D2.6: Results on the resources evaluation activities for the use of biomass as fuel

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T2.4: Resources evaluation for the use of biomass for fuel flexibility

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0 EXECUTIVE SUMMARY

The main goal of this task is to characterise the availability of biomass and their source location in respect to two specific magnesite production plants, i.e. GM's and MAGNA's that are located at Chalkidiki (Greece) and Esteribar Valley (Spain) respectively. Different resources were evaluated in order to provide multiple bio-fuels sources and provide flexibility to the operators of the plants. The availability of local, low-cost solid biomass resources (e.g. forest, agricultural & agro-industrial residues, etc.) was evaluated for the GM and MAGNA sites respectively. The evaluation was performed through the collection of regionally-specific data on current forest, agricultural and agro-industrial residues. Factors affecting the biomass availability, such as alternative uses, sustainability requirements, relevant legislation and support measures and socio-economic issues were taken into account. Cost estimates were made after the formulation of simplified logistic models and compared with the local biomass prices or prices for internationally traded biofuels (e.g. wood pellets). Fuel analysis for specific biomass samples were performed in order to better evaluate their suitability as fuels in the kilns and to be used for other Tasks in the framework of BAMBOO project including CFD simulations and demonstration activities in the aforementioned industrial plants.

In the present task CERTH and GM investigated numerous options for the alternative feeding of GM's industrial plant with biomass as low CO2 emissions fuel. GM is experimenting the use the use of biomass as feedstock in parallel with magnesite in their rotary kilns. This will also have a major impact in the simultaneous reduction of NOx and SOx emissions from GM's kilns. It is scheduled to start with low substitution of petcoke with 2% in weight of magnesite, which in later stages will be increased up to 8%. In the current situation, GM has as target the substitution of 30% of the pet coke that is introduced in the plant and the possibility to be increased later up to 50% will be investigated.

First of all, market analysis, for agro-industrial biomass was conducted, in late 2019, for the following types of biomass: a) wood chips, b) exhausted olive cake and c) wood saw dust. The first type was selected to be fed with magnesite, while the latter were investigated as options for the substitution of pet coke. The market analysis results showed that the market-available quantities of biomass in the country are limited and there are not biomass producers who can solely cover the energy of large industrial companies like GM. Moreover, pomace plants are not located in Northern Greece, although there are olive producers in this part of the country. This type of biomass has significant fluctuations and part of the available quantities is already used by their producers in order to cover their industrial energy needs. In addition, exhausted olive cakes prices are highly connected to the market demand for olive oil, thus the delivery prices of this type of fuel is subject to fluctuations.

The case of forest residues as a biomass source for GM was examined as a secondary option for the substitution of pet coke. This option is hindered by various factors (e.g. steep terrains limited workforce) and thus this option was rejected.

The third option was to examine the agricultural residues that exist in the area. The assessment of biomass potential in the region where GM plant is located showed that the major quantities of biomass can be derived from olive tree prunings. This type of biomass, if shredded in the required dimensions, can be used for the substitution of pet coke in GM's mills. The collection of olive tree prunings in a sustainable manner was investigated in terms of soil conditions and management strategies for preservation of soil organic matter. In the case of Chalkidiki and

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more specifically in the study area near GM facilities, the conditions are not optimal, but still fairly good for the removal of olive tree prunings. The two options that were taken into account for the planning of biomass olive tree prunings supply chain are the following: a) purchase of wood chippers and b) purchase of automated picker-up shredders. The first option requires the hiring of personnel which raises significantly the potential cost proportionally to the biomass quantities, while the second option requires very high capital costs that maybe the active Agricultural Cooperative cannot meet at the moment. Thus, olive tree prunings cannot fully cover GM's requirements and can be only used as supplementary fuel.

According to the previous options, numerous scenarios were assessed for the substitution of pet coke. The optimal quantities of biomass are based on the substitution ratios for each of the aforementioned materials. Finally, in order to evaluate the substitution of these materials, factors concerning the properties of the proposed biomass types were taken under consideration.

In the case of MAGNA, the company aspires to upgrade its processes to a more sustainable and environmentally manner. Thus, the company in cooperation with CIRCE investigated the options of partial decarbonisation in short term by identifying biomass from local sources and by-products. Moreover, CIRCE examined the feeding of the plant with biomass while preserving the operational efficiency, the maintenance costs, the lifetime and the safety of the kiln, the downstream equipment and the quality of the final product. Finally, the company is interested in the promotion of innovation technologies and social innovation connected to biomass.

In this task, CIRCE examined biomass sourcing from agricultural and forestry ecosystems. The agricultural residues contain: a) annual crops and b) orchards or permanent crops. The agricultural biomass' quantities in distances lower than 40km are almost negligible, while biomass quantities included in distances lower than 100km could contribute partly to MAGNA's requirements.

The case of forest biomass quantities includes tree tops and branches, which are produced from timber exploitations and silvicultural works. The evaluation of forestry biomass potential showed that this type of fuel has the higher quantities near MAGNA's facilities. On the other hand, in distances higher than 90km the potential biomass quantities of both biomass sources (agricultural and forestry) are almost equal. The exploitation of forestry residues can be a long term alternative, which will solve problems such pest proliferation and forest fires. The forestry residues gathering options were investigated in terms of: a) land slopes, b) collection processes, c) accessibility of the trees and d) road network. Thus, it is proposed for MAGNA to become the initiator for use of forestry residues from nearby forests.

Moreover, CIRCE investigated agro-industrial by-products, as a short-term option. Apart from woodchips, agro-industrial by-products include olive pomace, grape-wine pomace, almond shells, saw dust and grape seed flour. The consumption of large quantities of these by-products will not distort the current market and these types of feedstock are available, usually, dry and in granulated form. The study showed that olive pomace, almond shells and grape seed flour are more preferable options. In any case the establishment of Biomass Logistic Center (BLC) is required. The establishment of BLC has many advantages including the storage of huge biomass quantities, assistance in the pretreatment of biomass, reduction of MAGNA's efforts to coordinate the biomass supply chain and the significant reduction of the cost.

CIRCE has conducted a supply costs and biomass competitiveness analysis by comparing pet coke prices against biomass, by taking into consideration the supply options: a) with BLC and b) without BLC. When CO2 allowances prices increase biomass becomes a better option.

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Finally, the option of torrefaction was studied, as it provides significant advantages when it comes to handling complex types of biomass, storage, transportation and grinding. Although torrefaction is not an attractive solution with the current pet coke prices and CO2 allowances, future increase of these prices or if other forces enter in place, this option shall be taken into consideration as a medium term strategy.

It is concluded that for both cases there are available sources of biomass that can partly cover their energy demands. The most difficult stage is the organisation of the supply chain, which requires the establishment of either logistic center or good communication with the active co-operatives. Thus, as a short term scenario, the purchase of a high proportion of agro-industrial products is a more preferable option. The substitution of pet-coke can benefit these types of plants, by drastically reducing their CO2 emissions, which in the case of utilization of olive tree prunings can lead up to 96% reduction. The use of biomass can also assist in simultaneously De-NOx and De-SOx procedures, along with the preservation of the flame stability. Finally, biomass can become a better option in terms of cost, if CO2 prices are increased.

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1 INTRODUCTION

BAMBOO aims at developing new technologies addressing energy and resource efficiency challenges in intensive industries like minerals. BAMBOO will scale up promising technologies to be adapted, tested and validated under real production conditions. A major challenge resides in the high temperatures required to produce dead-burnt magnesite. Under these conditions thermal production of NO_x is unavoidable, which adds to that produced by the fossil fuel. Due to the high temperature required by the process, partially replacement of coke with a high quality biomass shall be investigated. This will assist in the reduction of fossil fuel dependence, the reduction of CO_2 emissions using carbon-neutral biomass as well as the reduction of NOx emissions by using a low-NOx burner and biomass as fuel. Finally, the reduction of the current fuels costs by using alternative fuel options is of great importance to these types of industries.

In accordance to the above, one of main EU's challenges include the decarbonisation of the energy system by the implementation of renewable energy sources which will lead to a transition to more secure and highly competitive energy systems. In this framework the industrial sector has to play a major role in terms of energy saving and managing the current energy demands. Thus, industries must strengthen their role by achieving the goals set by EU for low carbon economies, the reduction of their emissions and the adoption of environmentally friendly practices. According to EU regulation, magnesite industries must tackle their emissions in order to face issues due to rise of CO_2 prices. The partial substitution of the current fuels with biomass could be an option.

Biomass feeding in these types of industries involves a series of challenges, such as the obtaining of sufficient quantities and transition towards a partial decarbonisation. This can be achieved by identifying strategies for biomass collection from local sources or by-products currently not exploited which will have a positive effect on both local economies and in the environmental footprint. These strategies include market analysis for the available biomass options, the organisation of supply chains that can provide the required quantities by activating the involvement of local actors (Cooperatives). Finally, the preservation of the operational efficiency and costs, along with sustainable production and the integration of new technologies can be seen as major challenges.

In line with the aforementioned, this task includes the investigation of the available biomass sources that can be fed to GM and MAGNA's plants, in order to achieve partial decarbonisation of their processes. Thus, in the present work a holistic approach concerning the substitution of conventional materials with sustainable biomass sources was studied. This approach includes: a) market analysis, b) supply chain organisation, c) cost analysis and d) analysis of the proposed material properties. The results of the current study will be used in later stages of the BAMBOO project that involve CFD simulations and demonstration activities in the aforementioned industrial plants.

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2 CASE STUDY 1 - USE OF BIOMASS AT GM (GREECE)

2.1 The interest to switch from fossil to renewable

GRECIAN MAGNESITE (GM) is a privately owned company established in 1959 as a mining and industrial concern. The company produces and commercializes Caustic Calcined Magnesia, Dead Burned (Sintered) Magnesia, Magnesium Carbonate (Raw Magnesite) and Basic Monolithic Refractories. A wide range of grades is currently produced, addressing practically all applications where magnesite is used. GM ranks among the top magnesia producers and exporters in the world, with a staff of around 340 people (plus 30 permanent subcontractors) and a turnover of some 45 million Euros (consolidated turnover in the range of 70 million Euros). The time horizon of interest for the plant of reference is at least 20-30 years.

In caustic magnesia in particular, the company is a leading world-wide producer both in volumes and spectrum of applications served. The produced magnesite is famous for its whiteness due to the low iron content (as low as 0.02 % Fe in the calcined/final product) and the low levels of heavy metals and trace elements. Moreover, low lime content and microcrystalline structure are its additional advantages. The company's major deposits and production facilities are located in Chalkidiki, northern Greece, 70km south-east of Thessaloniki. The "Chalkidiki" deposits consist of three (3) main active concessions: Yerakini 7 km2, Ormilia 10 km2 and Kastri 23 km2. The company also owns "reserve" concessions totalling 16 km2 for future exploitation, while company's capacity is close to 200.000 tons of calcined products and 50.000 tons of Basic Monolithic Refractories. In Grecian Magnesite's operation at Yerakini, the ore is extracted by open pit methods. The process to transform the extracted Run of Mine (RoM) to final products consists of five (5) different main stages: Mining, pre-beneficiation, main beneficiation, calcination/sintering and final-processing.

Figure 1: GM's major deposits and production facilities

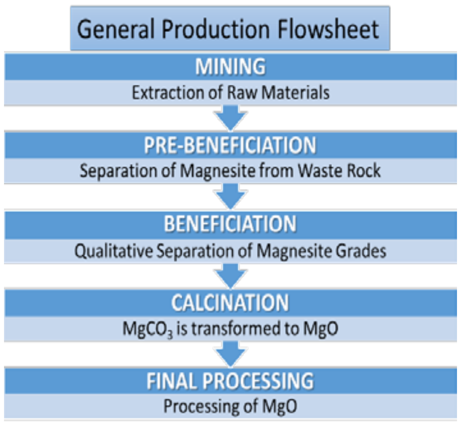

Figure 2: GM's general production flowsheet

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In the GM' case, a flexible scheme in raw materials consumption would lead not only to more sustainable value chains, but also to a potential cost reduction as this particular company would be able to incorporate low value materials into their processes, opening as well new opportunities to by-products valorisation by industrial symbiosis concepts. Nevertheless, it is important to understand how this flexibility in raw materials affects the process characteristics and energy consumption, as well as the final products quality. In order to evaluate the potential of establishing a flexible raw material scheme in this resource and energy intensive industry sector, a non-exhaustive analysis of current feedstock and flexibility options has been performed, together with the potential valorisation of their main by-products. Thus, this project will help in the increase of raw materials flexibility while optimizing the plant cost structure.

