



INTEGRATED BIOMASS LOGISTICS CENTRES FOR THE AGRO-INDUSTRY

Success case of the integration of a logistics centre into an agro-industry of the olive oil sector

Deliverable D4.8

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ABBREVIATIONS

a.r.: As received

CAPEX: Capital Expenditure

d.b.: Dry base

EFC: Effective field capacity

FiP: Feed-in-Premium

GCV: Gross Calorific Value

IRR: Internal Rate of Return

MC: Material capacity

MCPD: Medium Combustion Plant Directive

NCV: Net Calorific Value

n.d.: Not determined

NPV: Net Present Value

OGC: Organic Gaseous Carbon

OL: Olive Leaves

OPEX: Operational Expenditure


OTP: Olive Tree Pruning

RT: Reference tariff

TSP: Total Suspended Particles

TVOC: Total Volatile Organic Carbon

UF: Urea-formaldehyde

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PARTNERS SHORT NAMES

CIRCE: Fundación CIRCE

WFBR: Stichting Wageningen Research

ZLC: Fundación Zaragoza Logistics Centre

CERTH: Ethniko Kentro Erevnas Kai Technologikis Anaptyxis

RISE: RISE Research Institutes of Sweden

CREA: Consiglio per la Ricerca in Agricoltura e L'analisi dell' Economia Agraria

APS: Agroindustrial Pascual Sanz S.L

NUTRIA: Anonymi Biomichaniki Etairia Typopiisis Kai Emporias Agrotikon

LANTMÄNNEN: Lantmännen Ekonomisk Forening

PROCESSUM: RISE Processum AB


SCO-OPS: Cooperativas Agro-Alimentarias de España. Sociedad Cooperativa

INASO: Institutouto Agrotikis Kai Synetairistikis Oikonomias INASO PASEGES

AESA: Agriconsulting Europe S.A

UCAB: Association Ukrainian Agribusinessclub

UBFME: University of Belgrade. Faculty of Mechanical Engineer

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EXECUTIVE SUMMARY

The AGROinLOG project is based on the idea of Integrated Biomass Logistics Centres (IBLC) which implies to diversify the activity of the agro-industries through alternative business taking advantage of the synergies related to the current activity (as for instance, equipment, contact network, staff capacity, etc.).

This deliverable summarizes the final outputs of the AGROinLOG project regarding the demonstration of the IBLC concept in the olive oil sector. The demonstration was performed in Greece and was centered on NUTRIA S.A., as the agro-industry demo partner, with the collaboration of CERTH as the principal demo technical supporter.

NUTRIA operates an olive oil mill and a larger oil refinery plant that produces standardized olive oil, pomace oil and seed oils. NUTRIA's facilities are located in Agios Konstantinos, Fthiotida, Central Greece and the implementation of the IBLC concept is based on the exploitation of an untapped local biomass resource, olive tree prunings (OTP), mainly as feedstock for energy production.


During the AGROinLOG project, NUTRIA and CERTH have evaluated three different concepts for exploiting local OTP biomass. Each concept targets different types of end-users and requires different levels of investments:

- **Concept A, OTP hog fuel sales:** NUTRIA remains with the existing infrastructure and equipment (the one integrated harvester/ shredder and storage/ handling facilities of NUTRIA) and becomes a logistic centre for harvesting, storing, handling and selling hog fuel derived from olive tree prunings. The hog fuel is produced for external consumers (e.g. biomass power plants, industrial biomass consumers, maybe 1-2 local heating boilers). That would be mean around 2,500 tons of hog fuel harvested per year.
- **Concept B, OTP pellet plant:** NUTRIA invests on an OTP pellet plant with a targeted annual production of 5,000 tons pellets. The OTP pellets will be sold in the Greek market for solid biofuels.
- **Concept C, OTP power plant:** investment on a biomass power plant of 1 MWe that will be using exclusively the hog fuel of OTP. Electricity generated will be sold directly to the grid.

Raw material availability

NUTRIA is located in the town of Agios Konstantinos, Fthiotida, where 1,100 ha of olive groves are located. The Agios Konstantinos olive groves are part of an extended zone of olive tree cultivation in the coastal part of Fthiotida, where more than 34,000 ha of olive groves are located.

Local olive tree varieties are mostly targeting edible olive production and are characterized by their high vigour, e.g. high biomass productivity from prunings. Local conditions in Agios Konstantinos have been assessed via questionnaires, while a GIS tool estimating the OTP availability, extended to the whole region, has been developed by CERTH. Overall, it is estimated that OTP availability in a radius of 5 km from NUTRIA is 5,000 dry tons of OTP, which increases to 10,000 dry tons when the

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radius is extended to 10 km. Overall, all investment concepts can be implemented while keeping the sourcing radius short.

Harvesting and Supply Chain

Local conditions in Agios Konstantinos, specifically the distance between trees and the relatively flat fields, favor mechanized harvesting of OTP prunings. Within AGROinLOG, different harvesting options have been assessed by project partners CERTH and CREA; the integrated harvesting/shredding options using tilting bins for discharge of the material was ultimately selected as the most appropriate and mature option for harvesting OTP biomass in Agios Konstantinos.

During the project's duration, two large harvesting demonstrations were organized in 2018 and 2019. The main technical implement used for the demonstration was a Facma Comby TR200 harvester/shredder. The harvesting demonstration were implemented by the Agricultural Cooperative of Agios Konstantinos, under the supervision and support of project partners CERTH, INASO-PASEGES and NUTRIA. The harvested areas were 53.8 ha for 2018 and 27.2 ha for 2019, resulting in the collection of 174 and 78 dry tons of OTP hog fuel respectively. Improvements in harvesting performance was noted in the 2nd year of the demonstration, due to the accumulated experience of the operators.

Through the detailed monitoring of harvesting and haulage operations, it is estimated that a final productivity of 2.5 dry tons of OTP per hour can be achieved, with a corresponding average diesel oil consumption of 9.0 liters per dry ton of OTPs. The total cost of the operation is calculated as 33 €/wet ton, with a 27.5 % weight average moisture content. The harvesting cost is considered as being quite competitive, where it can further be compressed.


Storage

OTP biomass is available only for a few months of the year. In Agios Konstantinos, the olive trees are generally pruned from February to March. Local farmers wish to be rid off the OTP biomass as soon as possible, and definitely before the summer months, since it is an obstacle to other agronomic operations as well as potential fire hazard. This means that the OTP harvesting season can extend from February to latest May, thus requiring long-term storage solutions for the yearly operation of an IBLC concept.

Within AGROinLOG, storage of OTP hog fuel piles during the summer till early autumn months was evaluated. Two different options were assessed: uncovered storage and storage under a breathable fleece. The first option corresponds to zero additional costs, while the second is a low-cost alternative to roofed storage. The fleece-covered pile storage ultimately resulted in a net energy content gain of 12.1 %, while keeping dry matter losses at 1.1 % after six months of storage. The uncovered storage resulted in higher dry matter losses of 4.6 % and an energy loss of 5.1 %.

Production Process

For the case of NUTRIA, the production process is different depending on the concept.

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Concept A (hog fuel sales) requires minimum to no additional processing, beyond loading of the product from the storage area to a truck for transport to a final consumer.

Concept B (pellet production) has been demonstrated within the AGROinLOG project in a commercial, modern pellet production facility in Greece, where a quantity of OTP hog fuel was transported and OTP pellets produced. The heat consumptions required for the pelletization of the OTP amounted to 1044 kWh primary energy per dry ton of produced pellet. In overall, the heat consumptions required for the pelletization process amount to the 69 % of the total energy consumption of the whole value chain, from biomass harvesting to pellet production. Regarding the electricity demands required for the pelletization, that amounts to 295.5 kWh primary energy per dry ton of produced pellet or 20 % of the total consumption of the whole value chain. Finally, based on the feedback retrieved during the pellet production, the pelletization cost was estimated around to 80 € per ton of pellet produced.

Concept C (power plant) has not been specifically demonstrated at industrial scale within the AGROinLOG project due to this approach was developed in the last months of the project. However, the concept is based on the operation of a gasification biomass power plant (with an installed capacity of 1 MWe) in Northern Greece. This plant applies biomass gasification, followed by combustion of the produced syngas in internal combustion engines.

Product Quality and Market Analysis


The current section contains information on the final properties of the new products of NUTRIA as an IBLC (OTP hog fuel and pellets). The Information on the final product quality and fuel properties derived from the demonstration activities (both harvesting and pelletization). Finally, the results of the validation activities of such products are presented, that shows the performance of the new products compared to other competitive fuels of the market.

In brief, OTP fuels have a good energy content but differ to forest biomass in terms of higher ash content. Thus, this type of biomass requires boilers with higher requirements in the systems dedicated to withdraw ashes or to clean the flue gases. Even though OTP pellets could compete with well-established industrial fuels, in terms of combustion efficiency and emissions, their cost is considerably higher (150 €/t), making them an unattractive solution for substituting industrial fuels.

The use of OTP in the form of hog fuel seems to be a promising solution. It is a more competitive biofuel due to its reduced fuel cost (50 €/t). However, it faces several challenges as well, as its need of a suitable feeding system to burn such fuel. Furthermore, OTP hog fuel has significantly lower (energy) density compared to pellets, thus increasing the transportation costs. In this light, its targeted end users should be in close range from the IBLC.

For Concept C, the main advantage is that electricity sales from biomass are eligible for a feed-in premium in order for operators to reach a reference tariff for a period of 20 years through a contract with the grid operator. Hence, NUTRIA would not have to deal with variations in demand and can concentrate on securing biomass fuel supply for uninterrupted plant operation.

Cost Structure and Performance of new business model

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This section summarizes the required new equipment and investments needed from NUTRIA towards its conversion into an IBLC, based on each concept. Furthermore, it summarizes the main economic parameters of such new business activities (costs, revenues etc.).

In brief, for Concept A (hog fuel commercialization), NUTRIA will not perform any significant investment and start its new IBLC activity with its current equipment and facilities. In this concept, no new investments are required. However, the new personnel required would be 5 seasonal employees in the harvesting (one harvester required). and transportation of hog fuel to NUTRIA and one part-time employee that would attract and interact with customers. The harvested OTP will be sold as hog fuel in few close-ranged industries or public buildings, with a selling price of around 50 €/t_{w.b.} from the IBLC gate. The commercialization of 2,500 tons hog fuel will increase the annual turnover of NUTRIA by 125 k€.

For Concept B, NUTRIA will invest around 0.6 M€ for a pellet line of 1 t/h. For the personnel that would be needed in the concept of the pellet plant, three full time workers per shift and two shifts would be needed, thus 6 workers per day. A seventh specialised operator would be in charge of the maintenance and supervision for the two production shifts. Again, around 15 seasonal employees would be needed for the harvesting of prunings (three harvesters required). Another one person will be needed for administration, logistics and sales activities. For the case where OTP pellets are produced, based on the results obtained so far, it has been estimated that these pellets could be sold in the Greek market at a price around 150 €/ t_{w.b.} for the OTP-pellet. For an annual production of 5,000 t of OTP-pellets, NUTRIA will obtain around 0.75 M€ turnover per year in this new business.

For Concept C, NUTRIA will invest on a power plant (1 MWe). The investment cost would be around 4 M €. The additional personnel that will be needed, will be 9 permanent employees operating in the power plant and 15 seasonal employees in pruning harvesting and transportation (three harvesters required). For the case of the power plant, the annual revenue for NUTRIA will be coming from selling electricity to the grid. By assuming a selling price of 185 €/ MWh, the turnover of NUTRIA would be increased by around 0.8 M€ annually.

