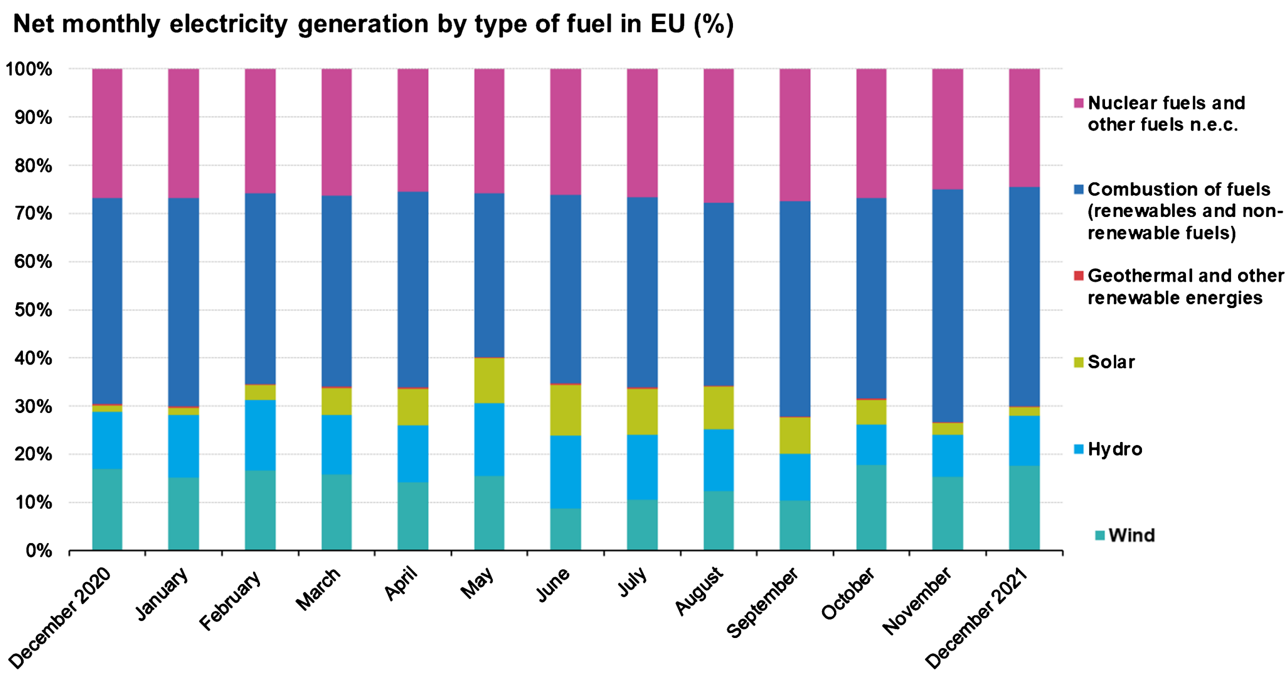

Figure 3. Net monthly electricity generation by type of fuel in EU [63].

matter, as food and materials) and high local emissions of pollutants [8].

Biomass can be used to meet a wide variety of energy needs, heating homes, supplying heat for industrial facilities, including generating electricity, and fueling vehicles, among other applications. The conversion of biomass to these valuable forms of energy can be achieved using various technological solutions that can be separated into two basic categories: thermochemical processes and biochemical/biological processes [9] [10].

The options for biomass conversion processes are classified according to the type of final energy products, including chemical and thermochemical processes. Focusing on thermochemical processes, the leading technology solutions are as follows [11]:

1) Combustion converts biomass energy into heat, mechanical energy, or electricity [11].

2) Gasification converts biomass into a fuel gas mixture of carbon monoxide, hydrogen, and methane, characterized by a low calorific value burned to produce heat and steam or used in gas turbine cycles to obtain electricity [11].

3) Pyrolysis is the conversion of biomass into a solid fraction (charcoal), a liquid fraction (bio-oil) and a gaseous fraction by heating the biomass in the absence of air [11].

4) Fermentation is when the sugars released during enzymatic hydrolysis are fermented to carry out ethanol production, also producing butanol, carbon dioxide, xylitol, organic acids, and furfural [12]. This process uses microorganisms to convert a fermentable substrate into recoverable products, such as alcohols, biomass, and organic acids. Hex-oses, especially glucose, represent the most assimilable substrate by microorganisms, while glycerin, pentoses, and other compounds need specific or modified organisms to convert possible [13].

5) Anaerobic digestion converts biomass into biogas, composed mainly of carbon dioxide and methane, through bacterial action in the absence of oxygen [11].

Last years the demand for biomass is increasing worldwide, consequently, there is a growing need to assess and better understand how much biomass is available and can be mobilized sustainably, how much is being used and for which purposes, what are the biomass flows in the economy and how the increased pressure on natural resources can be reconciled with environmental, economic and social sustainability in Europe and globally.