In this project GM will rely on the development of improved burner technologies which will play a major role in the upgrading of the company's industrial processes by the exploitation of solid biofuels. The proposed solution has been proposed on this basis and it is expected to assist in energy efficiency and towards more sustainable energy consumption. GM aspires to achieve a significant reduction in the energy costs, improved process efficiency and a considerable reduction in the CO2 emissions.

Finally, GM aims to cover its current needs regarding monitoring, control and optimisation of combustion processes by introducing to their system non-traditional fuels, in order to improve the fuel flexibility of combustion systems, implying important savings to raw materials consumption.

2.2 The challenge

The energy transition towards a secure, competitive and decarbonised energy system constitutes a challenge for the EU resource and energy intensive industries, since they must adapt their current consumption and production patterns to a higher share of fluctuating renewable energy supply. Energy saving and managing demand have been set as a responsibility for all and therefore, industrial demand response has gained importance over the last few years. The top priority for the EU Member States is to foster growth and competitiveness to sustain and strengthen recovery and to achieve the goals set by the European Union for a low-carbon economy, which includes an 80% reduction in emissions by 2050 compared with 1990 levels. However, there are cases of industries that their CO2 emissions derive from fossil solid fuels which are related to their production processes. A typical example of such industries is the production of clinker and the production of magnesium products. These type of emissions must be tackled so that these industries - though partially guaranteed by free CO_2 allowances until 2030 (Regulation EU 2019/331) – might not face issues due to rise of CO_2 prices (>> 40 € / CO2).

In this line, decreasing costs to improve competitiveness led many industries to reduce their energy demand (for the majority consisting of heat), usually through energy efficiency measures but most recently by implementing flexibility measures that include, e.g., industrial symbiosis concepts or the integration of RES. The current trends and potential for resource and energy intensive industries in moving to a more efficient and flexible production, concern the following three key factors: 1) waste heat recovery, 2) electricity consumption and flexibility and 3) use and valorisation of raw materials and by-products.

GM's processes run at a continuous basis, with only periodic planned stops and rare unexpected short term shutdowns. The main products that GM manufactures are: Caustic Calcined Magnesite (CCM), Dead Burnt Magnesite (DBM) and other monolithic refractory masses (DBM + additives), reaching a production of 155.000 t/year. The main raw materials consumption is Magnesite

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Olivine and Additives. Raw materials' reception and storage is at ambient conditions (winter: 15oC, summer: 32oC), while there is no cooling water system available. There are three (3) Rotary Kilns for the calcination process. Raw magnesite ($MgCO_3$) is calcined as it moves through the long kilns No1, No2 and No3. The process produces Caustic Calcined Magnesia and Dead Burned Magnesite, which are cooled (through RK No1, No2, No3 coolers) and then they are collected. The calcination plant uses Petroleum Coke (PC), Heavy oil and Biomass occasionally as fuel. At 2017, significant amounts of Petroleum Coke and Heavy oil were used and biomass in a small proportion.

The calcination process of magnesite to CCM and DBM in the Rotary Kilns of GM produces large amounts of CO_2 along with Nitrogen Oxides (NO_x) and Sulphur Oxides (SOX) as well, from pet coke combustion. The main challenge resides in the high temperatures required to produce DBM, close to 2000 ºC. Due to the high temperature required by the process, the production of thermal NO_x is unavoidable, which adds to that produced by the fossil fuel. In this task the main challenges are the following: i) co-feed biomass along with coke - ii) introduction of size of woodchips or other biomass source fed to the system along with the magnesite. Therefore, the main challenges are:

- Reduction of the dependence on fossil fuel by using biomass
- Reduction of CO_2 emissions by using carbon-neutral biomass
- Reduction of NO_x emissions by using a low-NO_x burner and biomass as fuel
- Flexible energy consumption according to market prices

The main goal of this task is to investigate the suitability of various biomass types for the magnesite plants and study the availability of biomass and their source location with respect to the specific plants. The availability of local, low-cost solid biomass resources which can be collected in sustainable manner (e.g. forest, agricultural & agro-industrial residues, etc.) are also evaluated by CERTH for GM. The evaluation is performed through the collection of regionally-specific data on current forest, agricultural and agro-industrial production. Factors affecting the biomass availability, such as alternative uses or sustainability requirements (e.g. GHG emissions, requirements to preserve soil organic carbon) are taken into account. Cost estimates are also calculated after the formulation of simplified logistic models and compared with the local biomass prices or prices for internationally traded biofuels (e.g. wood pellets). Fuel analysis for specific biomass samples are performed at the solid fuels laboratory of CERTH. The analysis results will be used in other tasks of the project where CFD simulations of GM's kiln as well as demonstration activities in GM will be carried out. Necessary pre-treatment steps at the plant site (e.g. grinding, drying, etc.) required for the feeding of the biomass fuels will also be assessed by CERTH, considering the limitations of the current processing equipment.

2.3 Prospecting the industrial use of biomass at GM facilities

The availability of biomass as a major source of energy production is subject to significant fluctuations due to weather conditions, the agricultural practices implemented in the region, the amount of subsidies for crops, current European and international regulations (eg. Common Agricultural Policy, World Trade Organization) and the competitive uses of biomass (eg. for industrial forestry, paper industry and livestock). Therefore, estimating the available biomass

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potential for energy production on an absolutely stable basis (eg. fuel analysis, calorific value, moisture and ash content and composition) is a difficult task. This task is hindered when the research is confined to a specific geographical area, as in the case of Regional Unit of Chalkidiki. However, if a well-structured and tested methodology is used, it is possible to safely estimate the available quantities of biomass, which are suitable for further use. The following sections deal with the assessment of biomass potential for the case of the Chalkidiki Regional Unit and include the investigation of local biomass sources, their characteristics and details concerning the logistics options.

2.3.1 Estimation of forest biomass potential

The first step was to estimate the potential biomass deriving from the nearby forests. In Greece, forests can be exploited either by the forestry authorities, or by the forest cooperatives, which gain permission to access the forest. Currently, there are two options for forest exploitation. In the first case, forest cooperatives are paid per unit of produced product. The produced product is then marketed by the Forestry Offices, via auctions. In the second option, the produced product is marketed by the forest cooperatives. In this case, 12% of gross revenue of technical wood and 5% of the gross revenue of firewood is attributed to the Central Agriculture, Livestock and Forestry Fund. Furthermore, 5% of the gross revenue of technical wood and firewood is attributed to the Local Regional Government that is responsible for the specific forest.

In Greece, logging activities are hindered due to the steep terrain of the forests, the lack of mechanization and the limited workforce. Moreover, the scattering of the residues in the forests, due to the forest management plans, as well as the overall system of cooperative forest exploitation do not encourage the removal of the forest residues. The amount of log wood per year is not stable, as it depends on the forest management plans of each forestry authority. The removal of the forest residues can deplete nutrients that affect, in long-term, the forest productivity, therefore, the actual availability of forest residues is much lower.

In the case of forest biomass, the estimation of the potential biomass is based on the data collected by the logging processes of public and private forests which were used as biomechanical and technical wood, as well as firewood. This data was taken from national statistics concerning the specific topic. Broadleaves are the major source of forest products, which, both in the case of the Regional Unit, as well as in the case of the Municipal Authority are very low. The estimations were conducted for multiple distances from the study area by implementing georeferenced information tool (Bioraise). Harvesting and transport costs from the field to a user-choice destination were calculated as well, and market related stakeholders' locations were displayed. Productivity tables derived from national forest inventories were used, considering a 20 years' period between forest activities producing biomass resources. In this case, GM facilities were set as the selected location and the computations were conducted for forest residues which are located in the following radiuses: a) 10km, b) 15km, c) 30 km and d) 45 km, from GM facilities (Figure 3).

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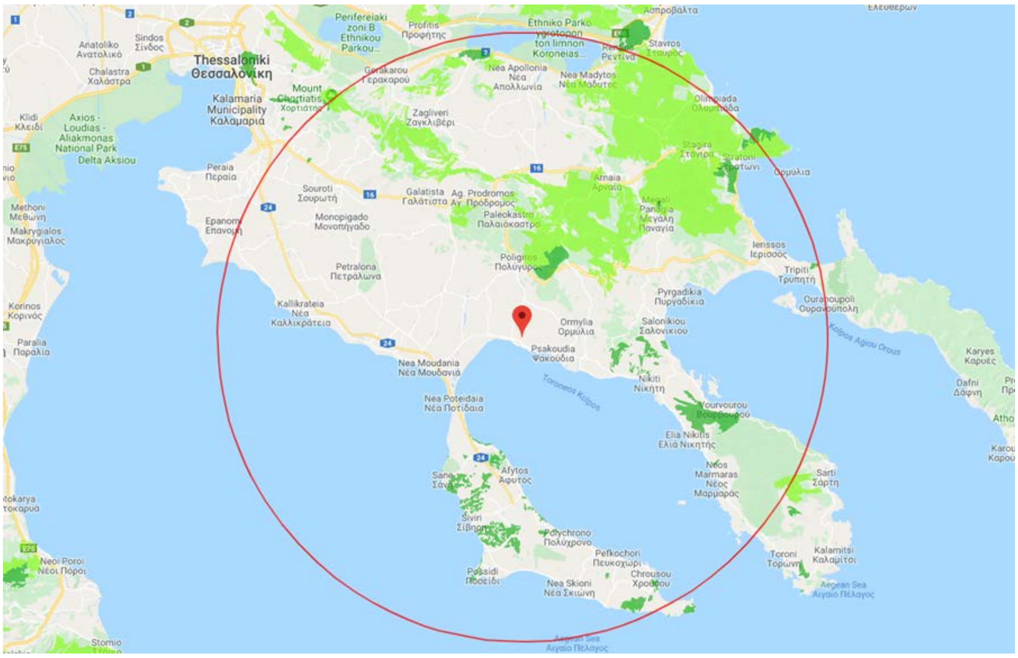

Figure 2: Location of GM's facilities and 45km study area for forest residues

According to the results presented in Table 1, in the radius of 10km from GM facilities there are no forest biomass residues. A negligible amount of forest residues can be found in a distance of 15km from the study area. On the other hand, a significant amount of potential resources can be found in a distance of 30km from GM facilities. Although, as mentioned previously, these potential resources are still only theoretical, because each forestry authority has a specific forest management plan, which allows exploitation of significant trees per year. Therefore, according to the forest management plans, there are high fluctuations concerning the availability of the forest residues, which hinder even more the exploitation of the forest resources.

Table 1: Potential forest residues in various distances from GM's facilities

Type of biomass	Surface of potential resources (ha)	Surface of available resources (ha)	Potential resources (tDM/yr)	Available resources (tDM/yr)	Energetic content (GJ/yr)
15 km from GM facilities					
Conifers	**383**	**375**	**174**	**80**	**1,416**
Broadleaved	**7**	**7**	**9**	**4**	**74**
30 km from GM facilities					
Conifers	**2,856**	**2,649**	**1,475**	**549**	**9,694**
Broadleaved	**13,605**	**13,584**	**15,004**	**4,919**	**80,301**
45 km from GM facilities					
Conifers	**8,036**	**7,750**	**4,369**	**1,632**	**28,792**
Broadleaved	**31,412**	**31,120**	**36,317**	**12,089**	**197,362**

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2.3.2 Market investigation

A second step was to investigate the local market for biomass resources by taking into account the following criteria: a) biomass resources from the Greek industry or from the nearby countries (e.g. Bulgaria), b) biomass from industries near the study area and c) biomass suitable based on the industrial plants specifications. After conducting a market research in Greece, the following conclusions are reached:

1. The market-available quantities of biomass in the country are limited; the market is quite immature and there is a limited number of industrial consumers of biomass.
2. For the targeted type of biomass fuels (**wood chips, wood saw dust and exhausted olive cake**), a mixture of suppliers will have to be used to source the required quantities.
3. Big companies operating in the industrial pellet industry use timber to manufacture their own products or to meet their industrial needs (e.g. fuel for cogeneration etc.).
4. In Northern Greece there are no pomace plants that can feed GM facilities, as most plants are located in Central or Southern Greece or on the islands.
5. The nearest commercial supplier for exhausted olive cake from GM facilities is located in a distance of approximately 240 km.
6. The available quantities of exhausted olive cake exhibit significant seasonal fluctuations, connected with the level of olive oil production. Part of the produced exhausted olive cake is used on-site by the pomace oil plants for covering their own energy demands. Changes in the technologies used by the olive oil mills in Greece (switch from three-phase to two-phase production) have also impacted the energy demands of the pomace mills, resulting in higher self-consumption of exhausted olive cake and reduced quantities available for the market. Prices commensurate with the prices and the market demands for olive oil, therefore they are subject to significant fluctuations.