IBLC implementation in the agro-industry

In the final section, the advantages and drawbacks of converting NUTRIA or any agro-industry of the sector into an IBLC are reported. In brief, it is presented, based on each IBLC concept, what issues are still needed to be addressed and optimized and what lessons learned have been derived from the experience throughout the duration of AGROinLOG project, in which NUTRIA evaluates its conversion into an IBLC.




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1 INTRODUCTION


The AGROinLOG project aims to implement and demonstrate the technical, environmental and economic feasibility of integrated biomass logistics centers (IBLCs) for food and non-food products into existing agro-industries. An **Integrated Biomass Logistics Centre (IBLC)** is defined as a business strategy for agro-industries to take advantage of unexploited synergies in terms of facilities, equipment and staff capacities, to diversify regular activity both on the input (food, feed and biomass feedstock) and output side (food, feed, biocommodities & intermediate biobased feedstocks) thereby enhancing the strength of agro-industries and increasing the added value delivered by those companies.

Becoming an IBLC increases the competitiveness of an agro-industry by opening new markets, prolonging their operational periods and retaining employees in their idle periods. One of the sectors that were investigated in the AGROinLOG project, and on which the activities of an IBLC were demonstrated, was that of the olive oil sector in Greece. The olive oil sector is one of the most important agricultural sectors in Greece as it contributes more than 0.4 % to the national GDP with a total annual sales of 832.7 M€ (inr.gr 2014). Greece is the third olive oil country in terms of olive oil productivity worldwide with over 2,400 industries in the sector (Michailides, Panagopoulos et al. 2011). Many agricultural areas in Greece dedicate their crops to olive tree cultivations. The pruning of which produces a great amount of agricultural biomass (olive tree prunings) that remain untapped and mostly burned in open fires or scarcely mulched onto soil. This reality offers a great opportunity to existing agro-industries in the sector in exploiting such raw material and upgrading it into added value products. The development of new business activities in existing agro-industries enhance their competitiveness and revenues.


This report presents the technical and economic feasibility of a bio-based value chain established in the olive oil industry and important factors to be carefully evaluated while an agro-industry of the sector decides to advance towards its transformation into an IBLC.

The deliverable is structured as follows:

- Previous study to evaluate the integration of an IBLC: the current situation of the agro-industry is briefly described along with the feasibility to implement a new business line and the market potential of the new products under investigation.
- Considerations to assess the technical and economic feasibility of an IBLC in the olive oil sector: various parameters that the agro-industry has to take into consideration towards its conversion into an IBLC (e.g. availability of raw material, harvesting solution and supply chain, storage of raw material, production process, quality of new products and their market potential).
- Additional IBLC activities in the olive oil sector: extra/ supplementary activities that could be implemented by an IBLC in the olive oil sector, apart from the exploitation of harvested olive tree prunings by energy means that is the focus of an IBLC in this sector.

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- Finally, the advantages and drawbacks are mentioned, as well as the lessons learned and the conclusions obtained for the olive oil sector.

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2 PREVIOUS STUDY TO EVALUATE THE INTEGRATION OF AN IBLIC

2.1 Current situation of the agro-industry

NUTRIA was founded in 1994 as a continuation of a smaller company, which essentially was an olive mill. Today, NUTRIA is one of the largest companies operating on the olive oil sector in Greece with a turnover of 32 M€ (2019).

The main facilities of NUTRIA are located in Agios Konstantinos, Fthiotida, Central Greece (around 200 km north of Athens) in an area of 60 ha (Figure 1). The main business lines of NUTRIA are the following:

- The main activity of NUTRIA is the refining of the olive oil coming from small olive mills all over Greece in order to increase its added value. NUTRIA increases the quality of the olive oil by a second refining process and ensures its final quality through its chemical laboratory. In addition, NUTRIA has implemented standardised processes and control quality procedures to be able to certify the olive oil with Protected Designation of Origin (PDO) or Protected Geographic Indication (PGI).
- A secondary activity of NUTRIA is the operation of a small olive mill within its facilities. The mill is used to produce olive oil from olives coming from local farmers.
- A third activity, unconnected to the previous ones, has to do with the storage of cereal grain. NUTRIA owns 8 silos that each can store up to 2,500 tons of cereals. Currently, NUTRIA rents them to brewery companies to store cereal grains.

As mentioned, NUTRIA is sourcing olive oil from the most important olive production areas in Greece: Creta, Peloponnese (Ilia, Lakonia and Messinia), Fthiotida, the island of Lesbos and Chalkidiki (Figure 2). The olive oil is produced in numerous small-scale olive mills and is purchased by intermediate bulk traders, which arrange for its transport via tanker trucks to NUTRIA, where it can be stored for longer time periods. Through the application of traceability procedures and standards, NUTRIA can place olive oil in the market labeled as Protected Designation of Origin (PDO) or Protected Geographic Indication (PGI).


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Figure 1. NUTRIA's facilities

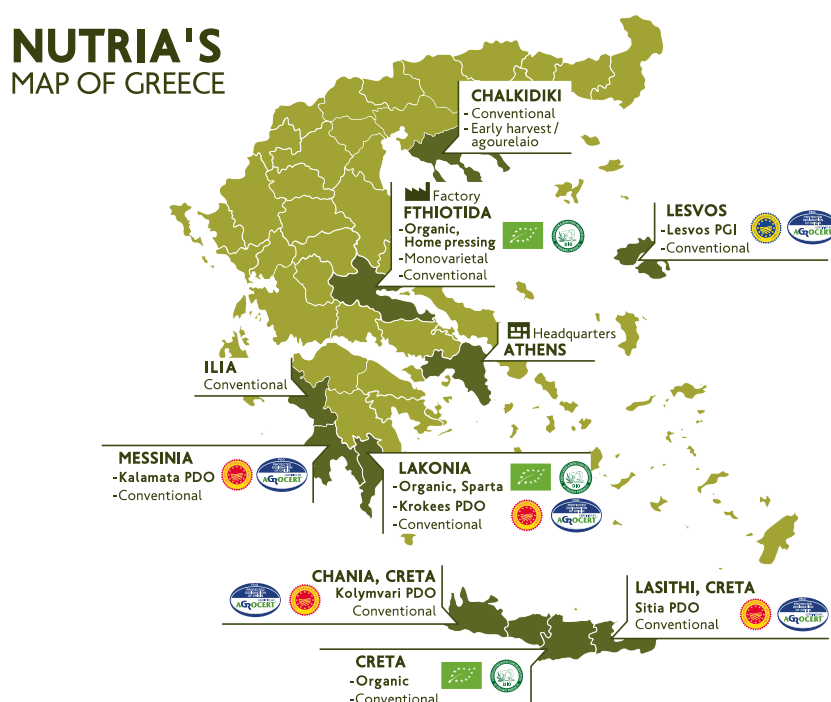



Figure 2. NUTRIA's oil sourcing map

2.2 Feasibility to implement a new business line

In terms of NUTRIA's conversion into an IBLC, the key unexploited biomass resource to be considered are locally produced olive tree prunings (OTP). Olive tree prunings are regularly (usually on annual or biannual basis) produced as a result of agronomic operations in olive groves and represent a huge agro-biomass potential in the major olive oil and table olives producing countries: Spain, Italy and Greece. The most common way of handling this residual stream is open-field burning; within the AGROinLOG project, the vision is the transformation of olive tree prunings into a tradeable bio-commodity as hog fuel or through their upgrade and "standardization" via a pelletization process.

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In this light, three concepts have been assessed for IBLC implementation at NUTRIA (Figure 3):

- **Concept A, OTP hog fuel sales:** NUTRIA remains with the existing infrastructure and equipment (the one integrated harvester/ shredder, and storage/ handling facilities of NUTRIA) and becomes an integrated logistic centre for harvesting, storing, handling and selling hog fuel derived from olive tree prunings. The hog fuel is produced for external consumers (e.g. biomass power plants, industrial biomass consumers, maybe 1-2 local heating boilers). That would mean around 2,500 tons of hog fuel harvested per year.
- **Concept B, OTP pellet plant:** NUTRIA invests on an OTP pellet plant with a targeted annual production of 5,000 tons of pellets. The OTP pellets will be sold in the Greek market for solid biofuels.
- **Concept C, OTP power plant:** investment on a biomass power plant of 1 MWe that will be using exclusively OTP hog fuel. Electricity generated will be sold directly to the grid.

Concept A explores the possibility of marketing directly OTP biomass as harvested, e.g. in the form of hog fuel. Since pre-processing is minimal, the fuel costs (in €/GJ) are finally much lower compared to OTP pellets, even when considering the higher moisture content of hog fuel. Interest in this concept has been primarily motivated by the local presence of a large industrial end-user that seems capable of using OTP hog fuel as part of its fuel mixture; a few other possibilities for selling OTP hog fuel have also been explored.

Regarding **Concept B**, as the AGROinLOG project progressed, it became apparent that it would be hard to place OTP pellets on the market. The two main reasons are a) incompatibility with the domestic heating market regulatory requirements and b) price competition from already established solid biofuels in the industrial market (mostly exhausted olive cake and sunflower husk pellets).

Concept C is based on the mobilization of the same volume of OTP biomass as in the case of pellet production (Concept B), however the production process and market orientation is totally different. The level of investment required for an OTP biomass power plant is much higher than both other concepts, however it offers the advantage of a guaranteed reference tariff for a period of 20 years and a secure market for the electricity.

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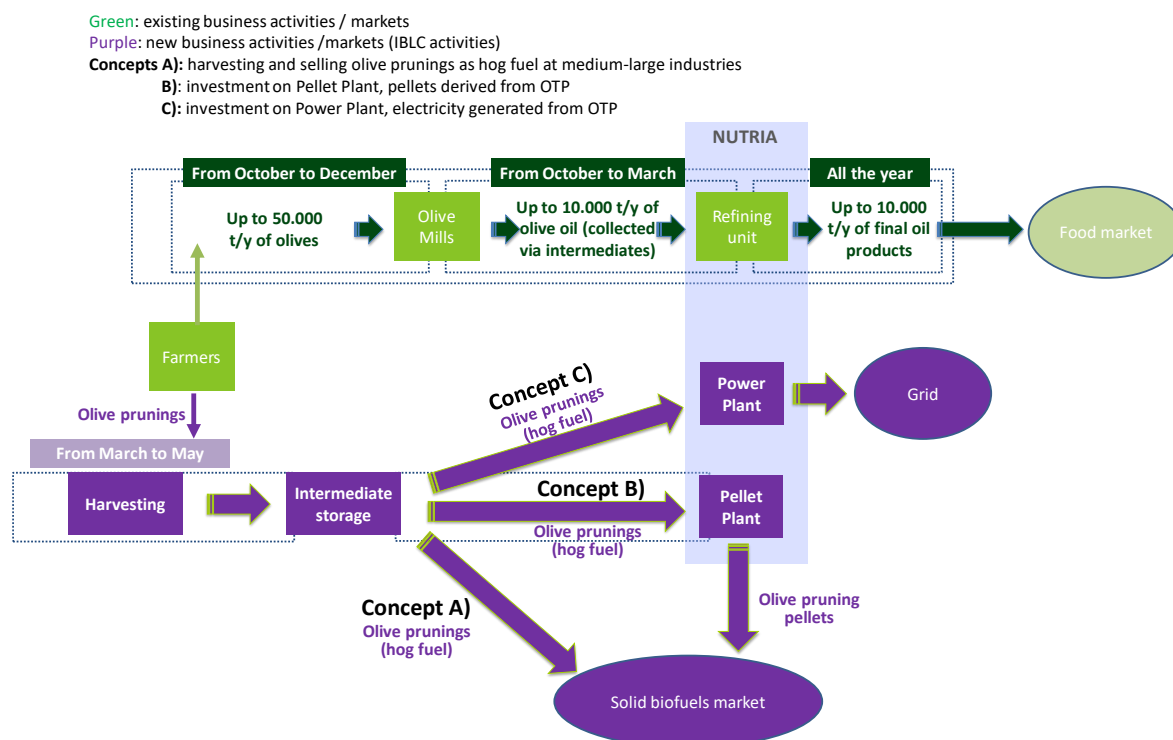