3. Sources of Biomass

Biomass resources that are available on a renewable basis and are used either directly as a fuel or converted to another form or energy product are commonly referred to as "feedstocks" and are the followings:

Biomass Feedstocks: Biomass feedstocks include dedicated energy crops, agricultural crop residues, forestry residues, wood processing residues, municipal waste, and liquid waste (crop algae, wastes, forest residues, purpose-grown grasses, woody energy crops, algae, industrial wastes, sorted municipal solid waste [MSW], urban wood waste, and food waste) [14] [15].

Dedicated Energy Crops: dedicated energy crops are non-food crops that can be grown on marginal land (land not suitable for traditional crops like corn and soybeans) specifically to provide biomass.

These break down into two general categories: herbaceous and woody. Herbaceous energy crops are perennial (plants that live for more than 2 years) grasses that are harvested annually after taking 2 to 3 years to reach full productivity. These include switchgrass, bamboo, miscanthus, sweet sorghum, tall fescue, kochia, wheatgrass, and others. Short-rotation woody crops are fast-growing hardwood trees that are harvested within 5 to 8 years of planting. These include hybrid poplar, hybrid willow, silver maple, eastern cottonwood, green ash, black walnut, sweetgum, and sycamore. Many of these species can help improve water and soil quality, improve wildlife habitat relative to annual crops, diversify sources of income, and improve overall farm productivity.

Agricultural Crop Residue: Crop residues are classified as primary and secondary. Primary residues are generated during harvesting and primary processing of the crops in farms and crop plantations [16].

Primary residues are generated during harvesting and primary processing of the crops in farms and crop plantations (include corn stover, leaves, stalks, husks and cobs) [16].

Agricultural crop residues, wheat straw, oat straw, sorghum stubble, barley straw, and rice straw is the secondary crop residue [17] [18].

Forestry Residues: forest biomass feed stocks fall into one of two categories: forest residues left after logging timber (including limbs, tops, and culled trees and tree components that would be otherwise unmerchantable) or whole-tree biomass harvested explicitly for biomass. Dead, diseased, poorly formed, and other unmerchantable trees are often left in the woods following timber harvest. This woody debris can be collected for use in bioenergy, while leaving enough behind to provide habitat and maintain proper nutrient and hydrologic features [19] [20].

The amount of logging residues that can be practically harvested is estimated using logging residue recoverability fractions. This is the fraction of the generated logging residues that can be realistically harvested for energy application and is estimated to be about 25% in developing countries [21]. Residues are also generated during processing of wood and are estimated using wood processing residue recoverability fraction. Available literature indicates that up to 42% of wood processing residues can be recovered from sawmills in developing countries for energy application [21]. The procedure for estimating the energy potential of forest residues proposed by Smeets and Faaij [22] was used. The energy potential of logging residues was calculated using equation:

$$Q_{HR} = \sum_{i=1}^{n} \left(Wi * h * H * LHV \right) \quad (1)$$

where, Q_{HR} is the energy potential of logging residues and Wi is the annual production of round wood of category i. Factor H and h are respectively, logging residue re-coverability fraction and logging residue generation ratio. Factor H is estimated to be about 25% in developing countries and h was assumed to be 0.6 [23] [24]. The energy potential of wood processing residue generated was estimated using equation:

$$Q_{PR} = IRW * p * P * LHV \tag{2}$$

where, Q_{PR} is energy potential of wood rocessing residues and IRW annual consumption of industrial round wood. Factor P and $p$are respectively, wood processing residue recoverability fraction and wood processing residue generation ratio. Factor p is the fraction of logs that is convert into residues during the processing of wood and depends on the efficiency of sawmills. Usually a p value for developing countries of 70% [25]. Factor P is estimated to be about 42% in developing countries [23].

Algae: algae as feedstocks for bioenergy refers to a diverse group of highly productive organisms that include microalgae, macroalgae (seaweed), and cyanobacteria.

Wood Processing Residues: wood processing yields byproducts and waste streams that are collectively called wood processing residues and have significant energy potential. The processing of wood for products or pulp produces unused sawdust, bark, branches, needles and leaves. These residues can then be converted into biofuels or bio products. Because these residues are already collected at the point of processing, they can be convenient and relatively inexpensive sources of biomass for energy [26] [27].

Sorted Municipal Waste: "Municipal Solid Waste (MSW)" discard has been a vital solicitude in most urban cities globally, and it has reached an alarming stage. Burke *et al.* [28] has performed a study on the global solid waste management (SWM) and expected that the rates of waste generation would be facing an alarming stage of escalation from 1.3 billion tones (MSW) annually to 2.2 billion tones by 2025, which is almost twofold in the next twenty years in low wage countries [29]. In addition, Burke *et al.* further added that globally, the cost of (SWM) would show a sturdy growth from today's annual of £165.56 billion to about £302.67 billion in the year 2025 [30]. Municipal Solid Waste (MSW) resources include mixed commercial and residential garbage, such as yard trimmings, paper and paperboard, plastics, rubber, leather, textiles, and food wastes. MSW for bioenergy also represents an opportunity to reduce residential and commercial waste by diverting significant volumes from landfills to the refinery [26] [27].