The aforementioned market survey (conducted in late 2019) showed the following:

1. The required quantities for **wood chips** can be almost met by Greek and Bulgarian companies, with delivery prices ranging from **45€/t to 80€/t**. The high price range is due to the type of wood and the distance from the study area.
2. The required quantities for **wood saw dust** can be met not easily, by Greek and Bulgarian companies, with delivery prices ranging from **58€/t to 80€/t.** This price range is due to the type of wood and the distance from the study area. Moreover, many companies must make modifications to their production lines in order to meet the GM's required demands concerning the size of the fuel.
3. The required quantities for **exhausted olive cake** can be solely met by Greek companies, with delivery prices ranging from **70€/t to 100€/t**. The high price range is due to the distance from the study area. The prices, as well as the available quantities, are subject to the fluctuations concerning the olive oil production.

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2.3.3. Estimation of agricultural biomass potential

A third step was to evaluate the theoretical biomass potential of Chalkidiki by implementing statistical analysis on data provided by statistical authorities and other organizations that possess suitable data for the study. Based on this data the largest crops of this Regional Unit were the following: **a) olive plantations, b) cereals and c) fruit trees.** The olive plantations are by far the most important crops near the study area (GM facilities) (Table 2). The highest quantities of this type of biomass can be found in the Municipality of Polygyros. In order to have in depth analysis of the biomass resources deriving from olive plantations, georeferenced information was used concerning their availability on an annual basis in a selected location. The estimations are based on two biomass assessment tools.

Table 2: Theoretical agricultural biomass potential of Chalkidiki

Type	Area (ha)	Yield (wet tn/ha)	Product/ Residue Ratio (1/RPR)	Moisture (%)	Availability (%)	Available Residue (dry t/yr)	Energy (GJ/yr)
Wheat (D.)*[1]	15,736	2.03	1.00	15%	15%	4,073	55,960
Wheat (S.)*[2]	2,643	2.08	1.00	15%	15%	701	9,632
Oat	2,458	1.90	1.24	15%	15%	738	9,829
Barley	4,125	2.66	1.27	15%	15%	1,777	23,806
Rye	95	2.39	1.26	15%	15%	36	500
Cereals (V.)*[3]	747	1.87	1.15	15%	15%	205	2,789
Sunflower	288	1.58	0.50	40%	60%	82	870
Cotton	579	2.82	0.50	15%	60%	416	5,901
Maize	202	9.98	2.59	55%	60%	1,408	16,473
Olive Trees	24,388	3.95	0.98	35%	50%	30,682	325,226
Apricot Trees	1,136	8.28	2.84	40%	80%	12,825	126,707
Vines	1,015	15.97	1.20	40%	80%	9,335	102,501
Almond Trees	53	3.59	0.28	40%	80%	25	236
Walnut Trees	69	3.18	0.60	40%	80%	63	583

The first tool (BIORAISE) computes resources on the fly from user-selected points, by taking into account EUROSTAT data. This model also provides cost estimations which include pruning chipping, stocking, extraction, loading and transport of biomass to the manufacturer. The results of the first model showed that the amount of biomass deriving from **olive tree prunings**, that can fully cover GM's energy needs, can be found within a distance between 15km to 20km GM's facilities (approximately 17.5km).

The second tool, developed by CERTH GIS tool, provides more accurate estimations concerning the olive tree pruning potential in areas of interest in Greece. This tool uses highly accurate spatial information on the olive grove areas, based on the data from the CAP's beneficiaries' payment (Greek Payment Authority of Common Agricultural Policy). In order to estimate the olive tree prunings for the current study, by using this tool, GM location was set as the central point and the computations were carried out for areas within a radius of 5 km, 10 km and 15 km from the plant facilities. In the first case, the area within a radius of 5 km, the olive tree groves

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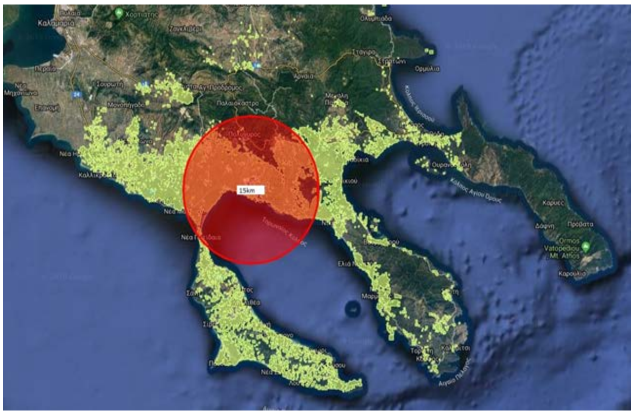
are located in the Municipalities of Ormylia and Polygyros, whereas in the case of 10km radius from GM facilities, the olive trees can be found in the Municipalities of Ormylia, Polygyros and Moudania. Finally, the area within a radius of 15 km from GM facilities includes olive tree groves of the following Municipalities: a) Ormylia, b) Polygyros, c) Moudania and d) Sithonia. According to this model, the required biomass for GM can be collected within a radius between 5km and 10km from the study area (Figure 4).



Distance from GM	Available resources (tDM/year)	Energetic content (GJ/year)
5km	8,307.7	150,369.37
10km	22,294.1	403,523.21
15km	30,601.8	553,892.58

Figure 3: Olive Tree Prunings Potential for Various Distances from GM (CERTH GIS tool)

Prior to the investigation of logistic options, it is assessed whether the tree prunings could be removed in a **sustainable manner** from the field and they can be used for energy purposes or they should be released on the soil to enhance the soil fertility. The soil management methodology included the following steps: a) assessment of soil condition, b) setting soil management strategies and c) application of the technical options that can be implemented in order to preserve soil organic matter. This methodology takes under consideration the soil conditions which are defined considering a number of indicators including soil organic matter, soil texture, soil slope and climatic conditions of the area (Table 3). Based on these, the soil conditions of the area are not optimal but still fairly good for prunings removal. **Therefore, olive tree prunings can be removed from the soil and addressed to energy purposes provided that specific management options are applied.** These options include fertilization strategies, mechanical soil processing etc.

Table 3: Soil quality indicators – Results of quality assessment of soil conditions

SCORE	SOC (%)	TEXTURE (%)	SOIL SLOPE (%)	CLIMATIC CONDITION
3	> 3.0	CLAY 10-30; SILT < 50; SAND < 50	< 5	> 30
2	1.5 - 3.0	CLAY 10-30; SILT > 50; SAND > 50	5 - 20	20 - 30
1	< 1.5	CLAY < 10 or CLAY > 30	> 20	< 20
Case of Areas Located near GM				
2.25	>2	3	3	1

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In Chalkidiki the most common practice is that the branches are manually stacked on the center of the lane between the olive tree rows. The largest branches are removed from the field in order to be used for space heating purposes. The remaining prunings are shredded into small pieces and they are left on the field in order to enhance the soil organic matter. These residues are very difficult to collect. In order to overcome this difficulty, two scenarios are examined for the collection of the prunings. **The logistics and the cost structure** are based on following options:

1. The purchase of chippers which should be fed manually and they are suitable for olive tree prunings.
2. The purchase of automated machinery (picker-up/shredder). The machine collects the residues in windrows by the frontal harvester, and then they are sent towards the chopping axle and they are pushed to the back container which can be emptied to trucks.

The first scenario includes the following steps:

1. The prunings are left on the field
2. Cleaning of the field/ shredding of prunings and depositing in a small truck
3. The truck transports the prunings directly to the GM facilities
4. GM is responsible for storage and feeding the plant with the prunings

The second scenario includes the following steps:

1. The prunings are left on the field
2. The prunings are organized in the center lane between tree rows
3. The prunings are chipped and loaded in picker-up/shredder which does not require manually feeding
4. The prunings are transported to GM facilities via a medium capacity truck
5. GM is responsible for storage and feeding of the plant

The cost structure was estimated for the aforementioned scenarios and depends on the amount of prunings that needs to be collected. The collection of large quantities requires the hiring of greater number of personnel and the purchase of more equipment. Moreover, large quantities of biomass can be collected in bigger distances and this factor increases the cost of the value chain. According to the estimations for the first scenario, the total cost of the prunings has high fluctuations depending on the required quantity of the prunings. For small quantities (1,500 $t_{,wet}$) the cost is estimated slightly over 40€/t, whereas in the case that the olive tree prunings can almost cover all the energy needs of GM, the cost increases slightly higher than 110 €/t (Figure 5).

The total cost estimated for the second scenario does not have so high fluctuations, as in the first case, although it requires that the personnel has to work more days in order to collect the required quantities. Due to the more contemporary mechanization of the collection process, the cost ranges **from 30€/t to 40€/t**, depending on the required quantities of prunings. This scenario requires a significant capital cost, 15 times higher than the capital cost that is required in the first scenario (Figure 6). Finally, for both the aforementioned scenarios, the greenhouse gas emissions savings were calculated. It is estimated that the substitution of GM's conventional fuels by olive tree prunings can reduce $CO_{2,eq}$ by 96%.

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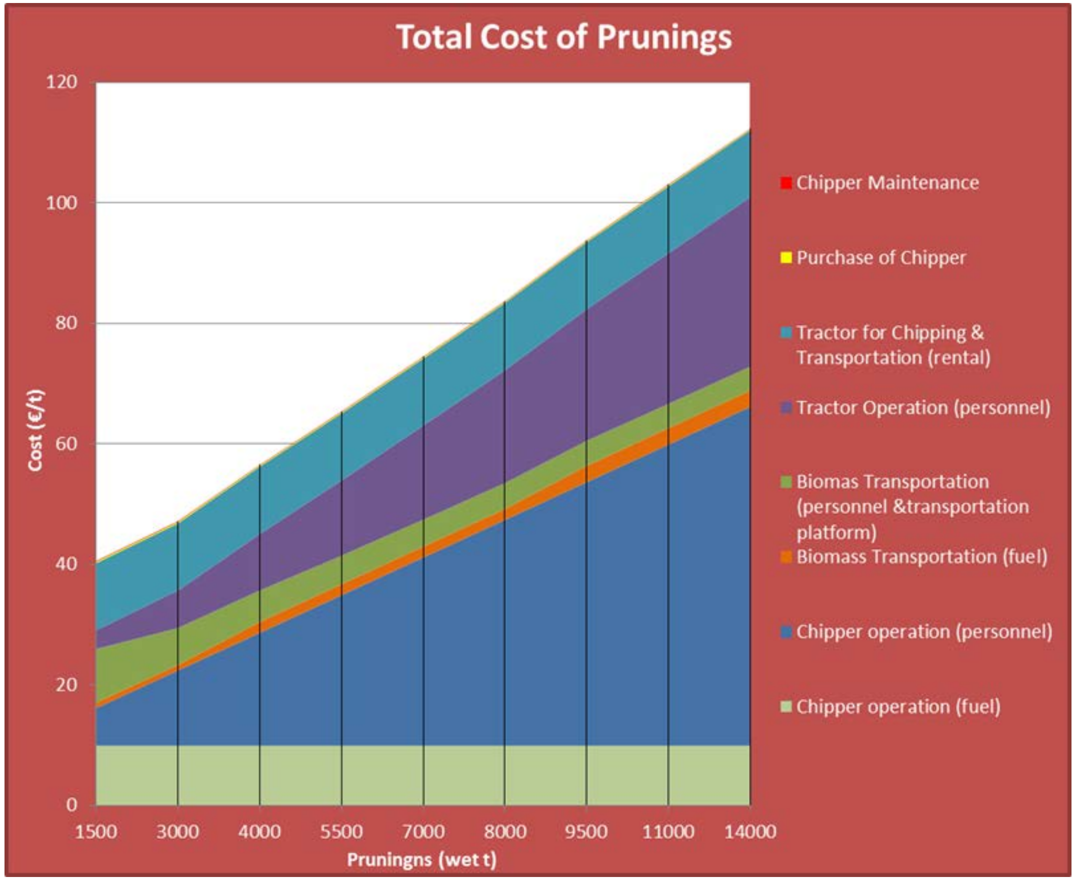