Figure 3. NUTRIA's alternative business concepts


2.3 Market potential of the new products

The main product of the future IBLC of NUTRIA is expected to be based on a currently unutilized biomass resource both locally, e.g. in Agios Konstantinos, as well as all over Greece, olive tree prunings (OTP). There are two main strategies that can be followed for commercialization of this biomass resource as a solid biofuel:

- Upgrade OTP in the form of pellets; the process results in a solid biofuel with higher bulk density and reduced moisture, hence high energy density. It also comes in standardized dimensions, allowing its feeding into most, if not all, existing biomass boilers. However, the negative side is the increased production cost due to the pelletisation process.
- Sell OTP as hog fuel, e.g. with minimal to no processing after harvesting. The cost is significantly lower compared to OTP pellet production, however there are more severe limitations regarding transportation, storage and feeding.


In both cases, the end-product is a solid biofuel, sold to the end users in the Greek market. Potential end-users can be grouped into three categories: users of solid fossil fuels, users of liquid/gaseous fossil fuels, users of other solid biofuels.

The main strategy for NUTRIA as an IBLC is to primarily target existing users of solid biomass, which might be interested in switching from their current fuel to a new one derived from OTP. Technical

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incompatibility is a knock-out criterion for such a fuel switch; the most usual form it can take is related to the fuel feeding system restrictions, although other factors (e.g. too high ash content, too high moisture, etc.) might also play a role. Once technical compatibility is established, cost-effectiveness, e.g. economics, is the other main parameter that should be evaluated. Finally, other issues might need to be assessed: flue gas emission limits, social acceptance, etc.

For the concept of power production from OTP biomass, there is already a guaranteed market for renewable electricity in Greece. Details on the current support schemes for biomass power are provided in Section 3.6.5 of this report.

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3 CONSIDERATIONS TO ASSESS THE TECHNICAL AND ECONOMIC FEASIBILITY OF AN IBLC IN THE OLIVE SECTOR

3.1 Raw Material availability

Greece is the third olive oil country in terms of olive oil productivity worldwide and that is why many agricultural areas in Greece dedicate their crops to olive tree cultivations. One of the most important areas in Greece in olive production is Fthiotida region (NUTS 3), located in Central Greece. Fthiotida region possess over 34,000 ha of olive groves (Elstat, 2015). The Greek IBLC area, Agios Konstantinos is part of the Fthiotida region. Agios Konstantinos' agriculture depends mainly on olives production where they amount at around 1100 ha (Elstat, 2015) of olive groves producing two main edible olive varieties (Kalamon and Amfissis). Olive farmers in Agios Konstantinos prune their olive trees once every year. The olive tree varieties grown in Agios Konstantinos are quite vigorous, thus favouring high biomass productivity from prunings. The current common practice to deal with olive tree prunings (OTP) in Agios Konstantinos is that of mainly burning them in open fires inside the olive groves or, less frequently, mulching them on soil. The former practice is a threat for fire hazards in the olive groves and the latter option represents a threat for transmitting soil diseases. Thus, Agios Konstantinos was considered a perfect candidate region for implementing an IBCL concept in the olive sector, also due to the morphology of its olive groves that are mostly in flat land and with big distances between trees (over 8 m), that favours mechanized harvesting.

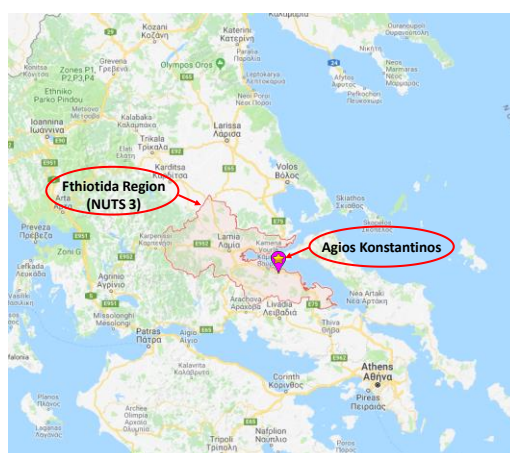



Figure 4. Implementation of IBLC activities in Agios Konstantinos, Fthiotida, Central Greece

3.1.1 Methodology

A first step towards the valorisation and harvesting of olive tree prunings is to map the biomass sources and accurately estimate the biomass productivity in the surrounding area in order to ensure a stable supply of OTP to the IBLC facilities. In this light, a GIS mapping platform for the spatial estimation of the biomass potential from olive tree prunings was developed by CERTH. The GIS tool

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was developed with the aim to assist in the more accurate estimations of the olive tree pruning potential in areas of interest for the IBLC concept in Greece. The tool:

- 1) Uses very accurate spatial information on the olive grove areas, based on data supplied from the Greek Payment Authority of Common Agricultural Policy (C.A.P.) Aid Schemes. Essentially, each olive grove in the CAP scheme are depicted as a polygon with information on field size, number of trees and olive tree varieties.
- 2) calculates biomass availability using a biomass per tree ratio, which can be adapted to local conditions based on empirical data from field measurements. Such measurements were performed by CERTH within AGROinLOG, for the area near NUTRIA, as well as in the uP_running project (uP_running) for other olive areas of Greece.

3.1.2 Results

In this light, a first step towards the implementation of an IBLC concept by an agro-industry in the olive oil sector is the mapping and estimation of the available feedstock in the area. Figure 5 presents an overview of the available olive groves in Agios Konstantinos, through the GIS tool.

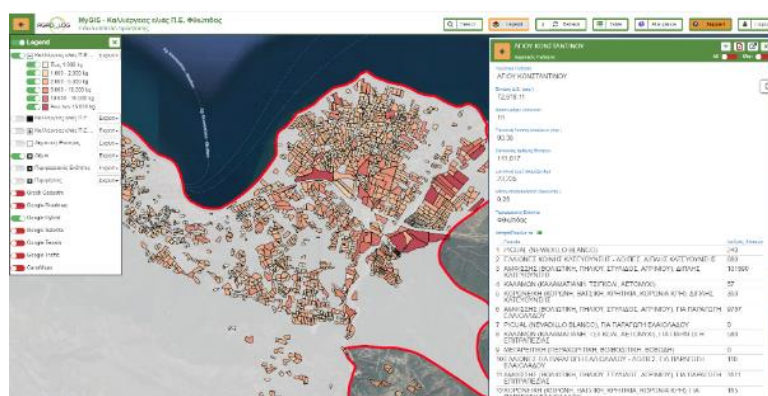



Figure 5: GIS mapping tool developed by CERTH. Olive groves in Agios Konstantinos

The biomass potential has been calculated based on the distance from NUTRIA. Figure 6 presents the GIS-tool as it calculates a radius around NUTRIA to estimate the olive tree pruning potential inside the selected circles. The distances that are depicted address a radius of 5, 7, 10 and 15 km around NUTRIA.



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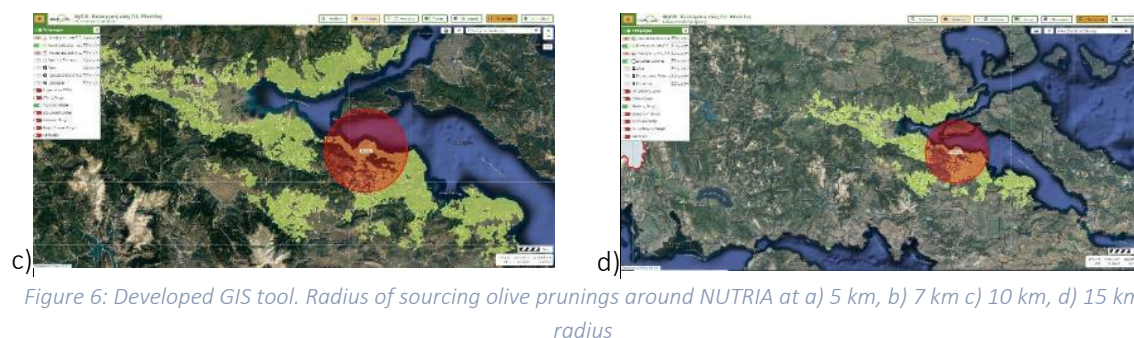



Table 1 presents the results of the GIS-tool concerning the different above-mentioned radius around NUTRIA. The required amount of olive tree prunings in the concept A, where NUTRIA uses its own equipment to commercialize OTP as hog fuel, without further investments, is around 2,500 tons of hog fuel (or around 1,800 dry tons prunings, 27.5 % moisture content). This amount can be covered by all selected radius. In the IBLC concept (concept B and C) where NUTRIA further invests in the harvesting of OTP and increases its harvesting capacity to reach a maximum of 8,000 tons of hog fuel (around 5,800 dry tons of prunings), to fulfil the demands of both the concepts, the power plant or the pellet plant, the sourcing radius has to be increased. The most reasonable radius would be in the range of 7 km to 10 km around NUTRIA in order to count on an additional amount of prunings in this range as a backup (e.g. in case some olive groves have a very high slope and is difficult to harvest the prunings from there). The over 10 km radius of course is an adequate distance to cover the demand of the Greek IBLC, however it implies an increase of the harvesting distance from the IBLC, and thus the logistics costs.

Table 1. Olive tree pruning potential for different radius around NUTRIA

OTP potential around NUTRIA				
	5 km	7 km	10 km	15 km
Number of trees	167,260	212,629	393,760	1,118,294
Cultivated olive groves (ha)	1,143	1,428	2,386	6,089
OTP Productivity (dry t)	4,918	6,173	11,163	32,186

3.1.3 Conclusions

The first step prior to the implementation of an IBLC concept in the olive oil sector should be the estimation of the available feedstock in the surrounding area of the agro-industry. The IBLC should be in place to develop the best strategy to secure its sourcing of OTP from the nearby area. A first estimation of the available feedstock along with its mapping can contribute in developing an optimized value chain that can result to the viability of the IBLC concept, via the mitigation of the logistics costs of the raw material. In this light, the developed GIS tool can contribute in the spatial estimation of olive tree prunings availability at national level.

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3.2 Harvesting/ Supply chain

Harvesting is a key stage that influences the product quality, the type of logistics chain and the economic sustainability of the pruning supply chain. Equipment for harvesting and processing agricultural pruning are already available on the market and many manufacturers offer different models that are tailored to specific harvesting chains. The quality of the woody biomass is affected by the techniques used along all the supply chain. One specific type of machinery or solution does not exist, and currently used machines do not match all types of field conditions. The choice of the best technology should be made on a case-by-case basis because the economic viability of recovering prunings depends on how the costs of the residue collection are managed as well as on how the benefits are redistributed between owners, harvesting contractors and biomass users.