Wet Waste: wet waste feedstocks include commercial, institutional, and residential food wastes, organic-rich bio-solids (treated sewage sludge from municipal wastewater), manure slurries from concentrated livestock operations, organic wastes from industrial operations and biogas derived from any of the above feedstock streams.

4. Energy Consumption in Greece

The most important measure in the energy balance of Greece is the total consumption of 56.89 billion kWh of electric energy per year (**Table 1**). Per capita this is an average of 5309 kWh [31].

Greece can partly provide itself with self-produced energy. The total production of all electric energy producing facilities is 52 bn kWh. That is 91% of the countries own usage. The rest of the needed energy is imported from foreign countries. Along with pure consumptions the production, imports and exports play an important role. Other energy sources such as natural gas or crude oil are also used [31].

The Development of RES is very high in Greece, because the geomorphological and climatic characteristics that allow for the high energy and economic efficiency of the projects. Significant progress has been made since 2010 when Greek Parliament implemented the Directive 2001/77/EC to the Greek Constitution [32]. In the total RES power installed in Greece, the share of biomass is very small (**Figure 4**), with the main reasons being the complex institutional framework and the negative reactions of the local community [31]-[37].

The use of biomass for electricity generation is very interesting because it is RES, but it is limited by the cascade principle, which is a key EU strategy [38] According the principle of the sequence suggests that biomass should be used in the following order of priority: reuse, recycling, bio-energy, and disposal. The rationale behind the principle of sequencing is that the life cycle of biomass needs to be maximized in order to ensure the viability of the bio-economy, but also to bring some balance to the market due to subsidies in the field of bioenergy [39].

Table 1. Energy balance in Greece [64].

Electricity	total	Greece per Capital
Ownconsumption	56.89 bnkWh	5316.55 kWh
Production	52.05 bnkWh	4864.23 kWh
Import	9.83 bn kWh	918.92 kWh
Export	1.04 bn kWh	96.91 kWh

Note: The 100% of the countries has access to electricity.

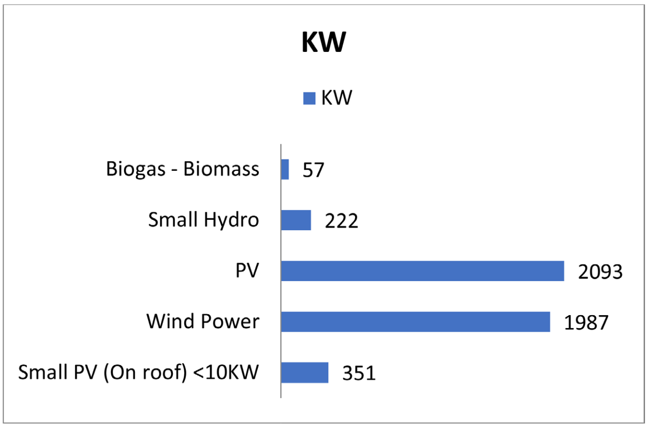

Figure 4. Installed Renewable energy sources in Greece, October 2016 [37].

While most European countries classify the energy use of biomass as a major source of electricity and thermal energy [26], Greece unfortunately disposes it in the environment uncontrollably or in landfills, with effect the use of biomass is little of bioenergy for both electricity and heat generation, while farmers usually proceed with the burning of residual biomass in their fields [40]. These solutions have a great risk of ecological disaster. In order to meet the needs of cooling, heating, electricity, and transport targets for installed power and output the energy production from biomass was set in line with EU Directive 2009/28/EC. The estimations of total non-hazardous agricultural and livestock production from 2011 and the forecast amounts for 2020 are shown in **Figure 5**.

According to data by the Ministry of Development (2007), the energy equivalent of the agricultural and forest residues available annually is estimated at 1.100.000 tones, while other calculates show that the total available biomass in Greece is about 7.600.000 tones of residues of agricultural crops and 2.600.000 tones of forest logging residues [41] [42] [43]. **Figure 6** is show the distribution of annual biomass production, in tones, by agricultural waste category in Greece.

Figure 7 and **Figure 8**, shows the annual quantities of biomass, resource and region. **Figure 7** is, specifically, the annual quantities of biomass per source in the Greece. The arable crops are the first place, with tree plantations in second with about 1 million tons of annual biomass production. The lignocellulosic biomass (vineyards, forest and tree plantations) it is estimated at about 2.200.000 tones at an annual basis [44] [45] [46].