Figure 4: Total cost of prunings collection (Scenario 1)

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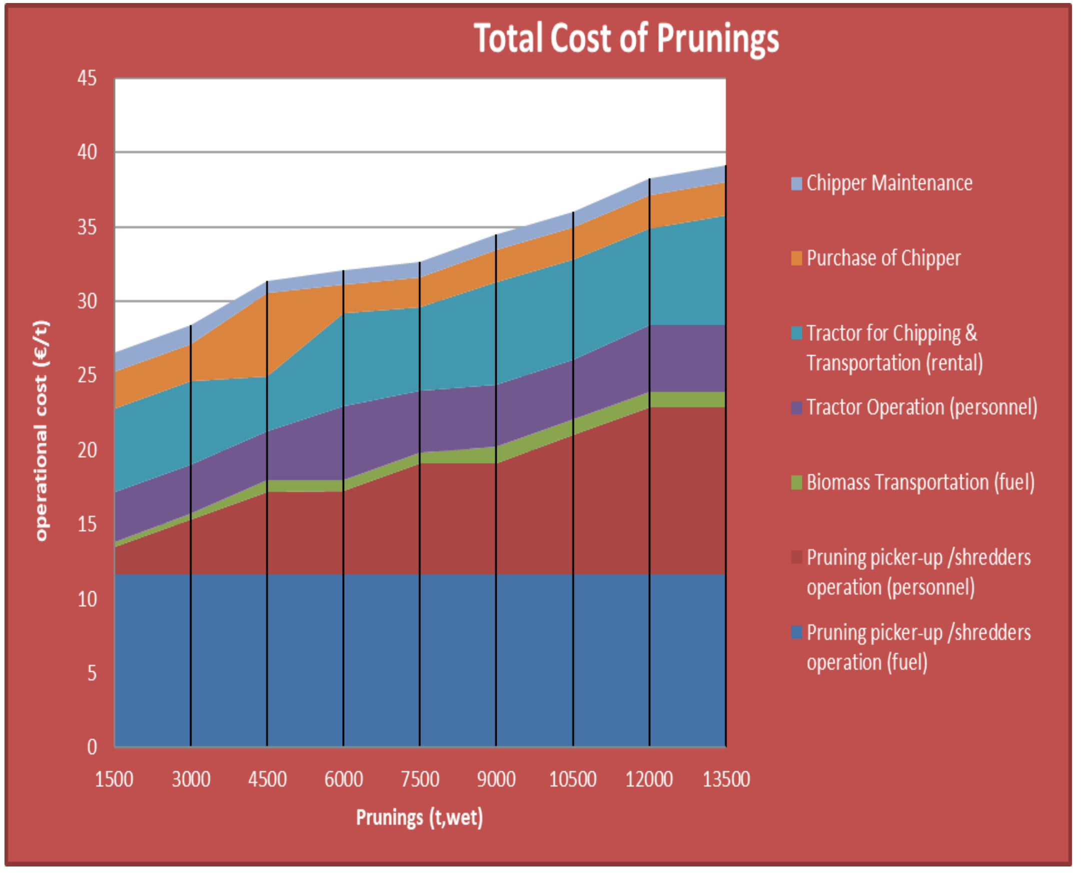

Figure 5: Total cost of prunings collection (Scenario 2)

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2.3.4 Substitution of pet coke feed with biomass

The available options for substitution of petcoke are the following: **a) wood saw dust and b) exhausted olive cake**. Wood saw dust can be available all year long in contrast to exhausted olive cake that is produced in specific time periods. Moreover, wood saw dust has significantly lower size, which can assist in the flame stability. In addition, exhausted olive cake is widely used in olive oil pomace plants to cover their energy needs, thus there are limited available quantities near GM facilities. Another critical factor is that the price of olive cake in most cases is higher and subject to fluctuations as it depends on the market demands of olive oil. On the contrary, olive cake has higher energy content, thus lower quantities are required for the substitution of the already used fuel. Therefore, the **following scenarios** are examined based on the various substitution ratios of pet coke with the aforementioned types of biomass:

a) 100% wood saw dust (WSD) – 0% exhausted olive cake (EOC),

b) 75% WSD – 25% EOC,

c) 50% WSD – 50% EOC,

d) 25% WSD – 75% EOC and

e) 0% WSD – 100% EOC.

These scenarios are based on the substitution of petcoke with biomass proportions from 5% to 50%. The costs of the scenarios for the substitution of pet coke with biomass, delivered at GM facilities, are depicted on Figure 7. **Based on the aforementioned, the best option for the substitution of 30% pet coke, which mainly interests GM currently, is by using 50% wood saw dust and 50% exhausted olive cake as it less expensive than the other options.** Finally, the aforementioned mixture presents good fuel properties.

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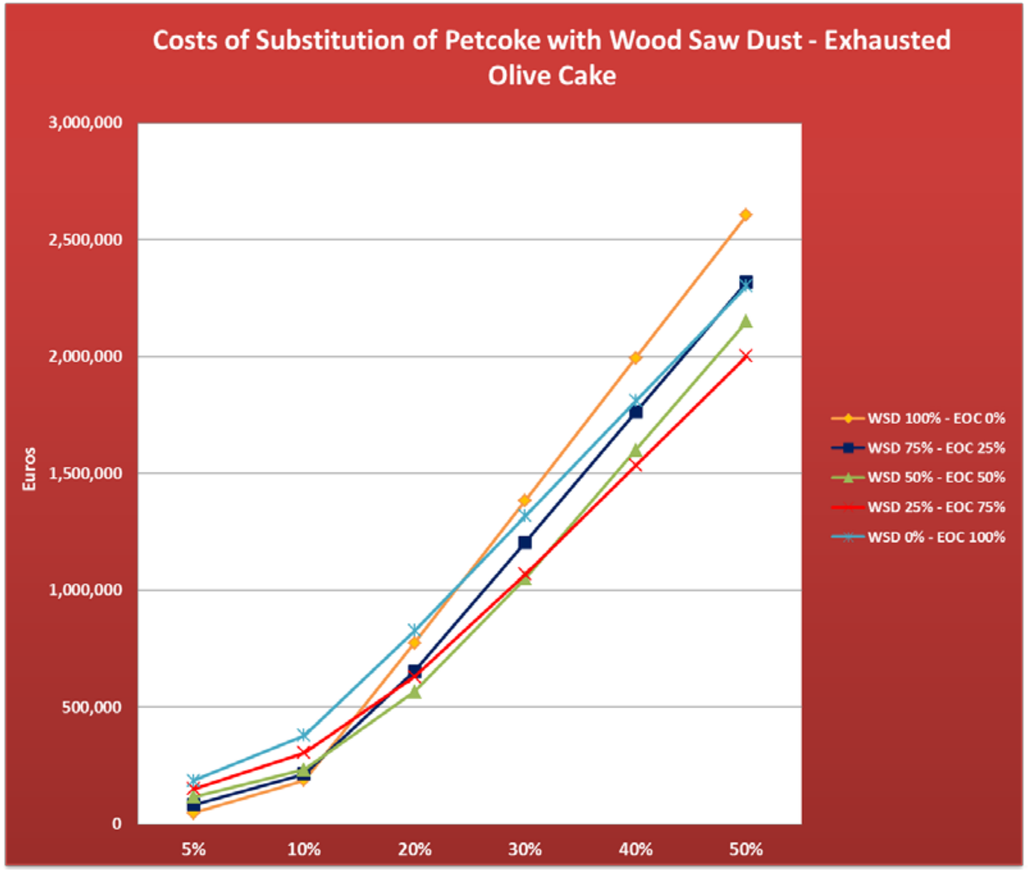

Figure 6: Costs of substitution of petcoke with mixtures of wood saw dust-exhausted olive cake

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2.3.5. Use of wood chips – olive tree prunings as feedstock with magnesite

The available options that can be used as feedstock in parallel with magnesite are: a**) wood chips and b) olive tree prunings**. Wood chips can be available all year long in contrast to olive tree prunings which are logged in specific time periods and thus they require storage in GM facilities. Moreover, both these fuels have the suitable size required by GM's specifications. On the other hand, wood chips are already available for feeding, whereas the collection of olive tree prunings require investments and a well-organized biomass supply chain. Although the olive tree prunings potential is high for the study area, the capital and the operating cost of the supply chains can be an aversive factor for the purchase of a large number of machinery. In the case of the olive tree prunings collection, two scenarios were investigated:

a) supply chain based on the purchase of wood chippers (scenario 1) and

b) supply chain based on the purchase of automated picker-up shredders (scenario 2).

Moreover, the following scenarios are examined based on the various feedstocks types of biomass:

a) 100% wood chips (WC) – 0% olive tree prunings (OLP),

b) 75% WC – 25% OLP,

c) 50% WC – 50% OLP,

d) 25% WC – 75% OLP and

e) 0% WC – 100% OLP.

The costs of these scenarios concerning the delivery prices of biomass at GM's facilities, are depicted on the following figures, where index 1 refers to the purchase of wood chippers and index 2 refers to the purchase of automated picker-up/shredders**.** For this case, the substitution of petcoke is scheduled to start at 2% in weight of magnesite and it is expected to increase up to 8%. The optimal scenario is to purchase a large number of automated picker-up/shredder machines**, as the feeding solely from olive tree prunings is the option with the lower cost**. In addition, the organization of supply chains require good communication with the active Cooperative of the area and high capital costs for the purchase of these machinery. In the present situation, this means that the fuel mixture must include higher amount of wood chips. In the case of fuel mixture of 75% WC – 25% OLP, both scenarios for the collection of olive tree prunings have approximately the same cost. Finally, this mixture has better fuel properties.