3.2.1 Methodology

The months during which the prunings can be harvested are from February/March to May. During these months, the IBLC should secure its supply of raw materials needed for either of the alternative scenarios that can be implemented by NUTRIA at its current situation. The harvesting performance that would be applied in the Greek IBLC, independently of the concept chosen to be implemented by NUTRIA, was recorded via real life demonstrations. Two consecutive and extensive harvesting demonstrations of olive prunings were performed in Agios Konstantinos in 2018 and 2019. Both of them were performed in April and May accordingly. The main scope of these demonstrations was to evaluate a real pruning value chain in terms of performance (times, weight of harvested material) and economics (fuel consumptions, logistics costs) in order to use these results to select the best alternative for the IBLC implementation, considering the specific needs of the Greek demo case.

The harvesting was performed with an integrated harvester/ shredder FACMA Comby TR200 (Figure 7). The harvester, attached to a 130 hp tractor, drives over the aligned olive prunings (Figure 7) and harvests them by shredding them and keeping them in its automated lifting bin. The produced material is an inhomogeneous material that its size varies and can be labelled as “hog fuel”. Furthermore, the produced material includes the woody part of the prunings along with the leaves.



Figure 7. Left: Alignment of olive tree prunings before harvesting; Right: FACMA Comby TR200 harvester

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The value chain of the harvesting of olive prunings is depicted in Figure 8. Firstly, farmers manually align the pruned olive prunings between the rows of olive trees. Olive prunings that are subjected to harvesting are thin branches which are previously separated from thick branches (over 5 cm diameter). The latter are collected from farmers to be used as firewood. Thin prunings are left on the olive groves for a month before being harvested, in order to decrease its moisture content and reduce the amount of leaves. After the alignment, the integrated harvester FACMA TR 200 goes over the rows of prunings and harvests prunings by shredding them into small and inhomogeneous pieces. The produced chipped prunings are temporarily stored inside the harvester's automated lifting bin (5 m³ volume). After the bin gets full of harvested prunings, the harvester discharges the prunings onto platforms (attached to tractors) waiting at field side (Figure 9). After the platform is fully loaded with harvested material, it is transported to an intermediate storage area nearby the agro-industry in Agios Konstantinos (Figure 9).

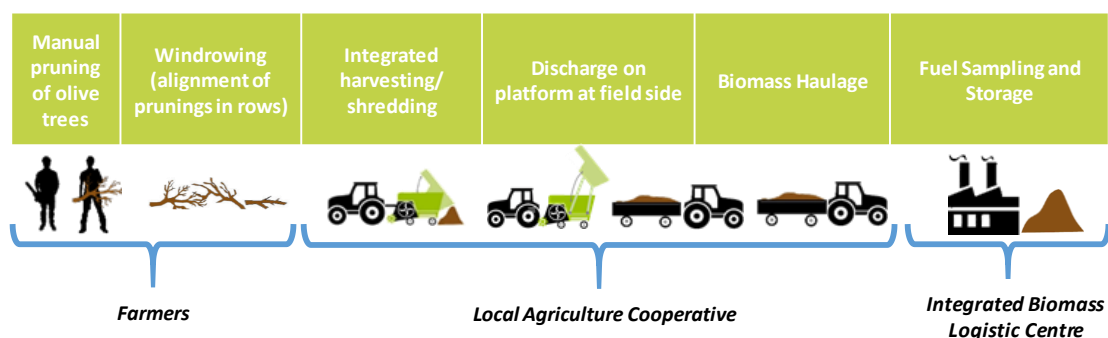


Figure 8. OTP harvesting demonstration value chain in Agios Konstantinos, Fthiotida, Central Greece



Figure 9. Left: Discharging harvested prunings on platform; Right: Storage area of harvested prunings

3.2.2 Results

In overall, the harvesting performance of both harvesting demonstrations in 2018 and 2019 is summarized in Table 2. It can be seen that during the second year's demonstration, the average harvesting tons of prunings and ha per hour were increased comparing to the previous year's performance (harvesting ha per hr were increased from 0.69 to 0.86 and harvested dry tons per hour from 2.23 to 2.43). However, the high harvesting performance led also to higher fuel consumption. From 11.9 l/hr fuel consumption of the harvester, it increased to 14.5 l/hr.


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Table 2. Comparison of harvesting performance of both harvesting campaigns of 2018 and 2019 in Agios Konstantinos

Comparison of Harvesting Performance of both demonstrations			
Parameter	Unit	1 st Demo (2018)	2 nd Demo (2019)
OTP harvested	dry t	174.0	78
Area harvested	ha	53.8	27.2
Average EFC	ha/h	0.69	0.86
Average MC	dry t/h	2.23	2.43
Harvested tons per ha	dry t/ha	3.23	2.84
Average Fuel consumption of harvester	l/h	11.90	14.51
	l/ha	17.21	16.95
	l/ dry t	5.33	5.97
Average Total Fuel Consumption (FACMA + platform) consumption	l/ dry t	8.07	8.95
Total Net Harvesting Time	h	~78	~32

Regarding the implementation of harvesting value chain by the Greek IBLC, the performance of the second year's demonstration is considered to be more close to the commercial operation of the value chain, as the actors participating had accumulated experience since the first year.

Regarding the harvesting cost, an estimated commercial operation case was calculated based on the harvesting costs of both demonstrations. For the estimated commercial operation case, it was assumed a realistic 2.5 dry t/hr harvesting efficiency. Finally, the harvesting cost was calculated around to 45.7 €/dry t (or 33.1 €/wet t, 27.5 % moisture content).

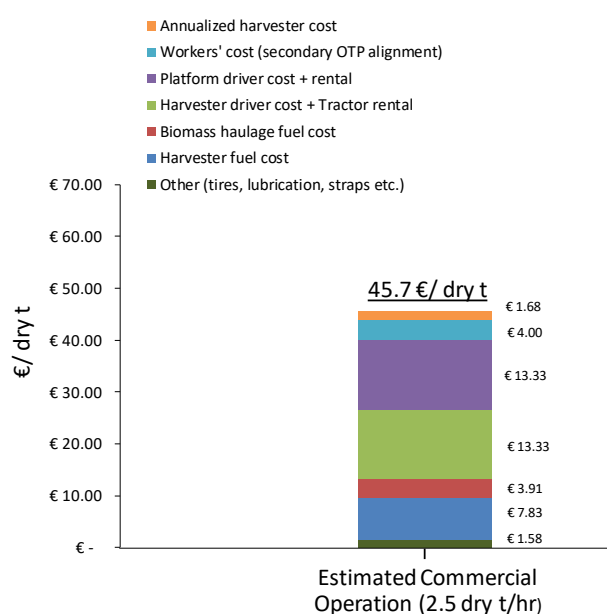



Figure 10. Cost- breakdown of more realistic harvesting olive prunings value chain (estimated commercial operation case with 2.5 dry t/hr net harvesting efficiency)

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3.2.3 Conclusions

The harvesting of the OTP is an important step for the implementation of the IBLC concept in the olive sector. It does not only affect the production cost of the final new product (whether it is hog fuel, chip, pellet or burned for electricity), but it can also affect the biofuel properties (due for instance to the presence of soil contamination or stones). Thus, the impact on the final product is significant and depends on the harvesting solution applied. After the successful implementation of the harvesting demonstrations in the IBLC area of Agios Konstantinos, the choice of an integrated harvester was considered a promising solution that could meet the challenges of the local olive varieties and morphology of the local olive groves. However, the harvesting solution has to be addressed case by case, based on each IBLC's local area conditions.

3.3 Storage


3.3.1 Methodology

Harvesting is only one component upstream of the more complex chain of logistics, a process also involving transport, storage, handling and pretreatment. Regarding the storage of harvested prunings at the IBLC, pile tests were built to investigate how the OTP are influenced over the period of storage.

In this sense, two almost identical piles were built at NUTRIA: i) one pile as is, without any coverage and ii) one pile covered with a fleece. The special fleece is a green polypropylene nonwoven of 300 g/m², UV rays treated, breathable, wind resistant, hydrophobic fabric that is specifically designed for compost maturation and woodchips protection. Each pile had a height of 3 m and a diameter of 5.5 m. For the construction of each pile around 10 wet tons of harvested OTP were used. In each pile, 4 thermocouples (PT 100) were used in order to measure the temperatures variations inside each pile in four different spots. All eight thermocouples were connected to a data logger located between the two piles in order to record the temperatures inside both piles. Temperature was recorded every 10 minutes.



Figure 11: Piles A (without coverage) to the right and pile B (with fleece) to the left

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3.3.2 Results

In overall, the covered pile recorded a pretty much stable average temperature at 36.1 °C, whereas the uncovered pile recorded more violent temperature fluctuations that resulted to an average temperature of 32.7 °C throughout the storage period. Furthermore, results regarding the quality of the stored olive tree prunings and the impact of storage on the fuel properties were investigated. In brief, the covered pile showed greater storage performance than the uncovered pile, where the latter depended mostly on the weather conditions. Moreover, the covered pile presented lower dry matter losses after 6 months of storage (average value of 1.1 % compared to 4.6 % of the uncovered pile), higher moisture losses (average pile value of 44.5 % moisture losses from the initial moisture, compared to 5.7 % of the uncovered pile) that also resulted in energy content gain (average pile value of energy content gain of 12.1 % compared to energy content loss of 5.1 % of the uncovered pile)

3.3.3 Conclusions

Based on the storage trials, the storage solution with the fleece seems to have positive impact on the stored material with a relatively low cost (around 2.2 €/ m², excl. VAT). However, the trials were performed for six months. Thus, the storage behavior of the material during the rest six months is questionable. However, compared to the outdoor storage with no further cover, the storage solution with the fleece seems to protect the stored biomass from weather phenomena (e.g. rain) and thus, being a more promising storage solution than the non covered storage for a storage period of one year.

3.4 Production process

Based on each concept that can be implemented by NUTRIA in the near future, the corresponding production process changes.


3.4.1 Production of OTP hog fuel

Beyond harvesting, haulage and intermediate storage, no further pre-treatment of the OTP hog fuel is envisaged. Once required by the end-users, the OTP hog fuel will be loaded (e.g. with a wheel loader) into a truck and sent to the place of consumption. Transport is foreseen to be bulk.

3.4.2 Pellet Production of OTP

In the pellet concept (concept B), after the olive tree prunings are harvested, they are transported to the IBLC and follow several steps towards the production of pellets such as chipping, milling, drying, pelletizing, cooling and finally packaging.

For this concept, and in the frameworks of AGROinLOG project, the pellet production from olive tree prunings was demonstrated in a pellet plant in Southern Greece. In brief, during the pellet production demonstration, 105 t of biomass were processed for the production of 63 t of pellets

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and 17 t of biomass where burned at the furnace to produce heat for drying. No additives were used during the production process, since preliminary results for the mechanical durability of the pellets confirmed that their addition was not required to reach the minimum value of mechanical durability.