Figure 8 show the total woody biomass by region. **Figure 6** presents a more specific the total biomass from tree forest and plantations per administration region. From figures, we see that the first in production of woody biomass is the region of Central Macedonia with about 1.100.000 tones per year, followed by Thessaly with about 800.000 tones, Thraky and East Macedonia with about 55.000 tones. The quantities of biomass from forests and tree crops, is again the

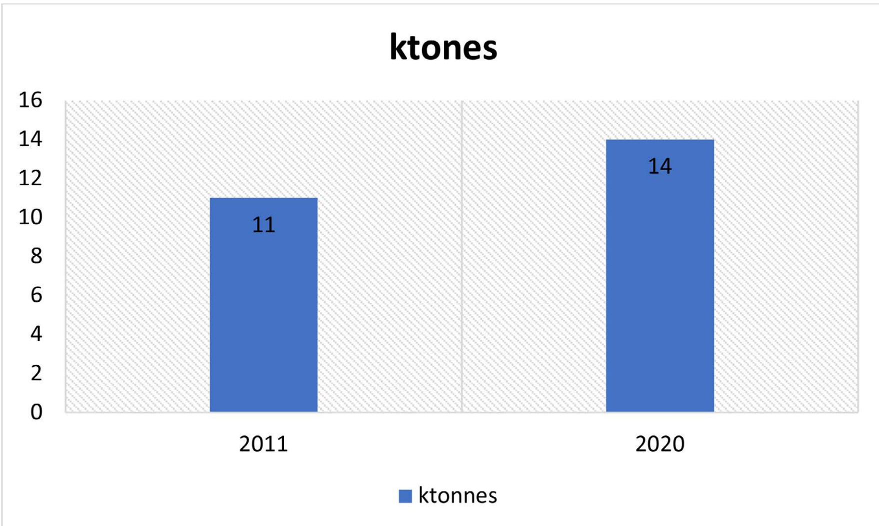

Figure 5. Estimation of non-hazardous agricultural and livestock production Greece [65].

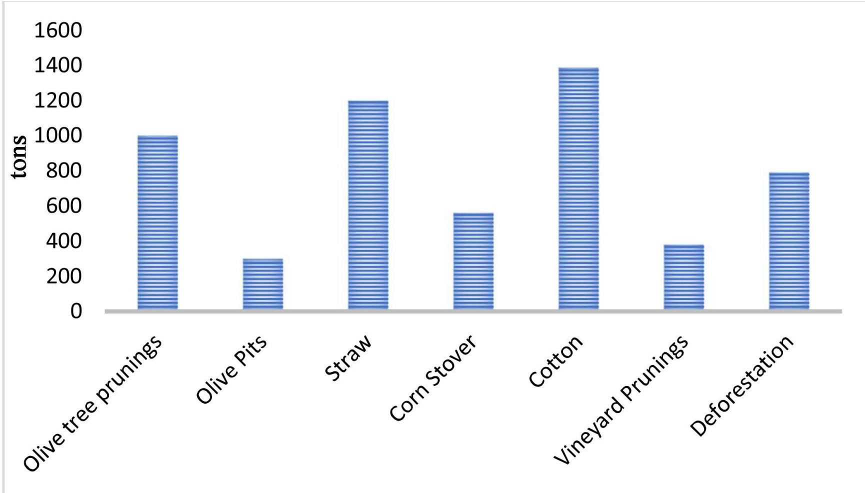

Figure 6. Distribution of annual biomass production, in tons, by agricultural waste category in Greece [65].

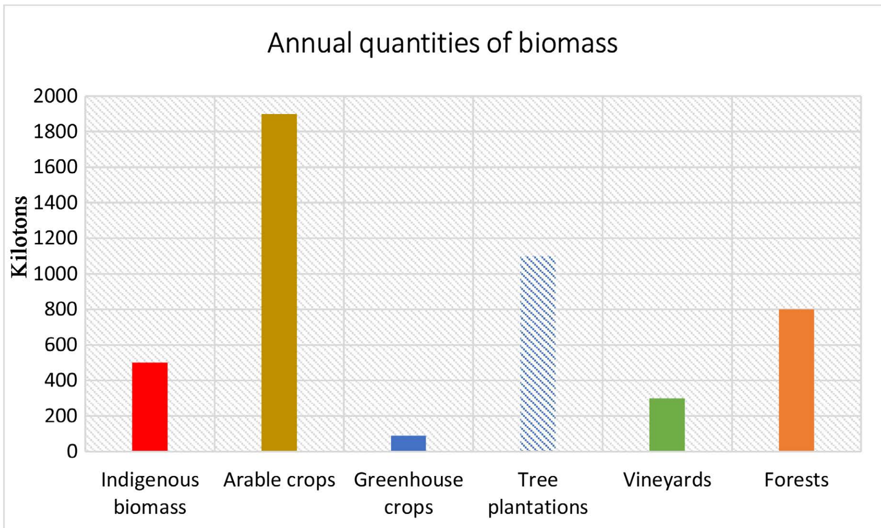

Figure 7. Annual quantities of biomass per source in Greece [65].

first Central Macedonia with about 450.000 tones, continue by Crete with about 240.000 tones and end is Peloponnese with 220.000 annual tones [47].

5. Methods

Life Cycle Assessment (LCA) is the tool used to evaluate the environmental impacts of wood pellet production. By including the impacts from each stage life cycle, LCA can provide the environmental impacts of a number of scenarios based on selection of different production or processing techniques [48]. This study will be used to evaluate the environmental impact of wood pellets production in the area of central Macedonia.