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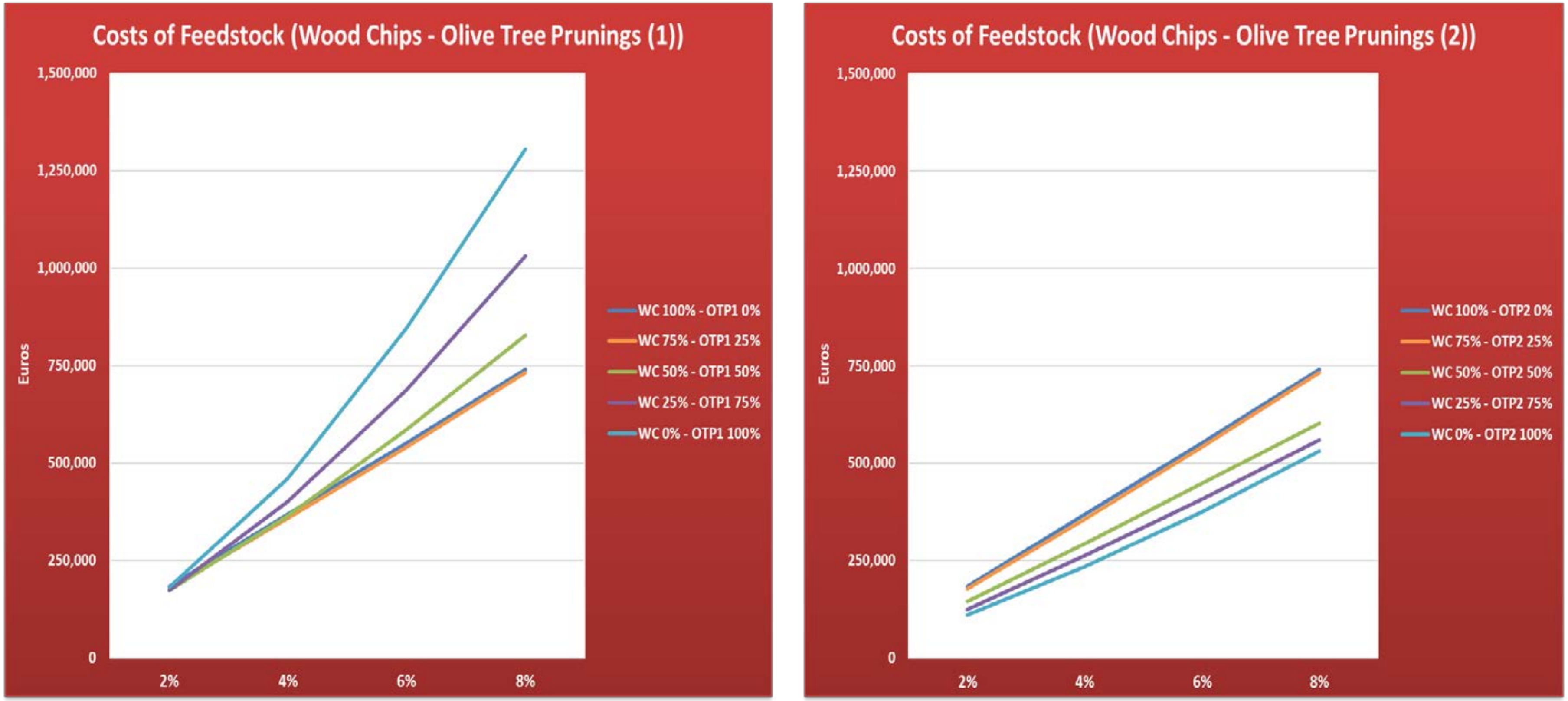

Figure 8: Costs of feedstock mixtures of wood chips - olive tree prunings for the examined scenarios

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2.3.6 Biomass Characteristics

A full characterization of the properties of the proposed fuels were conducted, including proximate and ultimate analysis, minor and major element analysis, ash melting behaviour, particle size distribution and calorific value determination. As it was expected all the proposed fuels have significantly lower S ($\%_{,\text{dry basis}}$) and N ($\%_{,\text{dry basis}}$) content than the ones already used. Moreover, depending on the fuel, the aerosol emissions can be characterized from low to high. Furthermore, all the proposed fuels are having high risk of corrosion appearance on the surface of the boilers or heat exchangers. Finally, all of the proposed fuels have high tendency for the formation of deposits due to low Rs indexes (Table 4).

Table 4: Fuel specific indices (Sommersacher et al., 2012)

Fuel Indexes						
Type of Fuel	**N**	**S**	**Sum of K, Pb, Na,Zn**	**Molar 2S/Cl**	**Si/(Ca+Mg) Ratio**	**Rs Index (slagging index)**
Wood Chips	**4-6 times < petcoke**	**102 times < petcoke**	**1,050 mg/kg Medium aerosol emissions**	**1.34 corrosion risks**	**0.15: sintering temperature > 1,100 °C**	**1,164 high tendency in the formation of deposits**
Wood Saw Dust	**14 times < petcoke**	**116 times < petcoke**	**533 mg/kg Low aerosol emissions**	**1.54 corrosion risks**	**0.51: sintering temperature > 1,100 °C**	**1,092 very high tendency in the formation of deposits**
Exhausted Olive Cake	**~ equal to petcoke**	**19 times < petcoke**	**9,675 mg/kg Medium aerosol emissions**	**3.2 corrosion risks**	**0.2: sintering temperature >1,100 °C**	**875 very high tendency in the formation of deposits**
Olive Tree Prunings	**2 times < petcoke**	**64 times < petcoke**	**149 mg/kg High aerosol emissions**	**2.865 corrosion risks**	**1.22: sintering temperature <1,100 °C**	**876 very high tendency in the formation of deposits**

2.4 Conclusions and further steps

In the present work a number of factors were studied in order to evaluate the resources for the use of biomass as a fuel in GM's plant. First of all, based on the specifications provided by GM, market research was conducted both in Greece and in the adjacent countries. The research showed that for the requested quantities of biomass that can substitute the current conventional fuels, companies from Greece and Bulgaria can cover GM's needs. Greece in general lacks high quantities of biomass; therefore, each type of biomass can be supplied by more than one company to GM. The fuels that can substitute the ones already used are the following:

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1. Wood saw dust than can replace an amount of petcoke in the plant's burner
2. Exhausted olive cake for the substitution of petcoke in the plant's burner
3. Wood chips or olive prunings feeding along with the magnesite at the kiln

Apart from the market research, other biomass sources that may be fed to GM were also estimated. The first option concerned forest biomass that can be collected from nearby forests. In the case of Chalkidiki and more specifically near GM's facilities there are limited quantities of biomass. Although this is not the only decisive factor in order to reject the option of forest biomass. In Greece, forest activities are hindered due to the terrain, the lack of contemporary mechanization and the limited workforce. Another factor that makes the project even more difficult is the great scattering of the residues in the forests. This is due to the forest management plans that permit the logging of tree tufts, which in most cases are significantly scattered. Last but not least, the quantities of the available log wood per year are not stable, which means that this option for feeding GM's plant on a constant basis should be discarded.

A second option was to estimate the availability of biomass from agricultural resources that can be found in the Regional Unit of Chalkidiki. The estimations were based on statistical analysis methods, which showed that the most important biomass sources for the specific area are the following: **a) olive trees, b) apricot trees and c) vines. Olive trees can produce the highest quantities of biomass in the Regional Unit.** Furthermore, olive trees in the Municipality, where GM facilities are located, have the highest biomass potential when compared to the other crops. The majority of both the apricot trees and the vines are located in a significantly longer distance from GM facilities than the olive trees. As a matter of fact, GM facilities are literally surrounded by olive trees and thus this type of biomass seems a very promising option.

In order to have a better estimation of the biomass quantities (olive tree prunings) that can be collected, tools that provide information based on georeferenced data were implemented. The results showed that the required olive tree prunings can be collected within a radius between 5 to 10 km from GM's facilities. Subsequently, a number of factors concerning the decision to remove the prunings from field were assessed and it is concluded this action may take place, only if specific soil treatment options are implemented. Based on these facts, two scenarios for the collection of olive tree prunings were proposed and simplified logistic model options were investigated. The implementation of both these scenarios require good communication and cooperation with the Cooperative which is active in the area and capital costs will depend on the amount of the prunings that will be collected. Moreover, fuel characterization concerning the proposed types of biomass were conducted and compared to the fuels already used in the plant. The chemical analysis showed that all the proposed fuels can assist GM to achieve its goals of reducing the plant's emissions (CO_2, NO_x, SO_x). Based on the aforementioned, alternative scenarios are proposed, concerning the substitution of the pet coke and magnesite with the fuels investigated in the present study.

In addition, further actions need to be taken, in order to evaluate the substitution of the conventional fuels with those proposed in this study. As sintering, which is the core process in magnesite production, takes place at high temperatures (between 1500 - 2000ºC) which are related with the quality of the product and NOx emissions, it is necessary to find a compromise between high temperature and the reduction of pollutant formation. Moreover, the exact composition and quality of final product is very variable, and it depends on the mixture of raw materials and temperature. Therefore, it is crucial to control accurately the power, shape and size of the flame in order to increase flexibility of the process. Thus, a full size burner (~20MWth) will be adapted for the proposed fuels simultaneously, in task 5.4, in order to achieve reduction of NO_x and SO_2.

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Furthermore, in task 5.5, CFD simulations of the rotary kiln at GM plant will be carried out with the purpose to determine: a) the optimum types of biomass proposed in this study and b) the substitution rate of the current fossil fuel. In addition, analysis of NOx emissions will be estimated, when the selected burner is installed in the kiln. Likewise, CO_2 emissions and pollutants formation (mainly NOx) will be studied before and after the substitution of the current fuels with biomass. The results of the simulations will be used to define the conditions to be tested at GM's furnace.

Finally, demonstration activities of combustion at GM's furnace will be carried out, in task 10.2, in order to investigate the operation of the burner proposed by CFD simulations. This experimental campaign in the selected kiln will determine the suitability of low-NOx burner and the proposed biomass, which will be used to substitute the current coke fuel, while monitoring the key indicators: flexibility, quality of combustion and of production, saving costs and reducing pollutant emissions. During these trials, the accessible temperatures, the quality of the product and the flue gas composition (O_2, CO, CO_2, SO_x, and NOx) will be used to assess the performance of co-combustion and the low-NO_x burner.

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3 CASE STUDY 2 - USE OF BIOMASS AT MAGNA (SPAIN)

3.1 The interest to switch from fossil to renewable

Magnesitas Navarras (MAGNA) is a worldwide reference company producer of magnesium oxide based solutions and materials for the steel, agricultural and environmental industries. As a mining and industrial company, it is dedicated to the extraction and treatment of magnesite in its facilities since 1945. The company, which belongs to the Roullier multinational group, has a strong export vocation, with its products (magnesite and its derivatives, including magnesium oxide, magnesium hydroxide, calcined dolomite and refractory masses) present in more than 60 countries.

With an annual production of 260,000 Tm/year of magnesites, the production process at Navarra's facilities includes various stages: (1) extraction of raw materials from the mine, (2) transportation to the factory of Zubiri, (3) enrichment of the magnesium carbonate, and (4) calcination and/or sintering of the magnesium carbonate and dolomite in a rotary kiln to obtain Magnesium Oxide. Depending on the operating temperature of the kiln, different products are obtained: Sintered or Dead Burned Magnesite (DBM), which is processed at more than 1800ºC, or Caustic Calcined Magnesite (CCM), processed at more than 1300ºC.

Figure 7: Magnesitas Navarras S.A. (MAGNA) facilities at the Esteribar Valley

MAGNA's production process is very intensive in energy, and the principal fuel utilised in the calcination kilns is petcoke. This solid fuel provides a stable combustion, facilitates an adequate temperature profile in the kiln, and allows reaching high temperatures necessary to obtain high quality products.

The interest in biomass stems from MAGNAs' Social Corporate Responsibility (SCR). Magnesitas Navarras practices a solid SCR, with annual plans and indicators, devoted to develop the

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company activity in a responsible manner, according to the highest ethical standards. As a company, it aspires to lead the process of change towards sustainable mining, advocating full integration in the environment and contributing to biodiversity and the protection of ecological values that converge in the area where it operates (specially municipalities of Esteríbar, Erro and Batzan). The SCR is implemented at MAGNA through four axis of compromise, as presented in Figure 10.

Figure 8: Social Corporate Responsibility – SCR of Magnesitas de Navarra (MAGNA)

Among the objectives of MAGNAs' SCR, it is of relevance the aim to prevent, mitigate, compensate and restore the possible negative impacts derived from its activity in the environment whilst increasing the value contributed by MAGNA to the area as an industrial and driving force of the valleys, creating positive environmental impacts and in connection and collaboration with the community.

In this line, biomass is a renewable energy resource that could contribute to MAGNA's SCR. Using local biomass addresses the 4 compromise pillars of MAGNA's SCR. Specially biomass is a source of energy that contributes to a more efficient and renewable production, with the additional benefits for the local community of a new added value for local underutilised resources and the promotion of new economic activities. It also supports the circular economy, since facilitates a clean and environmental sound valorisation of resources that otherwise would not have been utilised. Finally, it contributes to the sustainability by reducing the consumption of fossil fuels (petcoke) and the associated global GHG emissions.

Reducing GHG emissions is therefore in line with MAGNA's compromise with the environment and the sustainability, with a more stable and carbon-neutral operation.

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3.2 The challenge

Reducing the CO_2 emissions is a target of Europe towards 2050, where a full decarbonisation of the European Economy is planned. This target entails a challenge for Energy Intensive Industries like iron, cement, chemical, petrochemical, glass industries, or, as the case of MAGNA, the magnesites producing facilities. Switching from traditional fossil-fuel based production towards a more decarbonised production can be faced through diverse strategies like shifting to more clean processes, incorporating circularity and zero-waste priorities, increasing the use of renewable energy, or integrating carbon capture with storage and utilisation of CO_2.