Figure 12. OTP pellets

During the pellet production, the process was monitored and data regarding the energy consumptions were recorded. Figure 13 presents the energy balance of the whole olive pruning value chain from the harvesting of olive prunings to the production of OTP pellets. Energy is calculated in primary energy for comparison reasons. The most energy- demanding step of the value chain is the heating demands of the pellet production. The heat consumptions required for the pelletization of the OTP amounted 1044 kWh primary energy per ton of produced pellet. Regarding the electricity demands required for the pelletization, it implies 295.5 kWh primary energy per dry ton of produced pellet. In overall, the heat consumptions required for the pelletization process represents the 69 % of the total energy consumption of the whole value chain, from biomass harvesting to pellet production, whereas electricity demands amount to the 20 % of the total energy consumption. In addition, Figure 13 also presents the electrical energy consumption breakdown of the pellet production. The majority of electricity (47 %) is consumed during the pelletizing, followed by milling (28 %) and drying (19 %).

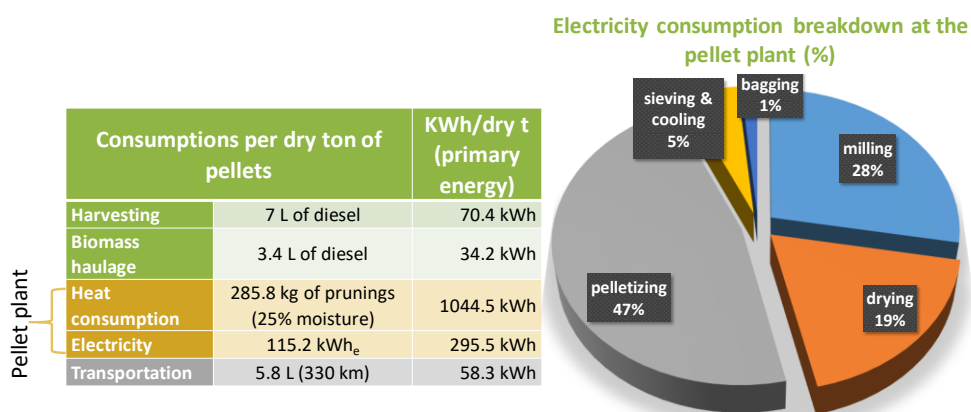



Figure 13: Electricity consumption breakdown (in primary energy per dry tonne of pellet) from harvesting of OTP to pellet production and electrical energy consumption breakdown at the pellet plant

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Finally, based on the feedback retrieved during the pellet production, the pelletization cost was estimated around to 80 € per tonne of pellet produced with the following cost break down: 25 €/t for electricity, 20 €/t personnel cost, 25 €/t maintenance, packaging, marketing costs and 10 €/t costs to banks, liabilities, etc. All the values are expressed per tonne of pellet produced at their moisture content, around 10 % over a wet basis.

3.4.3 Electricity production from OTP


Regarding the concept where NUTRIA invests on a power plant, the harvested OTP as hog fuel is stored prior to its conversion into power. The power plant concept can be mostly based on two technological solutions: i) gasification or ii) combustion of OTP.

The **biomass gasification option is followed by combustion of the produced syngas in internal combustion engines**. Yet, there is no example of a biomass power plant that applies this concept using exclusively OTP biomass. However, there is an example in Greece of a 1 MWe power plant applying biomass gasification to wood chips from fruit orchard plantation removals. The plant was built with a total investment of less than 4 MEUR, thus representing an interesting option from a CAPEX point of view. Moreover, the reference tariff that is applied in Greece to biomass gasification plants below or equal to 1 MWe capacity is slightly higher than the one applied on combustion plants of the same capacity ranges (185 €/MWh for gasification plants vs 176 €/MWh for combustion plants).

Within the AGROinLOG project, a quantity of OTP hog fuel was transported from Agios Konstantinos to the gasification plant, for testing of performance and emission measurements. Due to differences between the OTP hog fuel and the reference wood chips (OTP were less homogeneous and had higher shares of low particle sizes), the operators had to adjust the plant operating settings. Thus, the plant electrical efficiency was lowered knowingly and a final value of 6.5 % with OTP biomass was calculated. Obviously, with such low values, using OTP hog fuel in the existing gasifier does not make sense. However, the construction company believes that by carefully selecting the gasifier concept and constructing a purpose-built plant, the concept of an OTP biomass gasifier could work.

Another option for electricity production from OTP is to apply the concept of FIUSIS, an existing 1MWe power plant that produces electricity from OTP. The FIUSIS plant was visited twice during the AGROinLOG project in order to benefit from its experience on organizing OTP value chains. FIUSIS as considered as one of the “flagship” cases of agricultural pruning utilization in Europe by the uP_running project and details are given in a project report (uP_running 2017). A short summary is presented below.

FIUSIS is based on **biomass combustion coupled with the Organic Rankine Cycle (ORC) technology**, one of the few available options to convert boiler heat into electricity in small or medium sized units. Two Italian companies, Unicomfort and Turboden provided the two main components of the plant, the boiler (with moving grate and secondary combustion chamber) and the turbine, respectively. The power capacity of the turbine unit is 1 MWe, which provides production of 8,000 MWh annually (considering 8,000 operating hours per year). The plant typically consumes 24 – 28 tons of prunings

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per day, depending on their actual moisture content. The gross electrical efficiency is in the range of 24 – 25 %.

Overall, FIUSIS is a state-of-the-art biomass power plant, tailored made for OTP biomass. However, the high investment cost (8 M€) and the relatively low national reference price of 176 €/MWh (selling price of electricity generated from 1 MWe biomass combustion plants), makes it a non-promising investment for the Greek IBLC case. Nonetheless, the concept of a gasification power plant with an investment cost of 4 M € and a higher reference price of 185 €/MWh, makes it a promising IBLC concept. Therefore, for Concept C it makes sense for NUTRIA to follow the example of the gasification plant in design and implementation.

3.5 Product quality

Product quality for the NUTRIA IBLC applies to the two concepts (A and B) in which solid biofuels are sold to third customers. The desired product quality depends on the type of consumer, equipment installed (e.g. feeding systems, boilers, flue gas cleaning systems) as well as any relevant regulatory requirements. Generally, industrial end-users have less strict requirements compared to domestic ones.


Parameters that have to be assessed in all cases are moisture content (directly affecting the heating value), particle size and bulk density (affecting feeding, on-site storage and handling costs) and ash content (affecting various parameters related to the boiler operation, e.g. frequency of cleaning, as well as particle emissions). Other parameters, such as major and minor elements in ash, nitrogen, sulphur and chlorine content, ash melting temperatures, etc. can provide various insights into the combustion behaviour of the fuels and allow to anticipate possible malfunctions.

The advantage offered by OTP pellets compared to OTP hog fuel is the improved and controlled moisture content, particle size distribution and ash bulk density, which open up more possibilities for exploitation. The disadvantage is that pelletisation comes with a significant increase in production costs. Other fuel parameters, such as the ash content, are only limited or not affected by the pelletisation process.

During the demonstration activities performed during AGROinLOG project, fuel samples were collected at different times across along the value chain. Fuel characterization was performed in the solid fuels laboratory of CERTH/CPERI in Ptolemaida by applying established International or European standards (e.g. ISO 18134-1 for moisture, ISO 18134-3 for ash, ISO/DIS 18125 for heating value, ISO 16948 for ultimate analysis, ISO 16967 for major elements, ISO 16968 for minor elements).

3.5.1 OTP Hog fuel


OTP hog fuel samples were regularly collected during the two harvesting demonstrations in Agios Konstantinos. In general, one fuel sample was collected from each individual field during weighting of the platforms at NUTRIA. In total, 49 OTP hog fuel samples (30 during the 2018 demonstration and 19 from the second demo in 2019) were analysed; results are presented in Table 3.

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Overall, an ash content of 4.5 w-% d.b. derived from the harvested olive pruning samples of the first demo and 4.4 w-% d.b. from the second demo. The high amount of ash content appears due to the presence of olive leaves and soil contamination that is unavoidable in mechanized harvesting. Furthermore, the fuel analysis showed an average HHV content of 19.53 MJ/kg d.b. from the first demo's OTP samples and a slightly increased HHV content of 19.89 MJ/kg d.b. from the second demo's OTP samples. Regarding moisture content, there was an increase in moisture content in the second year's OTP samples to around 30.5 w-% w.b. from an average moisture content of 25 w-% w.b. in the first year's harvesting demo. The moisture content depends on how many days the prunings are left on soil. If olive prunings were left for more time on field before harvesting, it would further lower the moisture content of the prunings and their ash content as olive leaves would drop from the branches.

Table 3. Fuel characterization of OTP hog fuel collected during the two AGROinLOG harvesting demos in Agios Konstantinos.

OTP fuel characterization results							
		2018 Demo (30 samples)			2019 Demo (19 samples)		
Property	Unit	Min	Max	Avg.	Min	Max	Avg.
Moisture	w-% a.r.	19.2	31.3	25.2	21.8	40.5	30.5
Ash	w-% d.b.	2.9	5.8	4.5	3.2	8.2	4.4
Volatile Matter	w-% d.b.	77.2	79.7	78.4	74.8	78.6	78.0
Carbon, C	w-% d.b.	47.66	51.99	50.43	48.25	52.12	50.61
Hydrogen, H	w-% d.b.	5.61	8.38	6.79	5.54	6.35	5.96
Nitrogen, N	w-% d.b.	0.55	2.19	1.27	0.68	1.87	1.17
Sulphur, S	w-% d.b.	0.06	0.6	0.12	0.10	0.16	0.13
Chlorine, Cl	w-% d.b.	0.03	0.14	0.07	0.08	0.12	0.10
High Heating Value	MJ/kg d.b.	18.83	20.27	19.53	19.09	20.38	19.89
Lower Heating Value	MJ/kg a.r.	11.36	13.56	12.52	10.34	12.43	11.79
Bulk Density	kg/m ³ a.r.	190	300	240	180	290	210

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Regarding the major and minor elements, the appearance of calcium and silicon in the results is due to the soil contamination associated to the mechanized harvesting. In brief, olive tree prunings comply with class B graded wood chips (ISO 17225-4) apart from Cu. The average value of Cu found in olive prunings in the first year is at 32.4 mg/kg d.b. and for the second year at 20.6 mg/kg d.b. Both values are above the limit of class B (ISO 17225-4) wood chips at 10 mg/kg d.b. However, according to the upcoming standard (ISO 17725-9), the limit of copper of class B graded wood chips for industrial use will be up to 30 mg/kg d.b., thus the harvested OTP would comply with the standards. Finally, the amount of copper that is found in the analyses is a result from the copper that is sprayed on olive trees for plant protection from diseases.

In general, olive prunings have a good energy content but differ from forest biomass in terms of higher ash content. Thus, this type of biomass requires boilers with higher requirements in the systems dedicated to withdraw ashes or to clean the flue gases. Due to inhomogeneity, feeding issues (such as blockage of the feeding system) may be expected.

3.5.2 OTP Pellets

OTP pellets were collected during the pilot production at the Greek pellet plant. The raw material used for the pellet production was OTP hog fuel harvested during the 2018 harvesting demonstration; the hog fuel was stored uncovered, on unpaved ground for about one month, before it was transported to the pellet plant.

The OTP pellets exhibited an increase in the ash content: 5.5 w-% d.b. compared to the OTP hog fuels with an average value of 4.5 w-% d.b. This increase should be attributed to further soil contamination during the storage and loading of the hog fuel before transportation to the pellet plant and can be avoided through the adoption of proper storage solutions. It is however clear that even without this soil contamination, the ash content of OTP pellets is beyond the “standard” limits for domestic wood pellets.