It has been extensively used for product development, product improvement, public policy making, strategic planning, and marketing and communication [49] [50]. The SimaPro software (v.8.5.2.0) and the ReCiPe2016 Midpoint (version

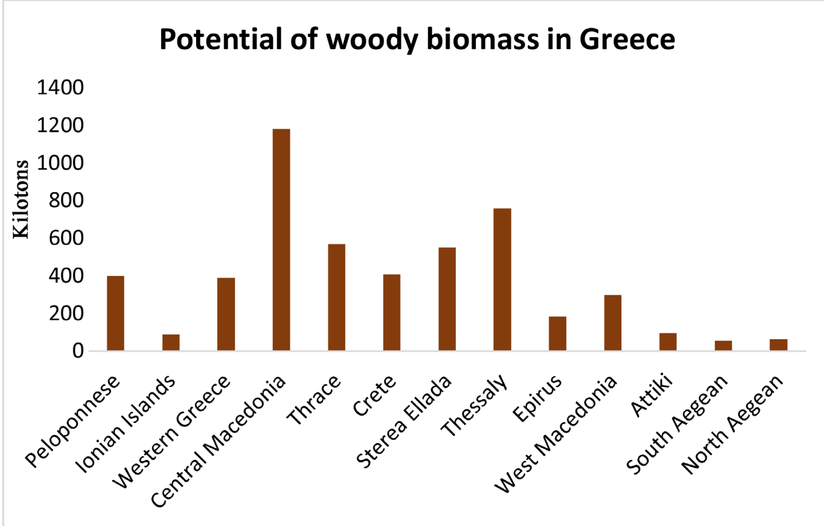

Figure 8. Potential of woody biomass in Greece by administrative region (Ktones) [65].

1.02) life cycle impact assessment method has been used for this study [51]. The 17 midpoint impact categories included are Global warming potential, Stratospheric ozone depletion, Ozone formation (Human health), Ozone formation (Terrestrialecosystems), Fine particulate matter formation, Terrestrial acidification, Freshwater eutrophication, Marine eutrophication, Terrestrial, Freshwater and Marine eco-toxicity, Human carcinogenic toxicity, Human non-carcinogenic toxicity, Land use, Mineral resource scarcity, Fossil resource scarcity, and Water consumption.

6. Functional Unit and System Boundary

The functional unit is one tone of wood pellet production from pine, oak and olive wood. For the production of one ton of wood pellet, two tons of wood waste (sawdust) will need to enter the production system. The results of this study can be used to choose for the implementation of appropriate policies in the production of electricity with a contribution to the reduction of greenhouse gases. A cradle to gate approach was applied, *i.e.*, from cultivation through wood pellet production and transportation. The system boundary is shown in **Figure 9**.

7. Life Cycle Inventory

Cultivation: fast growing tree plantation and cutting.

Fast growing trees are quite popular with the entrepreneurs anticipating to manage their feedstock by themselves. Oak, pine and less olives (due to the commercial use of oil) are of interest because they can grow very well in Greece [52]. The specific trees are cut from the forest of Pindos, for the production of wood for various constructions (furniture, wood constructions, etc.). The waste from the production of wood is collected (2000 tons per year) and transported to a factory for the production of wood pellets in Kozani. Calculations for wood

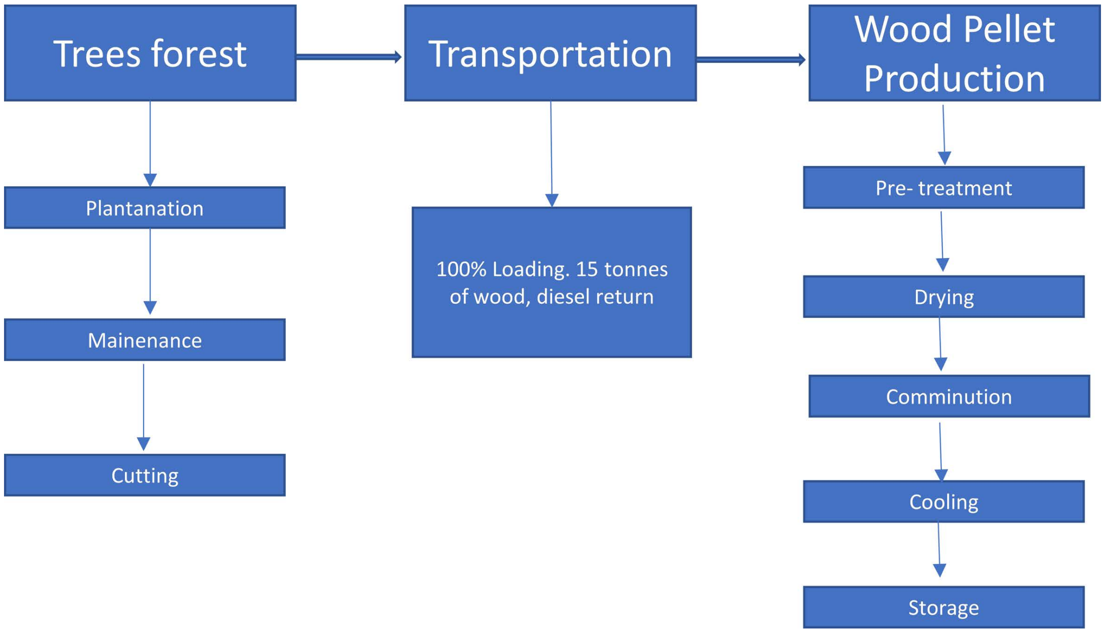

Figure 9. The system boundary for the cradle to gate life cycle assessment of wood pellets production.