Adopting biomass as a secondary fuel, with an increasing participation in MAGNA's energy share, involves a series of challenges, as mentioned next:

- Obtaining sufficient biomass to start a transition towards a partial decarbonisation in the short term
- Identify strategies for biomass sourcing from local available and underutilised biomass resources and by-products with capacity to create a positive impact in terms of local value and positive environmental impact
- Organise a supply chain able to provide the biomass with adequate quality and logistics costs, whilst synergising with the interest of existing local actors to be involved
- Perform a simple, sound and effective integration of biomass utilisation at MAGNA's plant
- Achieve an operation with a growing share of biomass whilst preserving the operational efficiency and maintenance costs, preserving the lifetime of the kiln and downstream equipment
- Identify niches for promoting new projects of technology innovation for a more sustainable production in the path towards decarbonisation, as well as social innovation opportunities linked to the biomass supply

The work developed by MAGNA and CIRCE in the framework of BAMBOO Task 2.4 has focussed in providing answers and counsels to these challenges.

3.3 Prospecting the industrial use of biomass at MAGNA facilities

3.3.1 Challenges in adopting biomass

The conditions to adopt biomass at MAGNA have been revised. The principal issues relevant for biomass adoption, and that may imply a challenge are:

- Safe operation of the kiln, with efficient and complete combustion of the biomass, and limited effects of kiln corrosion of creation of slags and deposits on kiln and preheaters surfaces
- Preserving quality of the product, with absence of unburnt biomass and:

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- For animal feeding Caustic Calcined Magnesite (CCM) must ensure absence of heavy metals
- For Sintered or Dead Burned Magnesite (DBM), silica, phosphorus and sodium can also affect negatively on the density of the final product for refractory materials

- Ensure no cross-contamination of the CCM and DBM, therefore ensuring that biomass particles are not introduced in the final product due to inadequate practices during storage and handling of biomass at MAGNA facilities
- Finding the adequate methods for biomass storage and handling at MAGNAs' plant, in the existing facilities, and involving existing spaces, facilities and machinery
- Be cost competitive in respect of petcoke costs and CO_2 allowance prices

3.3.2 Biomass sourcing

Residual biomass from agricultural and forestry ecosystems

The resources that have been object of identification are:

- Agricultural residues:
  - From annual crops: straw and maize /sunflower stalks from rainfed and irrigated lands
  - From orchards / permanent crops: vineyard, fruit and olive tree pruning wood
- Forestry residues: tree tops and branches produced in timber exploitations and silvicultural works in forests of broadleaved, evergreen and mixed forests

The online Bioraise tool (http://bioraise.ciemat.es/Bioraise) has been used as a data source for this purpose.

The biomass assessment has been performed in an area of proximity of 100 km, by means of an analysis by circular areas with a growing distance of 10 km (See Figure 11).

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Figure 9. Location of MAGNA Plant and 10 to 100 km distance area of study utilized for the assessment of biomass in the nearness.

The results obtained from Bioraise are summarised in Figure 12. This potential considers the whole biomass production in the area, from agricultural and forestry eco-systems. It corresponds to a total theoretical potential, and does not discount the biomass already in use, which price or supply costs may be too high, or that should be preserved due to its multifunctional value (environmental or social considerations). The principal value of this tool is to obtain an initial outlook of the prevailing biomass resources that can be strategic, in order to focus the initial supply strategy.

Regarding agricultural biomass, approximately 90% of this resource corresponds to cereal straw (from rainfed areas principally) whereas the amount of other agricultural resources such as vineyard pruning, rice straw, fruit plantation and olive prunings is almost negligible for distances below 40 km. Bioraise estimations indicate that the amount of these resources available in a radius of 100 km is around 11.000 ton/year. Due to the widespread and the limited relevance, this biomass type could contribute partly to MAGNA strategy, though cannot be considered a strategic biomass resource.

As for forestry biomass, Bioraise evaluates only the residual forestry biomass, that is, branches and tree tops left after the silvicultural works. Timber wood is not included in the assessment given the fact that in principle wood finds a higher value in other markets like construction, furniture, boards etc. Figure 12 illustrates that forestry residues around MAGNA plant are the most relevant potential source of biomass in the vicinity (10 km radius). When the area of study is extended, forestry residues become half of the potential, as large areas of agricultural biomass are then included.

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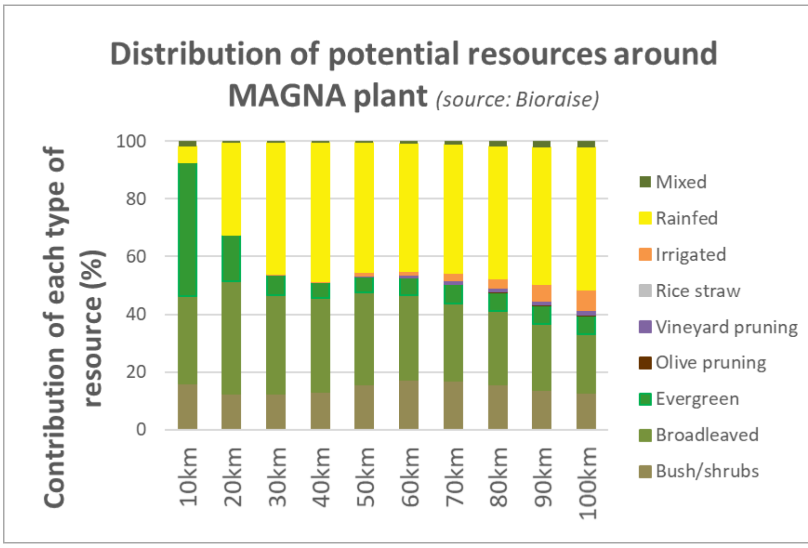

Potential biomass around MAGNA plant (expressed as tons of dry matter)			
Distance from MAGNA	Agricultural biomass	Forest biomass	TOTAL
10km	501	11,126	11,628
20km	16,786	42,206	58,992
30km	65,345	87,520	152,865
40km	127,064	152,497	279,561
50km	185,121	246,108	431,229
60km	263,088	350,639	613,726
70km	365,112	457,459	822,570
80km	490,606	562,047	1,052,653
90km	676,918	654,540	1,331,458
100km	921,675	752,393	1,674,068

Figure 10. Potential biomass (tons of dry material per year) available around MAGNA plant (Source: Bioraise) and its distribution by resource.

As summary, the principal biomass that can be strategic for establishing a new supply are **straw and forestry residues**. There is already a market for straw, and it is expected that not more than 50% of this resource is available. Being most of straw produced in rainfed conditions, and due to the interannual variability in rains and the more prone periods of droughts, the resource may be even object of shortage in some years. Therefore, its use may be considered complementary for MAGNA, in some years of abundance, whereas the principal supply may be based in other resources.

In respect to forestry residues, they are currently available, with non-existing competitive use. However, there is no current supply established and therefore they are not a resource applicable for a short term utilisation. Mobilisation of forestry residues require the adaptation of the technical specifications for forestry exploitation, and a dialogue between foresters, forestry managers, timber and environmental service companies. Furthermore, not all the residues may be easily mobilised. And some forestry areas may discourage the exploitation due to access, orography, or other environmental considerations (protected areas, prevention of erosion, among others).

Alternative biomass for a supply in the short term

Establishing an initial consumption of biomass at MAGNA shall rely on biomass resources with a stable market and options for a diversified sourcing. Beyond of the biomass woodchips from log wood, there are in Spain alternative options from agroindustrial by-products such as **olive pomace, grapewine pomace, almond shell, sawdust, or grape seed flour**. These by-products are essentially not modified (come through physical operations), and are available in the market currently. The market is sufficiently large so that a new consumption of several tenths of tons can be covered without distorting the current biomass market.

An advantage of the mentioned feedstock is the fact that they are usually available dry (moisture lower than 15%) and in granulated form. Both characteristics are desirable, and reduce the need of pretreatment, which would be limited to a refining milling, if the biomass is

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supplied in the right conditions. Furthermore, the current market prices are lower than for woodchips (50 – 70 €/t of irregular and moist woodchips), as for example: olive pomace ranging 30 – 40 €/t with moisture lower than 15% (at plant gate), almond shells ranging 55 – 70 €/t at 15% moisture, or grape seed flour ranging 65 – 85 €/t (with moisture of 15%).

As a drawback, these agroindustry by-products have a higher content of inorganics (ash forming elements), chlorine, phosphorus and alkali, which may have undesired effects in the quality of MAGNA's final products, or which may affect the operational performance or maintenance costs of the kiln and other devices downstream. A second drawback is the fact that the characteristics of the agroresidues are dependent on the agroindustry and therefore are more susceptible to inhomogeneity. Finally, some of these by-products are considered as residue, as for example, olive pomace from olive pomace mills undergo a chemical extraction of oil with hexane. Therefore, they may be subjected to classification as residues depending upon the regulations in place, which vary from region to region.

Relevant biomass for procurement to MAGNA

Biomass to be considered for the short term are agroindustry residues, **especially olive pomace, almond shells and grape seed flour**. As other resources that may diversify the supply of woodchips as a fuel of good quality, straw as a biomass resource can be relevant as secondary fuel due its availability and existing supply chains. Both biomasses may require the establishment of a Biomass Logistic Centre to store (inter-seasonal), handle and pre-treat the biomass. Additionally, forestry residues are a resource to be explored for the diversification of the supply in the medium term, and contributing the most to the environmental and social compromises of MAGNA.

3.3.3 Biomass logistics

Principal considerations to organise the supply

The possibilities of MAGNA to organise a biomass logistic yard at their facilities is limited. Principally it is due to the fact that the raw material and final product storage areas are already well occupied. And secondly from the fact that the space for an inter-seasonal storage and handling of biomass might increase the risks of cross-contamination of the raw materials and final product with biomass particles.

Therefore, the most adequate strategy is the organisation of spaces to facilitate a short storage with capacity to cover the biomass supply during a short period, for example 2 days. Biomass, with low moisture and adequate particle size (in form of milled biomass, with average particle size of 3 mm) is to be fed to the burners. Therefore, the locations at the plant should be placed under cover, and separated from final products and critical raw materials to avoid cross contamination. The work performed has allowed to identify the zones where biomass storage can be placed to supply the biomass to a hopper connected to the pneumatic line conveying the fine solid fuel to the burner (either the primary, or alternatively the secondary).

Biomass could be received already in the appropriate form, with a refine milling, to ensure the properties in particle size and moisture. However, it is advisable to include by default a refining mill between the hopper and the pneumatic system. This brings MAGNA more flexibility in the type of biomass acceptable at plant gate, and reduces the risks of blockage or inefficient combustion in case a batch is wrongly accepted and fed.

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The "in plant" logistics for the material inside MAGNA's plant for start-up operation are advised to be based on existing facilities, spaces and devices. Therefore, the hoppers can be initially be fed by means of wheel loaders. However, once established a continuous use of biomass, it is recommended to foresee some improvements as:

1) Specific biomass storage sites of easy discharge for trucks, as could be bunkers / biomass pits
2) Conveyors of biomass from storage sites to biomass hoppers, to avoid the continuous driving of a wheel loaders
3) Foresee re-structure of some areas in case of intending to feed other biomass types in other form like straw bales (not granulated or powder format), since then a small (but not negligible area (e.g. 500 m^2) would be necessary for the reception, discharge, treatment and storage.

The logistics of biomass from the supplier to MAGNA's plant gate can be organised according to two different options:

1) through a biomass supplier company or energy service company, which establishes a Biomass Logistic Centre (BLC). This option is compatible with all biomass types mentioned.
2) through direct supply from the biomass provider. This option only is possible for biomass types that can be supplied already refined, or in an adequate form, so that the final treatment can be integrated as part of the feeding line to the hoppers connected to the pneumatic lines: therefore moist bulk biomass like forestry residues cannot be considered. In case of woodchips only those already with low moisture which could be object of further processing (shredding and milling)

Accordingly, the options for the biomass supply have been studied and facilitated to MAGNA, for their better understanding and decision making upon the best supply strategy.