From the regulatory perspective, the oil content detected in the pellets represents another limiting factor for their domestic usage. National legislation regarding the solid biofuels for non-industrial uses (Ministerial Decree 198/2013, FEK B/2499/2013), places an upper limit of 2 w-% d.b. of oil content for non-woody pellets. The oil content measured in the OTP pellets ranged from 2.3 to 4. w-% d.b., which can be attributed to the presence of chlorophyll from the olive leaves.

Other chemical properties are generally in line with those of the OTP hog fuel. The nitrogen, sulphur and chlorine contents are also higher than the typical values for domestic solid biofuels.

Parameters that could be controlled by the pellet plant, e.g. moisture, bulk density and mechanical durability, were at very good levels. It should be noted that high values of mechanical durability were possible to be met without the use of any additives; it is considered that the olive leaves acted as a binding agent.


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Table 4: Fuel characterization of OTP pellets.

Fuel characterization of OTP pellets					
Property	OTP pellets (6 samples-CERTH lab)				OTP pellets (1 sample at accredited lab)
	Unit	Min	Max	Avg.	
Moisture	w-% a.r.	4.4	8.7	6.3	6.5
Ash	w-% d.b.	5.4	5.6	5.5	5.3
Carbon, C	w-% d.b.	49.83	50.46	50.13	49.4
Hydrogen, H	w-% d.b.	5.85	6.38	6.17	6.2
Nitrogen, N	w-% d.b.	0.93	2.35	1.65	0.96
Sulphur, S	w-% d.b.	0.10	0.11	0.10	0.057
Chlorine, Cl	w-% d.b.	0.07	0.09	0.08	0.054
Gross Calorific Value, GCV	MJ/kg d.b.	19.58	19.95	19.76	19.55
Net Calorific Value, NCV	MJ/kg a.r.	16.74	17.34	17.11	17.00
Bulk Density	kg/m ³ a.r.	640	700	670	620
Mechanical Durability	%	98.0	98.9	98.4	97.4
Oil Content	kg/m ³ d.b.	2.3	4.1	2.9	n.d.

Regarding the major and minor elements of OTP pellets. Ca, Si, Fe and Mg are increased in pellets compared to the hog fuel. The increase in Ca and Si content is considered to be due to the soil contamination during the storage of hog fuel whereas the increase in Fe derive from the pellet production equipment. The reason for the increase in Mg is not yet defined. Regarding the minor elements, the increase in Cr and Ni derive from the pellet production equipment whereas the variation of Cu in pellets is reduced, perhaps due to the washout by rainwater. Minor elements, with the exception of copper, are below the limits of wood pellets for domestic use.

3.5.3 Conclusions

The intrinsic properties of the OTP biomass result in high percentages of ash, nitrogen and chlorine in any exploitable form of this resource (pellets or hog fuel). Improvements can be expected through implementation of appropriate harvesting and handling practices that result in reducing the collection of leaves and soil along with the woody part of the prunings. The inhomogeneity of OTP hog fuel, especially as concerns the presence of oversized particles, may be an issue for feeding systems. For OTP pellets, the production process resulted in excellent physical properties (e.g. mechanical durability, bulk density). Certification of the OTP hog fuel or OTP pellets may be possible if more care is taken to ensure that some parameters are within acceptable limits.

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3.6 Market analysis

3.6.1 Competitive solid biofuels in the Greek market


Concepts A and B involve the sales of solid biofuels made from OTP biomass: hog fuel and pellets respectively. In order to assess their potential for market deployment, the market status of competitive solid biofuels was assessed even though continuous update is needed considering the market volatility.

Excluding firewood used for domestic heating, the main solid biofuels used in Greece are: wood pellets; exhausted olive cake (and olive stones); sunflower husk pellets. Wood pellets are mostly used for the domestic heating market, while exhausted olive cake and sunflower husk pellets are used by industrial consumers. Other solid biofuels like nut shells, peach stones, rice husk have limited, local markets. Straw pellets are a niche product, used mostly for animal bedding. Finally, it appears to be a market for wood chips for industrial consumption. The table below summarizes both market information and fuel properties of the aforementioned fuels in comparison with the OTP hog fuel and pellets that could be produced from the NUTRIA IBLC.

Table 5. Comparison of solid biofuel properties¹.

Biomass fuel comparison						
	Moisture (w-% a.r.)	Ash (w-% d.b.)	Bulk density (kg/m ³ , a.r.)	NCV (MJ/kg, a.r.)	Indicative wholesale price (€/t)	Indicative wholesale price (€/GJ)
Wood pellets A1	≤ 10.0	≤ 0.7	≥ 600	≥ 16.5	190	≤ 11.5
Wood pellets A2	≤ 10.0	≤ 1.5	≥ 600	≥ 16.3	170	≤ 10.4
Exhausted olive cake	≤ 14.0	≥ 4.0 - 5.5	660	16.0	50 - 80	3.1 - 5.0
Olive stones	≤ 14.0	0.5 - 1.0	700	15.4	150	9.7
Sunflower husk pellets	≤ 12.0	4.0	540	15.7	80 - 120	5.1 - 7.6
Straw pellets	≤ 10.0	4.0 - 6.5	650	16.5	180	10.9
Wood chips	≤ 30	1.0 - 3.0	200	12.2	30 - 70	2.5 - 5.7

¹ Source: CERTH's lab analyses; Quotes from Greek pellet producer; Wood Fuels Handbook, AEBIOM; Carroll, J. P. and J. Finnan (2012). "Physical and chemical properties of pellets from energy crops and cereal straws." *Biosystems Engineering* **112**(2): 151-159.; Ukrainian Biofuel Portal "Straw pellets from Northern Europe".

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Biomass fuel comparison						
	Moisture (w-% a.r.)	Ash (w-% d.b.)	Bulk density (kg/m ³ , a.r.)	NCV (MJ/kg, a.r.)	Indicative wholesale price (€/t)	Indicative wholesale price (€/GJ)
OTP pellets	≤ 10.0	≤ 6.0	670	16.8	≥ 150	≥ 8.9
OTP hog fuel	≤ 30.0	≤ 6.0	230	12.3	≥ 50	≥ 4.1

From the comparison, it is clear that OTP pellets are a very challenging fuel to place on the market. Their fuel properties are out of specifications comparing to what is typically used in the domestic heating sector, having only a lower price advantage (if they can be sold as domestic fuels). On the other hand, their main properties are comparable to those of other established industrial solid biofuels, but due to harvesting costs their expected price is higher than the one corresponding to those alternative biofuels.

On the other hand, there seems to be some options for OTP hog fuel, provided suitable end-users can be identified at a fairly close distance. Unlike pellets, OTP hog fuel cannot be transported economically over long distances due to its lower energy density. However, the same limitation may apply to its main competitor, wood chips. The ash content and other fuel properties are worse than wood chips, so the question is finally whether they can be accepted by a potential end-user and whether OTP hog fuel can be delivered to its consumption site at a lower cost than wood chips.


The following sections investigate into more details the validation activities that have been performed within AGROinLOG at the facilities of various potential end-users of OTP pellets or OTP hog fuel.

3.6.2 Validation OTP pellets for residential heating

Regulatory limitations for using OTP pellets from NUTRIA in the Greek residential heating market have already been explained in Section 3.5.2 of this report and are related to the increased oil content of the product. In any case, the fuel specifications of OTP pellets are way beyond the limits of the A1 or A2 wood pellets often used in residential heating applications. Therefore, even if the oil content is reduced, there is always the risk that authorities might ban the sales of such pellets for air quality reasons. Such a scenario has also materialized in parts of Northern Italy even with the higher quality A2 wood pellets (Bioenergy Europe 2019).

Combustion tests of OTP pellets in residential boilers were not performed within the AGROinLOG project. However, such tests were performed in the framework of the Biomass Plus project and are available in a public project deliverable (BIOmasudplus). Three different boiler models were used for these tests, while the quality of the OTP pellets was comparable, if not somewhat better, to those produced by the AGROinLOG demonstration.

All measured pollutants (CO, NO_x, OGC and TSP) were beyond the limits of both Ecodesign (Ecodesign Regulation 2015/1189) and national regulations (189533/2011 which sets national limits for biomass central heating boilers). Elevated CO and OGC emissions from OTP combustion in domestic boilers

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may be reduced through the application of appropriate modifications / optimizations of the grate system and the combustion concept. TSP emissions can be controlled through applying an electrostatic precipitator (ESP); the limit of the national legislation may be met even without an ESP provided a suitable, modern boiler system is used. However, there are no state-of-the-art primary or secondary emission control measures capable of reducing the NO_x emissions below the limits of the Ecodesign Regulation or national legislation. Since the NO_x emissions are directly connected with the fuel nitrogen content and high nitrogen values appear to be an intrinsic part of the locally harvested OTP biomass, it can be concluded that using such fuels in small-scale, domestic boilers is not possible unless the NO_x emission limit is lowered.

In the framework of the AGROinLOG project, small quantities of OTP pellets were provided free of charge to residential biomass end-users in Agios Konstantinos who expressed interest in trying this alternative biofuel. Generally, the end-users expressed satisfaction with the energy content of the pellets and the efficiency achieved. However, they reported ash-related problems, mainly the shortening of the cleaning time intervals due to the higher ash content compared to A1 wood pellets.


3.6.3 Validation of OTP pellets for medium scale use

Using OTP pellets in medium-to-large scale applications makes more sense than targeting the residential market. The boilers used in such applications are usually designed for industrial solid biofuels. Moreover, emission limits should follow the Medium Combustion Plant Directive and may be more relaxed compared to the stricter requirements for residential applications.

Within the AGROinLOG project, the OTP pellets were validated at two such end-users. The first was a nursery greenhouse in Northern Greece, while the second was the olive oil facility of NUTRIA itself.

The nursery greenhouse could be considered as corresponding to the market segment of greenhouse heating with biomass. Greenhouses have large heating demands during the winter seasons and do not produce any combustible biomass residues of their own, hence they have to source fuel from the market. The nursery greenhouse has installed eight biomass boilers, each with 1.16 MW thermal output. During the AGROinLOG validation activities, OTP pellets were supplied to two of those boilers; the emissions (measured) and efficiency (calculated) were compared with the reference fuel used in the facility, sunflower husk pellets. The efficiency of the OTP pellets was found to be slightly decreased, however this was attributed to the lack of experience of the boiler operator with this new biofuel which had a higher energy density than the sunflower husk pellets. A proper adjustment of the feeding rate by the operator is expected to result in equal if not better results. The emissions for OTP pellets were lower for CO and NO_x emissions and higher for OGC compared to the sunflower husk pellets. With both fuels, the boiler emissions were within the MCPD limits for NO_x and SO₂ emissions. The TSP emissions however were much higher than the limits, indicating the need for installing an appropriate dust emission control device. The OTP pellets ash in the fixed grate boiler was found to be less sintered than that of sunflower husk pellets, indicating that boiler cleaning requirements would improve.

During the AGROinLOG project, NUTRIA installed a new 480 kW biomass boiler in its olive oil line. Such boilers are typically used by olive mills all over Greece in order to produce hot water for the

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process. Their operation is only seasonal, coinciding with the olive oil production period. They use almost exclusively exhausted olive cake as a fuel, which they can source at very low prices from the pomace mills to which they provide the olive pomace they produce.