pellet production were based on a plant in Kozani city, Greece, with an annual wood pellet production capacity of 1000 tones per year. The plant was assumed to have a lifespan of 20 years based on the design documents of the pellet plant. The energy and materials data of the wood pellet production process were collected by a local investigation and by an interview with the plant manager.

8. Wood Pellets Production

There are six wood pellet production processes that take place at the factory premises in Kozani. The stages of work are as follows: pretreatment, drying, comminution, palletization, cooling and storage. According to information from the wood pellets manufacturer, from October 01, 2019 to April 30, 2020, it will produce 1000 tons of pellets (**Table 2**), which will be made available to local residents. For the preparation of the compared quantity, it needs 2000 tons of sawdust, which is procured from wood cutting workshops in the surrounding areas. The ratio of pellets to sawdust is ½. The wood waste (sawdust) is transported to the plant by truck which carries 15 tons. For the transport of 2000 tons of sawdust to the factory, 134 trips had to be made [53]. The feedstock typically had a moisture content of 30% - 40%, which was reduced to 10% after drying. In detail, 40 routes had to be made from Grevena, 28 from Aridaia, 28 from Kozani, 20 from Trikala and 18 from Karditsa.

This factory the machines available has a chopper, a hammer mill, a screener, a rotary drum dryer, three pellet mills, a cyclone and a cooler. The performance of this factory can produce wood pellets at about 1000 tons per year from 2000 tons raw material. More precisely, in every hour 0.5 ton of wood pellets are produced. In an 8 hour shift 4 Tons per day are produced.

Electricity was used in the production process of about 6.000 kWh. To dry one

Table 2. Wood pellets production.

Months	Factory operating hours	Factory operating hours	Tone spellets/hour	Quantity oparating pellets per hour
May 2019	8	22	0.5	88
June 2019	8	22	0.5	88
July 2019	8	22	0.5	88
August 2019	8	15	0.5	60
September 2019	8	21	0.5	84
October 2019	8	22	0.5	88
November 2019	8	22	0.5	88
December 2019	8	21	0.5	84
January 2020	8	22	0.5	88
February 2020	8	21	0.5	84
March 2020	8	20	0.5	80
April 2020	8	20	0.5	80
Total Quantity operating pellets tones				**1000**

ton of sawdust, 100 kg of sawdust must be burnt. Given that the plant produces 1000 tons of pellets on an annual basis, it implies that 2000 tons of sawdust would have to be used as an input to the production process. About, 200 tons of sawdust would need to be burnt in the drying. Air emissions from firewood combustion were referred from the U.S. Life Cycle Inventory Database.

9. Transportation

For the transport from the wood cutting plants to the wood pellet production workshop, the distance is proportional to the loading city of the truck.

For the transport from the wood cutting factories with 0% loading on the trip to the wood pellet factory with 100% loading, the distance is proportional to the loading city of the lorry. More specifically, sawdust loading is carried out from the areas of Kozani, Trikala, Karditsa, Aridaa and Grevena. Trucks with a loading capacity of 15 tones are used for their transport. These trucks consume oil and are in the EURO 4 category as regards emissions. Their fuel consumption is 0.43 L/Km by local investigation. The kilometric distances and distances are shown in Table 3.

10. Environmental Assessment

The energy and air pollutant emissions of the pellet plant facilities were also considered by estimating the embodied impacts of the main equipment and machinery, such as the boiler for drying and the molding machine. Equipment

Table 3. Kilometric dinstances and litres of fuel oil consumption between factories.

Wood CuttingLaboratory	Transport Distance from the Forest to the Laboratory with Return (km) [38]	Truck Fuel Consumption L/km	TotalLitres of Fuel Consumed
Aridaia	480	0.43	206.4
Grevena	200	0.43	86
Karditsa	320	0.43	137.6
Kozani	280	0.43	120.4
Trikala	250	0.43	107.5

Table 4. Emissions from sawdust gr/ton.

Emmision	gr/tonsawdust
CO	102
NOX	346
SO_2	400
PM	123

and machinery were assumed to have a lifespan of 20 years, but their end-of-life, including dismantling and recycling, footprints were not considered.

The contribution of cultivation to Stratospheric ozone depletion, Land use, greenhouse gas increase Mineral resource scarcity, and Water consumption is more than 65% and the contribution of transportation more than 50% to Freshwater eco-toxicity, Terrestrial eco-toxicity and Marine eco-toxicity [54].