Establishing a supply with or without a Biomass Logistic Centre - BLC

Organising the biomass supply through a Biomass Logistic Centre (BLC) presents several advantages like: facilitates the storage of a huge amount of biomass in order to guarantee stability of supply to MAGNA, takes advantage of the inter-seasonal periods of lower prices, carries out the pre-treatment required to guarantee the quality of the product, performs treatments necessary to those biomass types or batches which require it, performs a refining operation prior the delivery of biomass to MAGNA, and reduces the intensity of efforts by MAGNA to coordinate the supply with multiple biomass providers. On the other hand, the disadvantage is related to an increased cost of the biomass and the dependence on the operation of a single actor.

The location of such BLC is envisaged to be in the nearness of the plant (10-20 km maximum) and have environmental conditions to allow the natural drying or the storage on the open air of the biomass. Open areas, not in the basin of closed valleys nearby rivers, are adequate. This fact avoids increase of the biomass moisture and degradation. Establishing a supply through a BLC could even allow an operation at MAGNA's plant without need of refining mills.

Considering all the operational costs, it can be foreseen that the operation of the logistics yard could increase the biomass costs up to 15 €/t. The refining milling could increase the costs up to 7 €/t extra. These costs consider the BLC operation in industrial facilities of a logistic operator,

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residues retailer or authorised scrap manager already counting with permits, several means and settled in the area.

Without a BLC, MAGNA should take care of organising the supply along the whole year. The purchased biomass would be delivered directly to MAGNA´s facility, where it should be downloaded and stored in the storage areas available by MAGNA. The transport of biomass would be carried preferably in large trucks, to reduce the transportation costs from long distances (as olive pomace, almond shells and grape seed flower are obtained from suppliers of other regions). Additionally, for extending the biomass use from granulated biomass (olive pomace, almond shells or grape seed flour) to other types (straw or log wood) MAGNA should reorganise spaces to install the pre-treatment operations before the hopper and the refining mill. Given the fact that the storage capacity foreseen at MAGNA is of maximum 48 h, settling this system entails several risks like:

(i) variation in quality, and possibility to accept batches of insufficient quality;
(ii) no possibility to mix or handle the batches at MAGNA, since the supply is organised without a pretreatment yard, only small storage site, hopper and refining milling;
(iii) high efforts in coordinating just-in-time delivery of the biomass along the year in contact with multiple providers;
(iv) higher risk of supply break.

The principal advantage for MAGNA is the reduction of costs in respect the operation with a BLC. In average a reduction of costs of 12 €/t could be expected.

Notwithstanding other conditions that may counsel MAGNA to adopt one or other supply scheme, the strategy suggested to MAGNA as the best alternative for the biomass supply is the establishment of a BLC. This could be placed in an area in the vicinity thus being in line with the intent to promote economic growth and opportunities for the local community.

Establishing the supply for forestry residues

Biomass from forestry residues is an alternative that may be relevant in the medium and long term, given the important available resources, and the economic and environmental values involved for the local community: using these residues could complement the current forestry exploitation in the areas nearby; it would solve the current situation of forestry residues, which are abandoned on the forest, have no use, and may be a source of pest proliferation and in certain stages contribute to a more dangerous and fast advance of the flames in case of a forest fire take place.

Forestry residues analysis was concentrated in two principal municipalities: Esteribar and Erro. The forestry residues potential has been estimated through Bioraise tool (http://bioraise.ciemat.es/Bioraise) to have a first hint (not a final assessment) of the amount and relevance of these resources may represent for MAGNA's interests. Results are presented next in Table 5.

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Table 5. Forest residual biomass considered to be exploitable (tons of dry material per year) in Esteribar and Erro municipalities (Source: Bioraise).

Zone	Forestry residual biomass		
	Area (ha)	% not exploitable (slope)	Available biomass (t DM / yr)
Esteribar	10,819	40.4	3,658
Erro	8,993	47.9	3,874
TOTAL	19,812	43.9	7,532

t DM: tons of biomass expressed as dry matter

Bioraise tool indicates that a total of 7,532 t/year (dry matter) could be exploited annually, and already discard as exploitable, areas that: are not easily exploitable due to slope, areas subjected to erosion and areas where biomass should be preserved as organic input for soils. The results of exploitable potentials are principally constrained by the factor of slopes. Otherwise the potential would be close to a theoretical ceiling of 17,000 t/yr (dry matter).

These values of the theoretical and exploitable biomass have been utilised to have a first idea of the amount of the forestry residues relevance in the area. However, for the purpose of a real exploitable amount of biomass, other factors are relevant, as the accessibility through roads, forest tracks and trails, and their adequacy to haul / extract the forestry residues, which present other added difficulties in respect to timber wood. As well the interest to collaborate and facilitate the conditions by all actors involved.

In order to go beyond Bioraise, the forest masses in the area have been object of identification, to gather data on their size, slope, nature (public or private ownership) and the current forest management.

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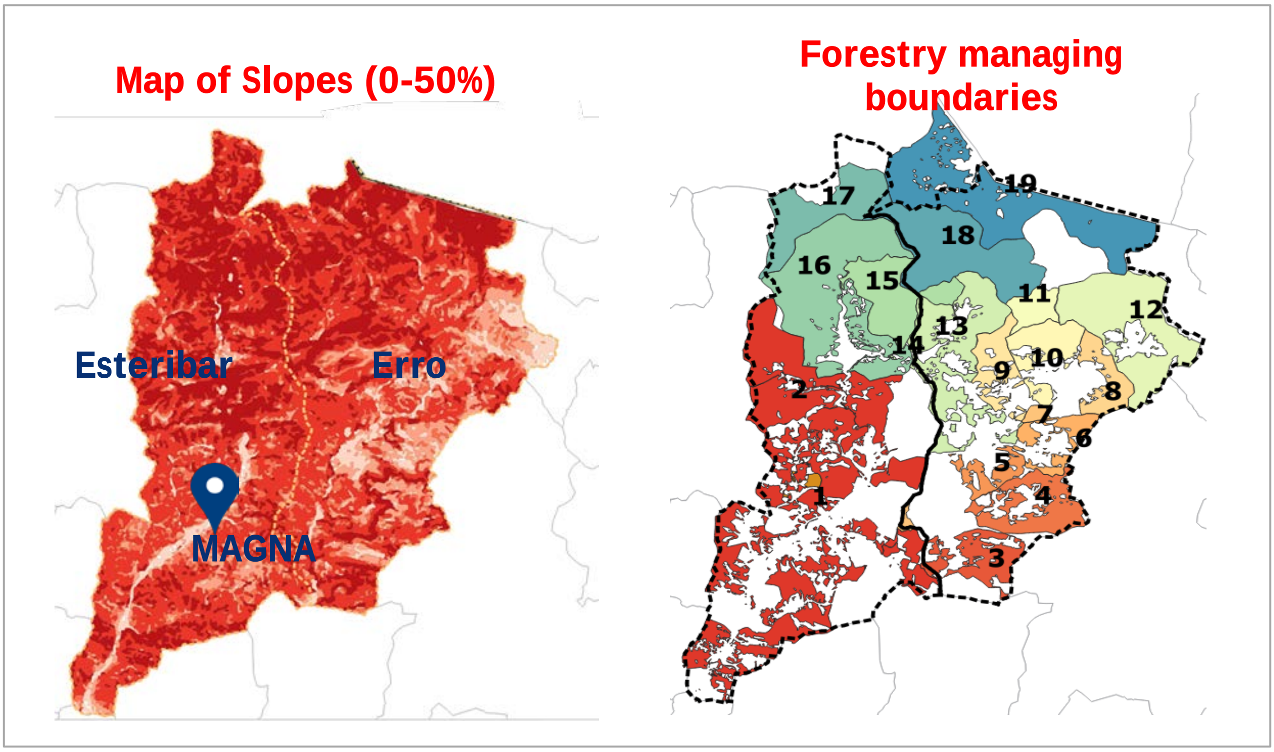

Figure 11. Map of Esteríbar and Erro municipalities. LEFT: slopes. RIGHT: boundaries of forestry management.

According to Figure 13 it is observed the difficult orography specially in the north of Erro and Esteribar municipalities. If depicted by forestry management boundaries (forestry manager or organisation responsible on the administrative management of the forests), then a total of 19 forestry areas are distinguished, as depicted in Figure 13. The forests placed in areas of lower slope are those principally sited in the south, and with code number between 1 and 12 summing circa 51% of the total forestry area. Among them all are public forests, except Nr 1 (small spot of a private forest). Most of the forests already count on with a PEFC certification. Forest Nr2 is specially of interest due to the large size grouped under a single administrator and its less complicated terrain. Rest of Forests (Nr3 to Nr12) are smaller in size, ranging from 200-700 ha.

The question to solve in respect to the forestry residues is how to perform the haulage outside the forest, or how to enter in the forest stand to gather the residues efficiently. The feasible practices are in principle those where the forestry residues are directly accessible at the forest stand after the treatment. This access if possible when a clearcut is performed as method in the regeneration works (all the forest stand is felled, and therefore mechanical means can enter easily after the timber extraction).

On the contrary, residues produced after exploitation of highgrading are not easily accessible. The reason is that only a set of trees are felled. Trees are delimbed in situ, and then the stem dragged out the forest stand till the forest track from where it is pulled with a wire. The residues remain next to the zone where every tree has been felled, and therefore, with the current structure of roads, tracks and trails they are not accessible. Highgrading could be applicable if the whole tree is dragged with the wire to the forest track side, and then delimbed

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(residues would be available at forest track side). However, the applicability is subject of several concerns like damages to other trees given the volume of the felled trees (which are selected for timber by its size). The possibility is to be discussed with each forestry manager, though for the present work is not considered an applicable option.

An alternative source of forestry biomass are the thinnings. Thinning operations are performed from early state of the forest, when a high density of small trees reach the canopy closure, till the final cut (regeneration cuts). Thinnings are silvicultural operations aimed to reduce the density of the forest stands by removing the smaller, weaker and poorer quality trees, to facilitate the growth of the trees remaining. Thinning is normally carried out several times during the rotation. The methods currently applied are similar to those applied for highgrading, with the difference that the whole trees are left without treatment when their diameter is small. Wood is only extracted in form of shortcut wood for firewood or industry (in pierces of 2 m e.g.) for intermediate diameters, or is delimbed and dragged (like in highgrading) when diameter is larger than 18 – 20 cm.

Given the fact that the residues are not accessible with the current network of roads, tracks and trails, exploiting the forestry residues from thinnings could be applied only if after the felling, the trees are pulled out of the forest stand with wires This implies potential damages to other trees, though they would be lower as the size of the trees is smaller. And the damaged trees would be object of removal in next thinnings (next treatment in 10 or 20 years). However these issues are to be considered by the forestry managers.

Several sources of information have been consulted in order to elucidate a possible range of costs for the forestry residues extraction, especially considering sources applicable to the reality in the area (pre-Pyrenees forest areas with fresh climate influenced by inland Mediterranean and Oceanic climates). The results of Bioraise tool (http://bioraise.ciemat.es/Bioraise) for the Esteribar and Erro municipalities and of WoodE3 (http://woode3.ctfc.cat/) for mountain areas in Aragon (adjacent region) have been utilised as reference. These works indicate that, under the consideration of a well organised value chain (avoiding non efficient practices which may cause the economic impact to be extremely high), the range of costs for the biomass (expressed at 30% moisture) could range 45 – 50 €/t (Bioraise) or 47 – 68 €/t (WoodE3). Additional industrial benefit to be added would indicate that forestry residues could be accessible with a price at the BLC of 60 €/t.

Even though the exploitation of forestry residues is possible, it is not a straightforward alternative in the short term. Making real the utilisation of such biomass requires a series of preliminary contacts to detect the areas where obtaining the forestry residues may be materialised. Afterwards it is precise to agree upon an operational plan for extracting the residues. The actors able to be involved are to be identified and consulted. And finally, it is precise to review and modify or adapt the instruments for the forest management or the technical specifications for the forestry works, to allow the implementation of the new practice. As well as a BLC has to be settled, or an actor able to perform such work has to be engaged.