During the validation activities, the boiler was fed over three consecutive days with the reference fuel (exhausted olive cake), OTP pellets and a mixture of OTP pellets and OTP powder. Generally, the emissions were quite high with all fuels and the efficiency varied from 61.4 to 80.8 % depending on the settings and fuel.


In both cases, the boilers used for the validation were relatively low-cost, robust systems designed for the combustion of exhausted olive cake. Compared to modern biomass boilers, the efficiency could be considered as acceptable, while the emissions – especially dust – were quite high. The lack of automated control options and secondary emission control systems (e.g. cyclones / ESPs) was noted. The use of OTP pellets can offer some improvements (e.g. less slagging), however their selling price is not low enough to make them competitive over the other established solid biofuels used in Greece: sunflower husk pellets and exhausted olive cake.

3.6.4 Validation of OTP hog fuel

As explained above, selling OTP in the form of hog fuel seems to be an interesting option for NUTRIA IBLC. It is a more competitive biofuel due to its reduced fuel cost. However, it faces several challenges as well. The most important requirement is the need to have a suitable feeding system, designed or adapted for larger sized particles and possibly considering some inhomogeneity of the material. Furthermore, OTP hog fuel has significantly lower (energy) density compared to pellets, thus increasing the transportation costs. In this light, its targeted end users should be in close range from the IBLC.

One such end-user has been identified in close proximity to NUTRIA. The company manufactures self-adhesive tapes in its production unit located in close range from NUTRIA. The production facility covers its large heating demands with three 10 MW biomass boilers: 2x10 MW thermal oil boilers and 1x10 MW steam boiler. The main fuels used are wood chips and sunflower husk pellets. The wood chips are usually made on-site, with a large chipper; various residual / waste wood fractions sourced from sawmills all over Greece are used for this purpose. Sunflower husk pellets are sourced from the market.

As part of the AGROinLOG project validation activities, 10 tons of OTP hog fuel from the 2019 harvesting demonstration were transported to the company. Because of the large quantities consumed daily by this particular end-user (180 t/day), it was not possible to use the OTP fuel exclusively long enough to perform emission measurements. Feedback received from the operators indicated their satisfaction with the fuel performance and that no issues were detected with the fuel feeding system. Since the production site is located in a very close distance to the harvesting site of AGROinLOG and is in fact located in the extended olive grove area of Fthiotida, establishing a supplementary fuel sourcing line with local OTP seems promising. The major challenges are a) to secure a quite large quantity that makes it meaningful for the plant operator and b) to maintain fuel costs at a very low level.

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In addition to the above, a smaller quality (around 2 tons) of OTP hog fuel was transported at the facilities of a boiler manufacturer. Among others, the company is producing a boiler model series, with capacities from 150 to 1,150 kW, capable of using both wood chips and wood pellets. The company was interested to test the compatibility of the hog fuel harvested in Agios Konstantinos with the feeding systems that could be supplied to such boilers. Generally, no major issues were identified, thus illustrating the possibility of using OTP hog fuel in such small to medium scale combustion applications.

3.6.5 Electricity production from OTP biomass


Concept C differs from the other two since the final product of the IBLC is electricity and not a solid biofuel.

The current framework for supporting renewable electricity production in Greece is based in Law 4414/2016 (FEK 149 A/2016). For most cases – including biomass power plants – the law awards a sliding feed-in premium in order to reach a specific Reference Tariff (RT). The duration for which the FiP is awarded is 20 years for most RES-E technologies. Installations receiving capital investment support or an equivalent support are subject to reductions of the FiPs varying with the level of support received and the accepted IRR, which differs per technology. The IRR is also used to set the level of the RTs. The feed-in premium scheme replaced the older feed-in tariff scheme that was set by Law 4254/2014.

In March 2020, a new Ministerial Decree (not yet published in the official government gazette) revised downwards the RT for biomass plants starting operation from 1st January 2022 and beyond. The following table summarizes the support schemes from 2014 till now. As can be seen the general trend is for a reduction in the guaranteed level of support over time, as the government considers that projects grow in maturity and are easier to be implemented. However, the reality is that the power generation from solid biomass in Greece is still in very early stages, not exceeding 12 MW in 2018. For comparison, the total installed capacity from solid biomass throughout EU-28 is 20,228 MW; Mediterranean countries like Spain and Italy are at 677 and 733 MW respectively (Bioenergy Europe 2020).

Table 6: Current support schemes for biomass electricity production in Greece.

Summary of recent biomass power support schemes						
Technology	Capacity range (MW)	Law 4254/2014	Law 4414/2016		New Decree	
		Feed-in tariff (€/MWh)	RT (€/MWh)	IRR (%)	RT (€/MWh)	IRR (%)
Biomass utilization with thermal processes: combustion or pyrolysis	≤ 1	198	184	9.0	176	8.0
Biomass utilization with thermal processes: gasification	≤ 1	198	193	9.0	185	8.0

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Summary of recent biomass power support schemes						
Technology	Capacity range (MW)	Law 4254/2014	Law 4414/2016		New Decree	
		Feed-in tariff (€/MWh)	RT (€/MWh)	IRR (%)	RT (€/MWh)	IRR (%)
Biomass utilization with thermal processes: all technologies	> 1 and ≤ 5	170	162	9.0	153	7.4
Biomass utilization with thermal processes: all technologies	> 5	148	140	9.0	133	7.4

Law 4254/2014: facilities starting operation from 1/1/2014 till 31/12/2015

Law 4414/2016: facilities starting operation from 1/1/2016 till 31/12/2022

New Decree: facilities starting operation from 1/1/2022

From a market perspective point of view, the main advantage of this concept is that the end product has a guaranteed market with a specific, set price for a period of 20 years. Therefore, the major uncertainties for this investment are related only to the reliable and cost-effective supply of OTP biomass as well as to the performance of the facility according to the specifications.


3.6.6 Conclusions

The results of the emission measurement campaign highlight the importance of choosing a modern combustion system, compatible with this type of biofuels that has all the necessary automations that will ensure a high efficiency and low emissions (e.g. automated control with lamda sensors, cyclone/ESP) and ease of use (automatic ash extraction). Adding to that, the fuel properties of the olive tree prunings are similar and, in some cases, even better than other industrial fuels.

Keeping this in mind, even though OTP pellets could compete with well-established industrial fuels, in terms of combustion efficiency and emissions, their cost is considerably higher, making them an unattractive solution for substituting industrial fuels. Thus, the value proposition offered by OTP pellets is dubious, since the product cannot be placed in the residential heating market and faces price competition from exhausted olive cake and sunflower husk pellets in the industrial market.

The use of OTP in the form of hog fuel seems to be a promising solution. It is a more competitive biofuel due to its reduced fuel cost. However, it faces several challenges as well, as its need of a suitable feeding system to burn such fuel. Furthermore, OTP hog fuel has significantly lower (energy) density compared to pellets, thus increasing the transportation costs. In this light, its targeted end users should be in close range from the IBLC. The compatibility of OTP hog fuel in properly designed feeding systems for small-scale heating applications has also been confirmed.

Finally, the main advantage offered by the sales of electricity from OTP biomass is the secured, 20-year contract with the grid operator.

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3.7 Cost structure and performance of the new business model

3.7.1 New investment / facilities required

The investment / facilities requirements in each concept are naturally different since the production process differs as well.

Concept A has minimum requirements and could proceed even with existing equipment already available in the local area (e.g. tractors, trailers, wheel loaders). Its upscaling would require additional harvesting capacity, e.g. the purchase of new integrated harvesters/shredders.


Concept B requires additional harvesting capacity, as well as investment in a dedicated pelletization line and storage infrastructure.

Concept C requires additional harvesting capacity, as well as investment in dedicated equipment used for power production from biomass.

An overview of the equipment / facilities to be used in each concept is provided in the following table.

Table 7. Comparison of equipment/facilities needed for each concept to be implemented

Required equipment / facilities needed for each concept			
	Concept A, OTP hog fuel	Concept B, OTP pellets	Concept C, OTP power plant
Harvesting	Integrated harvesters / shredders + tractors Tractors + platforms (for haulage)		
Storage	Intermediate storage area for prunings (hog fuel) Probably no roofed storage required	Intermediate storage area for prunings (hog fuel) Roofed storage required for final product	Intermediate storage area for prunings (hog fuel) Roofed storage for small amount of fuel
Feeding & Pre-treatment	Wheel loader	Wheel loader Feeding system (e.g. conveyor belt) Dryer & biomass boiler Hammer mills and other size reduction equipment	Wheel loader Feeding system (e.g. moving floor)

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Required equipment / facilities needed for each concept			
	Concept A, OTP hog fuel	Concept B, OTP pellets	Concept C, OTP power plant
Production Stage	-	Pellet mill Pellet cooling, bagging & storage lines	Gasification System & internal combustion engines
Transportation to final consumer	Trucks (bulk)	Fork lifter (for loading) or wheel loader Trucks (bulk, big bags or pallets)	Medium voltage grid connection

3.7.2 Cost structure for OTP hog fuel concept

For the hog fuel concept, the main costs are associated with the harvesting and haulage of the OTP biomass from the field, followed by its subsequent transportation to the end-users.

Based on the harvesting demonstrations carried out during the project, the cost of harvesting and transporting the prunings in hog fuel form at NUTRIA's plant is estimated at 33 €/t (wet basis) or 45 €/t (dry basis). The cost structure is presented in detail in Section 3.2.2.


In this concept, no new investments are required. New personnel required would be 5 seasonal employees in the harvesting and transportation of hog fuel to NUTRIA and one part-time employee that would attract and interact with customers.

In relation to the transport costs, NUTRIA is placed close to the highway that connects Athens to Thessaloniki and fairly close to some large consumption centres. An estimation of transport costs is around 0.13 €/t_{w.b.}·km (based on the transportation costs of hog fuel from NUTRIA to the pellet plant during the pellet production demonstrations performed in the project). For a transport distance of 150 km, the impact on the biofuel is in the range of around 20 €/t_{w.b.}.

The revenues are generated by the sales of OTP hog fuel to the end users. For the basic concept, where NUTRIA continues with the existing equipment and facilities, the commercialization of 2,500 tons hog fuel will increase the annual turnover of NUTRIA by 125 k€, by assuming a selling price of 50 €/t_{w.b.} at the IBLC gate.

Table 8. Estimated cost structure of Concept A – OTP hog fuel and sales

Assumptions on financial values, costs and processes used for OTP hog fuel commercialization concept	
OTP production (hog fuel)	2,500 t (a.r.)
CAPEX	20,000 €
Raw material costs	82,500 €/y

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Assumptions on financial values, costs and processes used for OTP hog fuel commercialization concept

Production costs	-
Revenues	125,000 €/y

3.7.3 Cost structure for OTP pellet concept

For the OTP pellet concept, the harvesting costs and transportation of the raw material are the same as in the previous concept. It is considered that three harvesters (around 20,000 € purchase cost per harvester) in total will be needed for the mobilization of around 8,000 t_{w.b.} of prunings, required for the targeted production of 5,000 t_{w.b.} OTP pellets.

Apart from the harvesting cost, there is another production cost in this concept, that of the pelletization of olive tree prunings. Based on discussions with Greek pellet producers and the monitoring of the OTP pellet production during the project, it has been estimated a pellet production cost of 80 €/t_{w.b.}. In this cost, it is included the one related to the pretreatment processes (drying and milling) as well as the one associated to the pelletizing and packaging process.