The air pollutant emissions of wood pellet combustion have been intensively studied for many regions in the world, such as Europe and North America [20] [21] [24] [44]. Therefore, we adopted the air pollutant emission factors of wood pellet combustion from Switzerland [31]. Given that the amount of CO_2 emitted during pellet combustion approximately equaled the emissions absorbed during wood growth [45], the pellet fuel was carbon neutral andthe CO_2 emissions of pellet combustion were not considered. Combustion equipment was rarely considered in LCA studies of wood pellets [21] [28], and this study didn't calculate the embodied energy and environmental emissions of the boiler because of its insignificant footprints for per unit of heat generation.

As mentioned before, for the drying of biomass it is necessary to burn 200 tons of tree waste. **Table 4** and **Figure 10** below shows the emissions of pollutants (gr/tone of sawdust) from the burning of biomass in the drying. The emissions produced by combustion are CO, NOX SO_2, PM [38] [55]-[60].

The emissions of the trucks are as follows [38] [55]-[60]:

- 1 g/L CO,
- 0.04 g/L HC,
- 0.10 g/L PM,
- 13 g/L NOX.

Tables 5-7 shows the calculated total emissions of CO, HC, NOx, produced during the transport of the trucks from the wood processing plant to the wood

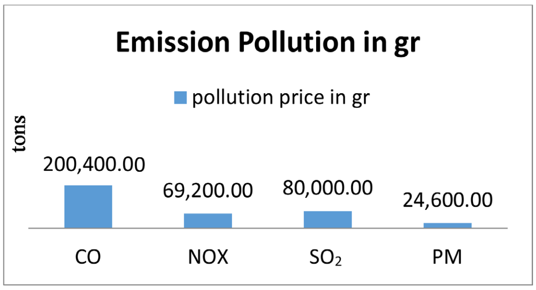

Figure 10. Emissions from the combustion of 200 tons of sawdust in gr.

Table 5. Total Pollution Emissions CO in gr.

Wood Cutting Laboratory	Total Litres of Fuel Consumed	Pollutant g/L CO	Total Emission of CO in gr
Aridaia	206.4	1	206.4
Grevena	86	1	86
Karditsa	137.6	1	137.6
Kozani	120.4	1	120.4
Trikala	107.5	1	107.5
		Total	**657.9**

Table 6. Total Pollution Emissions HC in gr.

Wood Cutting Laboratory	TotalLitres of Fuel Consumed	Pollutant g/L HC	Total Emission of HC in gr
Aridaia	206.4	0.04	3.44
Grevena	86	0.04	5.504
Karditsa	137.6	0.04	4.816
Kozani	120.4	0.04	4.3
Trikala	107.5	0.04	4.3
		Total	**22.36**

Table 7. Total Pollution Emissions NOx in gr.

Wood Cutting Laboratory	TotalLitres of Fuel Consumed	Pollutant g/L NOx	Total Emission of NOx in gr
Aridaia	206.4	13	2.683,20
Grevena	86	13	1.118
Karditsa	137.6	13	1.788,8
Kozani	120.4	13	1.565,2
Trikala	107.5	13	1.397.50
		Total	**8.552,7**

pellets production plant.

From the above tables an aggregated and Figure 11 was createdwith the total emissions.

11. Economic Evaluation Criteria

The economic evaluation will then calculate the cost of purchasing the raw material (sawdust), the cost of transport and the cost of producing wood pellets. Another element that will be assessed in the economic evaluation is the increase in jobs in the area. According to the wood pellets manufacturer, from 01 October 2019 to 30 April 2020, it will produce 1000 tons of pellets, which it will then sell to the local community. For the production of this quantity it needs 2000 tons of sawdust, which it obtains from sawmills in the surrounding areas. The ratio of pellets to sawdust is 1/2. The cost of transporting the sawdust from the cutting workshops to the pellet production plant was variable as a function of the town where the factory was located. The total raw material costs from September 2019 to April 2020 amounted to 133,050 euros. Table 8 shows in detail the transport costs for each region.

12. Cost of Raw Material

The cost of purchasing the sawdust raw material was EUR 45 per tonne, including the cost of transporting the tree trunks from the mountains of Pindos to the timber processing workshops. In contrast, the cost of transporting the sawdust from the cutting workshops to the pellet production plant was variable as a function

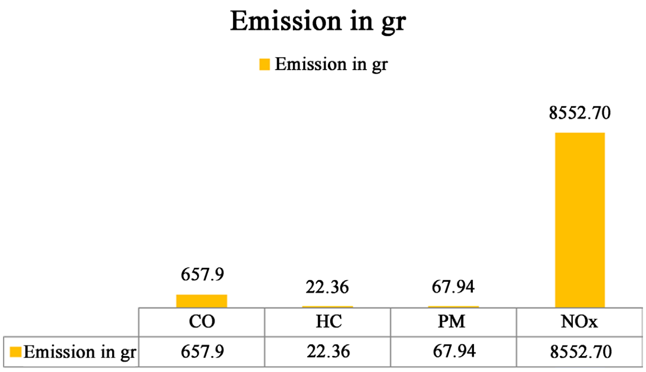

Figure 11. Total emissions.