It is envisaged to MAGNA to play an initiator or promoter role for triggering the use of the forestry residues. MAGNA should further explore the chances for obtaining the forestry residues from one or several forest areas of the Esteribar and Erro municipalities. For that purpose, the efforts to be placed are not negligible. The support of specialists is advised, as well as the development of promotional projects including social innovation for allowing a change in the current practices, by involving all actors needed, and accompanied with some pilot and demonstrative practices.

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Supply costs and biomass competitiveness

A comparison of costs of the petcoke against the biomass (including the purchase and supply costs as well as the costs derived from the operations to be carried at MAGNA's facilities (storage, handling and refining) has been carried out. The prices of the petcoke have been represented as affected by the prices of the CO_2 allowances. The comparison has been carried out considering the two supply options: with BLC and without BLC (Figure 14).

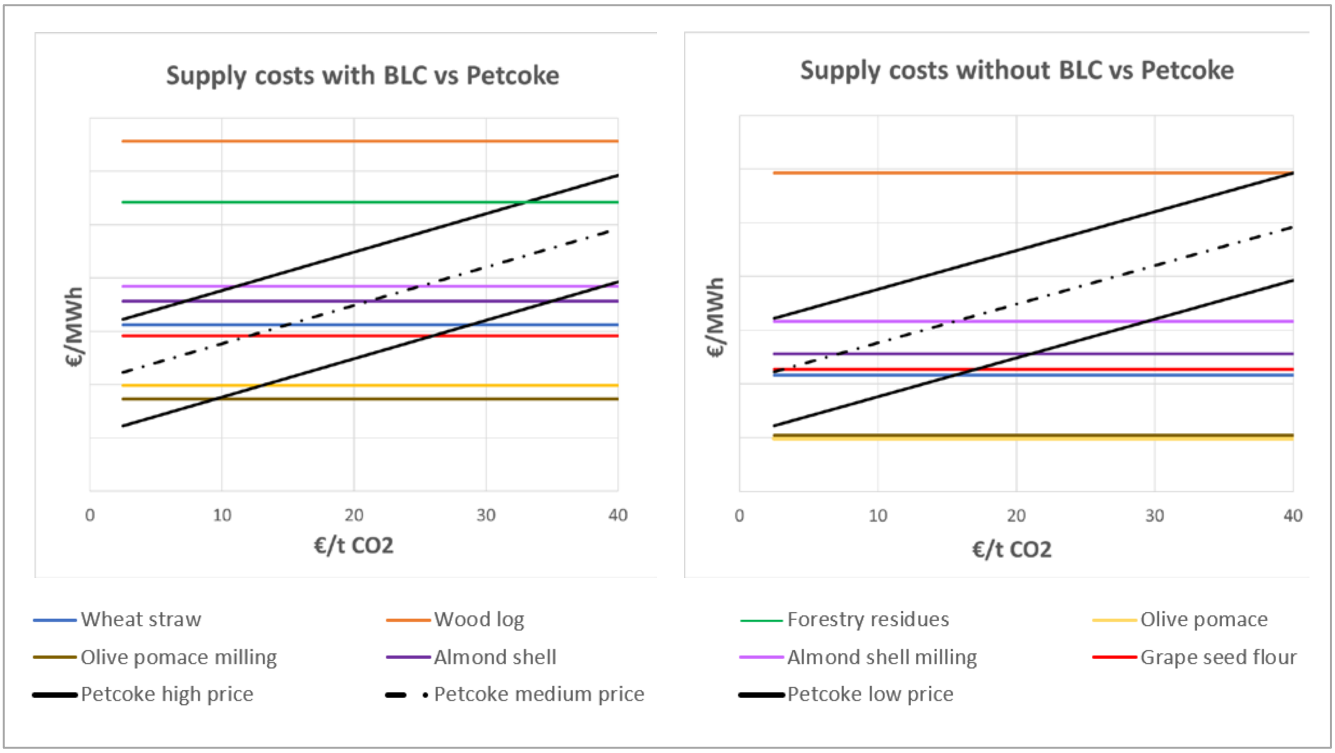

Figure 12: Comparison of the biomass and petcoke fuel costs considering the influence of the CO_2 allowances: LEFT Option 1 with BLC; RIGHT: Option 2 without BLC.

Figure 14 shows the results of the supply costs. Considering the current framework, with an allowance price of 25 €/tCO_2 it is observed that:

- Olive pomace (pre-refined, or without refining) is competitive, no matter the petcoke price or supply strategy
- Grape seed flower and straw may be competitive in case a direct supply (without BLC is established), disregarding the price of the petcoke. In case a BLC is established, these biomass types are competitive when the petcoke prices are intermediate or higher
- Forestry residues could be cost effective currently given the petcoke prices are very high
- Almond shells are competitive with intermediate prices of the petcoke, if the supply is performed without a BLC. With BLC supply costs increase and then it is competitive when petcoke prices are in the range of intermediate to high

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- Milled wood from woodlogs is not competitive except in scenarios of very high prices of both the petcoke and CO_2 allowances.

Biomass supply becomes more advantageous when CO_2 allowance prices rise. As a matter of fact, with CO_2 allowances above 30 €/t CO_2 (limit achieved in August 2019) all biomass become cost effective if the petcoke price is intermediate, except for milled wood.

Nevertheless, together with the price previously considered other important parameters as the quality of each biomass resource and their behaviour inside of the kiln should be observed, as the internal behaviour may have an effect in the operational and maintenance costs of the kiln and downstream systems, or an effect in the properties of the biomass.

3.3.4 Torrefaction

The use of raw biomass material as a fuel entails several problems, such as its high bulk volume, high moisture content, instability (tendency to decompose during storage) and relatively low calorific value. These characteristics cause multiple inefficiencies in biomass handling during the obtention and supply: higher transport costs, higher pretreatment costs (especially difficult to grind if fine particles) and losses of matter due to degradation. Additionally, at plant the low calorific value and low bulk density cause the biomass to have a very low net volumetric energy (kWh/m^3). This implies larger areas needed for storage and handling, as well as facilities of larger dimensions in the feeding lines (silos, ducts valves). Considering the effects in a rotary kiln for calcination, a fuel with properties closer to petcoke may favour the preservation of the stability and temperature profiles.

Torrefaction is a process already in an advanced status of development and applicable to obtain improved solid bioenergy carriers (solid fuel with enhanced properties). This treatment involves the heating of biomass at moderate temperatures (220-300 ºC) under an inert atmosphere. It is influenced by many parameters like the composition of the biomass, biomass form and moisture, and operation conditions like temperature profile and residence time (among others). During the torrefaction of lignocellulosic materials the major reactions of decomposition affect the hemicellulose. Lignin and cellulose may also decompose in the range of temperatures at which torrefaction is normally carried out, but to a lesser degree.

Torrefaction is an interesting pre-treatment of the biomass as:

- during the torrefaction process the density and the specific heating value of the product increases,
- moisture is reduced (under 10%)
- torrefied biomass has a hydrophobic nature, bringing two principal advantages: possibility to store in open spaces since no moisture is acquired during the storage of the product; fungal degradation becomes unlikely
- biomass is grindable, and therefore milling costs are substantially reduced. Torrefied biomass from different feedstock can be milled together.
- its homogeneity is larger as compared with raw biomass, contributing to improving the stability of the processes
- there is a loss of volatile material, and therefore the combustion is able to reach higher temperatures and keeps more similarities than raw biomass with the petcoke combustion

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Among the advantages of torrefaction, there is no significant effect in the reduction of undesired chemical fractions like ash content, volatile reactive alkali of chlorine content. Therefore, torrefaction should not be regarded as a method to improve the chemical behaviour or compatibility of biomass, but as method to facilitate the handling of more complex biomass types, facilitating their storage, handling, transport and grinding.

Even though torrefaction of biomass is not an extended practice, several plants are operating steadily currently in different countries. They are large plants with processing capacity above 100 kt/year, or pilot plants. Several references indicate that the costs could be in following ranges: investment costs from 7.5 to 14 €/t (cost impact per ton, considering total tons produced along the plant lifetime) and production costs (for a woody biomass with integrated torrefaction-pelletization process) between 11 and 16 €/MWh (though these costs are expected to be reduced in future as torrefied biomass use spreads and more plants start operation). If observing the effect of the torrefaction costs in the final energy cost of inhomogeneous biomass like forestry residues, woodchips or straw, torrefied biomass is not cost-competitive with respect the current prices of petcoke and CO_2 allowances nowadays. Substantial increments in these prices are necessary to make the torrefied biomass attractive. However, torrefaction may be an alternative in future, if the production costs sink, and if other driving forces enter in place, like obligations for the transition towards a full de carbonisation. Therefore, not being currently cost-competitive, it is advised to MAGNA to not disregard it as a potential strategy in the medium-long term.

3.4 Conclusions and further steps

BAMBOO Task 2.4 has contributed to provide MAGNA with vision to proceed in its strategy to decarbonise by substituting partly petcoke fuel by biomass in a cost end efficient manner, whilst creating positive impacts for the local community in terms of economic and environmental values.

Biomass from existing agroindustry by-products market may become an early alternative for the adoption of relevant amounts of biomass. The market has been explored, showing that there are available by-products like olive pomace, almond shells or grapeseed flour which prices are cost effective with the current level of the petcoke and CO_2 allowances (20-25 €/tCO_2). These by-products are to be supplied from other regions, are available in sufficient amounts (its use is not expected to cause an impact in the market and an increased competition), and contribute to their valorisation.

The utilisation of these biomass types may require the establishment of a Biomass Logistic Centre (BLC), to control quality, soften the seasonality changes in supply costs, reduce MAGNA efforts in organising the supply and reduce the risks of biomass supply break. Through the work carried out it is evidenced a higher cost derived from the BLC implementation, but its strategic relevance, specially taking into account that, in the medium term, the biomass strategy may shift partially to other resources that require specific handling and treatment.

The study concludes that the medium term is the right frame to promote an increased utilisation of local biomass resources currently underutilised. The principal resources are straw, from the open agricultural land in southern areas and the local forestry residues. Incorporating both biomass require the establishment of a BLC. Sitting the BLC in the nearness in open areas is a key piece for evidencing the positive impacts in the local economy.

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The utilisation of straw may be limited due to its composition in chlorine and alkali. As well due to its form. Actions of innovation are necessary to assure a sound and cost-effective use as fuel in the kiln. Innovation actions like treatments for leaching undesired fractions and obtaining an added value or market for them are recommended.

Forestry residues have revealed to have a high local potential. They are not utilised, and its extraction from forests after timber operations involve several environmental advantages, like reducing the risks for pest establishment and propagation, palliating risk of forest fires to start and reducing forest vulnerability in case a forest fire propagates. Its use definitively contributes to the local economy and MAGNAs compromise with the community in the creation of economic and environmental value. The work performed reveals that starting a new value chain based on forestry residues requires the participation of multiple local actors, like the forestry managers, the foresters, the timber and environmental service companies, and the local administrations. Social innovation projects of multiactor collaboration are a necessary key-piece where MAGNA can place its efforts to release the vast potential of forestry residues in the area.

As well torrefaction is a technology that may solve troubles specially in terms of the high energy costs associated to the milling of the biomass. This process has a limited capacity to improve the chemical properties, though improves the energy content, hygroscopicity, and grindability, and its combustion becomes more stable and similar to petcoke. The work performed reveals that torrefaction processing costs may cause the biomass to become not competitive under the current conditions. However, under a changing panorama, with higher fossil fuel costs, CO_2 allowances prices, and a need to perform steps towards a full decarbonisation of the industry towards 2050, torrefaction may become a strategic alternative. In this regard, innovation actions are an advisable strategy.

In synthesis, the work performed has provided the vision that biomass use in the short term is achievable. MAGNA may initiate biomass utilisation based on existing biomass with established value chains. The adequate and efficient use deserves a special attention in preliminary tests, as well as the potential impact in the quality of the products or in the lifetime of the facility equipment. The transition in the medium term to an enhanced use of other strategic biomass resources available in the area may require MAGNA to place efforts in technological innovation and in participating with the local community in social innovation actions. The work reveals that resources and pretreatment processes not being currently a solution for the immediate adoption of biomass, should not be disregarded, as may become strategic in the medium and long term.

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