Table 8. Sawdust transportation costs.

LaboratoryCity	TransportcostEuro/ton
Aridaia	20
Grevena	15
Karditsa	30
Kozani	5
Trikala	30

of the town where the cutting workshop was located. The total cost of raw material (Figure 12) from September 2019 to April 2020 amounted to 133.050 EUR. Table 9 gives a detailed description of the Total Raw Material Cost.

13. Economic Assessment of Wood Pellet Production

The economic assessment of wood pellet production is shown in Table 10. The results indicate that the wood pellet production and transportation of this factory can make a profit. The referenced business has begun to make a profit from the first year at a raw material price of 500 euro per ton.

The cost of raw material is an important factor for the sustainability of wood pellet production. The payback period of the investors money is 2 years the remaining 18 years under normal conditions will be profitable for the investors.

14. The Employment in Wood Pellet Production

According to studies, biomass power generating unit can produce a significant economic benefit to the area surrounding the plant [61] [62]. It is expected that a 10 MW biomass power project can create approximate employment for 100 workers during the 18-month construction phase, 25 full-time workers employed in the operation of the facility, and 35 persons in the collection, processing, and transportation of biomass material. A significant number of employees is needed in

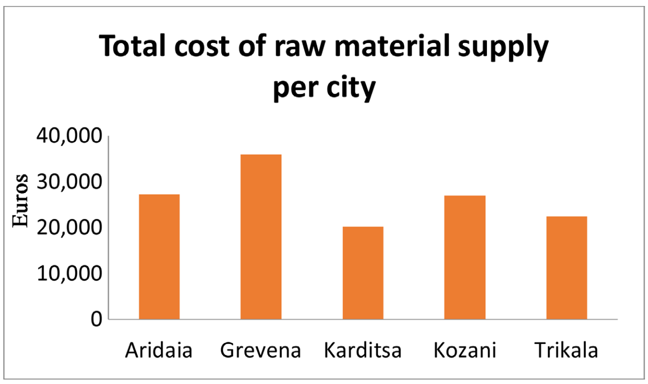

Figure 12. Total cost of raw material supply per city.

Table 9. Raw material cost.

Factory City	Raw material purchase cost Euro/ton	Sawdust Transport Cost	Total purchase and transportation cost Euro/ton	Number of lorries	tons of sawdust per truck	Total Raw Material Cost in Euros
Aridaia	45	20	65	28	15	27.300
Grevena	45	15	60	40	15	36.000
Karditsa	45	30	75	18	15	20.250
Kozani	45	5	50	28	15	27.000
Trikala	45	30	75	20	15	22.500
TotalCost		-	-	-	-	133.050

Table 10. Economic assessment of wood pellet production.

		cost	Proceeds
Price of wood (THB/tonne)	500.00 €		
Initial investment cost	−400.000,00 €		
Purchase &Transortation cost	155.000,00 €	155.000,00 €	
Electricity cost	30.000,00 €	30.000,00 €	
Salary & administration	60.000,00 €	60.000,00 €	
Maintenance cost	15.000,00 €	15.000,00 €	
Total cost		**260.000,00 €**	
Revenues	500.000,00 €		
Sales			500.000,00 €
Pre-tax profit	240.000,00 €		
Corporate tax	20.00%		
Profitability after tax	200.000,00 €		
Interest rate	5.00%		
Pay back Period	2.00		
NPV (20)	2.196.293,78 €		

producing Wood Pellets. The employment for wood pellet production is about 0.0019 person-year per ton of wood pellets [54]. This particular factory employs three workers.

There is other income to the rural economy in growing and harvesting of biomass. There is no other capital investment that can generate this much income per annum, perpetually, to the rural economy. The proximity of the plant to villages also ensures availability of manpower for operation and maintenance of the biomass power plants [60]. Therefore, the bioelectricity generation will involve creating a lot of opportunities among the local people for the biomass management, operation of plant and maintenance of equipment's in the plant.

15. Conclusions

This project aims to provide comprehensive data on the biomass potential (wood pellets) in Greece and detailed information on the environmental impact it will have on the local community from the emissions that will occur during the production cycle of the specific production for the different regions of the country. This unique and the in-depth study aims to provide a basis for future bioenergy efforts in Greece.

The authors believe that this study can assist the policy makers to develop relevant legislation that can assist the development of regional solutions that will be optimized for the locally available biomass. This can reduce the costs and carbon footprint from the transportation of biomass.

Furthermore, this study aims to motivate the Greek government by implementing appropriate policies to motivate investors to invest in equivalent biomass (wood pellets) production units, reducing the dependence on "other forms of energy which contribute to the increase of greenhouse gases as well as contributing to the increase of employment from the cultivation of energy crops".

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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