For the individual pellet line of 1 t/h, a total investment of around 0.6 M€ will be needed (based on quotes from pellet manufacturer).


In relation to the transport costs of OTP pellets from NUTRIA, an estimation of transport costs is around 0.04 €/t_{w.b.}·km (based on transportation costs monitored during the demonstrations in the Greek IBLC). Thus, for a transport distance of 150 km, the impact on the biofuel is in the range of 6 €/t_{w.b.}.

For the personnel that would be needed in the concept of the pellet plant, three full time workers per shift and two shifts would be needed, thus 6 workers per day. A seventh specialized operator would be in charge of the maintenance and supervision for the two production shifts. Again, around 15 seasonal employees would be needed for the harvesting of prunings. Another one person will be needed for administration, logistics and sales activities.

For the case where OTP pellets are produced, it has been estimated that these pellets could be sold in the Greek market at a price around 150 €/t_{w.b.}. For an annual production of 5,000 t of OTP-pellets, NUTRIA will generate revenues of around 0.75 M€ per year in this new business.

Table 9. Estimated cost structure of Concept B – OTP pellet production and sales

Assumptions on financial values, costs and processes used for OTP pellet production concept	
OTP pellet produced (6.5 w-% moisture, a.r.)	5,000 t/y
CAPEX	660,000 €
Raw material costs	264,000 €/y

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Assumptions on financial values, costs and processes used for OTP pellet production concept	
Production costs	400,000 €/y
Revenues	750,000 €/y

3.7.4 Cost structure for OTP power plant concept

For the power plant concept, the main cost that would be incurred is the CAPEX for the construction of a new, 1 MWe power plant. The estimated cost for the investment is based on the case of a gasification power plant and is assumed to be in the range of 4 M€. Additional investments in harvesting capacities would also be required, although compared to the power plant investment they are assumed to be marginal. For mobilizing 8,000 wet ton of OTP, three harvesters will be needed. The costs related to harvesting and haulage of OTP is the same as in the abovementioned concepts.

OPEX requirements for the plant operation are both fixed and variable:

- Fixed OPEX costs include personnel costs, scheduled maintenances, equipment / component replacements, insurance, etc. For bioenergy plants using gasification, fixed OPEX costs can be estimated as 4.5 % of the total installed costs per year (IRENA 2019).
- Variable OPEX is assumed to be relatively low, around 3.8 €/MWh. They include things such as ash disposal and unplanned maintenance and equipment / component replacement.


For this concept, the power plant is assumed to be generating around 4,270 MWh. The produced electricity will be delivered and sold to the national grid. The additional personnel that will be needed will be 9 permanent employees operating in the power plant and 15 seasonal employees in pruning harvesting and transportation.

No distribution or commercialization costs are needed in this concept, as the only customer of the OTP hog fuel is the power plant.

For the case of the power plant, the main revenue for NUTRIA will be coming from the sale of electricity to the grid. With a reference tariff of 185 €/ MWh, the turnover of NUTRIA would increase by around 0.8 M€ annually.

Table 10. Estimated cost structure of Concept C – OTP biomass power plant

Assumptions on financial values, costs and processes used for Power Plant concept	
MWh generated	4,270 MWh/year
Net Electrical efficiency	15 %
CAPEX	4,000,000 €

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Assumptions on financial values, costs and processes used for Power Plant concept


Fuel costs	264,000 €/y
Fixed OPEX	112,500 €/y
Variable OPEX	16,000 €/y
Revenues	790,000 €/y

3.7.5 Conclusions

At a first glance, from the comparison of the concepts, the hog fuel concept seems to be a profitable concept for implementation in the IBLC. However, it is considered that all the production of hog fuel is sold, which is the big question regarding the market demand of such product. Moreover, this concept is vulnerable in case unexpected costs arise, that will influence significantly the profits. Moreover, in terms of absolute numbers, the turnover of such concept (~125 k€) is relatively low compared to NUTRIA's current turnover (~32 M€).

For the pellet plant scenario, the economic results are acceptable with a selling price of 150 €/t. Nonetheless, this value is already high compared to other industrial fuels, thus, such concept cannot be considered viable as the market demand would be dubious for an industrial fuel with such a high cost.

Finally, the concept with the power plant seems to be the most promising one. The economic results conclude that the power plant concept is an economical viable investment. Moreover, the main advantage offered by the sales of electricity from OTP biomass is the secured, 20-year contract with the grid operator.


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4 ADDITIONAL IBLC ACTIVITIES IN THE OLIVE OIL SECTOR

4.1 Concept of TPOMW IBLC, high replicable on pomace mills

It is worth pointing out that during the AGROinLOG proposal preparation phase, NUTRIA was considering the expansion of its activities by building a new TPOMW processing plant, essentially a new pomace mill. Despite envisaged as a state-of-the-art facility, actually the pomace mill on its own is nothing new and several such plants operate in Greece. The key point for AGROinLOG was that the TPOMW (two phase olive mill waste) facility would include a drying plant, that was also to be evaluated in its potential as a drying plant for olive tree prunings, before their pelletization. Based on these process lines, a TPOMW concept of IBLC was developed, that can be replicable in pomace mill industries and exploit synergies with the idle time of the pomace dryer. This TPOMW concept was thoroughly examined in the AGROinLOG project, offering various new business activities to the IBLC.

Hence, the TPOMW concept examined (Figure 14) includes a TPOMW treating unit and an investment in a new pellet line which uses the pomace dryer. This is a more complex approach and introduces a higher degree of synergies in terms of equipment use. Such a business concept could be replicated by other pomace mills, which operate anyway in areas with high olive tree pruning biomass potential. Furthermore, due to the complexity of the pomace mill as an industry, more synergies are offered that can be further assessed and investigated for the conversion of a pomace mill to an IBLC, such as the heat integration of its processes, the separation of olive pits from the flesh and skin of the fruit, making them a better quality fuel than the exhausted olive cake, the installation of a CHP unit, fuelled with exhausted olive cake and OTP etc.

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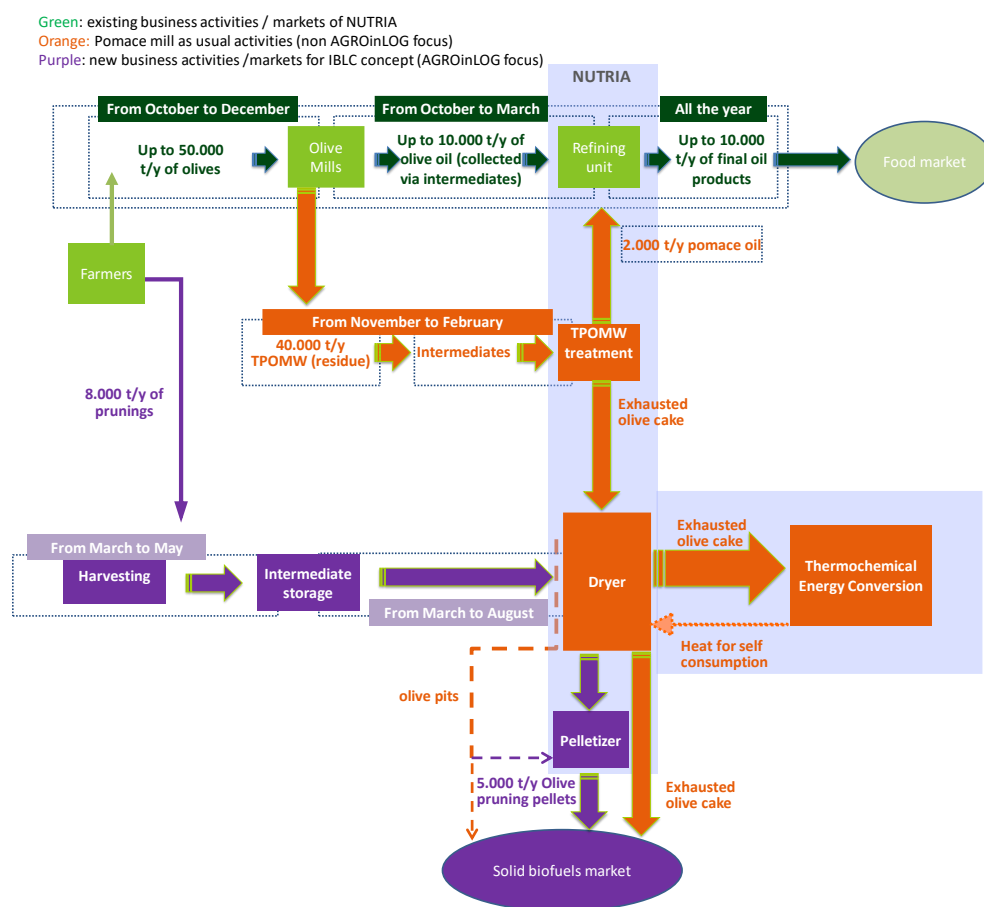



Figure 14. TPOMW IBLC plant process scheme.

4.1.1 Exploiting the TPOMW dryer

The main advantage in the TPOMW IBLC concept is the synergy that is offered by the TPOMW dryer of the pomace mill during its idle time. In general, pomace mills are operating from November to February (duration may vary from region to region). Thus, there is enough time for the agro-industry to exploit its idle facilities. In this sense, the TPOMW dryer was investigated for its ability to dry OTP, prior to their pelletization.

After contacting various pomace mills located in Greece, as concerns the capacity of their dryers to dry the harvested OTP, the operators highlighted that the inhomogeneous size of the harvested OTP is a bottleneck for implementation. The large size pieces of the harvested OTP could cause problems to the dryer. Thus, a further process would be needed to feed an already installed TPOMW dryer with the inhomogeneous harvested OTP. A solution for a pomace mill to exploit its already installed dryer for the prunings would be the following. A sieve would be needed in order to separate the large particles from the rest particles of the harvested prunings. Continuously, a small scale chipper would be needed to further reduce the size of the sieved large particles. Another option would be to invest on a higher capacity chipper in order to chip all the amount of harvested prunings, without the sieving step. However, the operational costs for reducing the size of all the harvested material

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would be higher than chipping only the large particles of OTP. Finally, both the chipped material along with the small particles of harvested OTP could feed the already installed TPOMW dryer.

Regarding the case of OTP drying in new pomace mill facilities, this option is most relevant for any new pomace mills facilities that wishes to replicate the IBLC concept. For this purpose several TPOMW dryer providers that could offer specific technical solutions were contacted. The feedback from various international TPOMW dryer manufacturers was that green-field TPOMW dryers could dry both TPOMW and harvested OTP without the need of any milling step beforehand.

4.2 Bio-commodities from an olive oil sector IBLC

Apart from the previously mentioned new activities that can be implemented by an IBLC in the olive oil sector, additional business pathways can also be derived by exploiting the available by-products of the olive oil sector.

4.2.1 Particle Board Production from OTP

Apart from the exploitation of olive prunings for energy purposes, the production of other bio-commodities such as particleboards, used in the construction and furniture sector, may be applied. In this light, AGROinLOG project investigated the potential of producing particleboards from olive prunings by replacing common wood at 20 %, 40 %, 60 %, 80 % and 100 % rate.

Different samples of olive tree prunings harvested during the demonstrations in Agios Konstantinos, Central Greece in terms of olive variety, pruning thickness (pruning diameter) and presence of olive leaves, were used for testing the production of particleboards.

The obtained particleboards were tested for their tensile strength, thickness swelling, modulus of rupture and modulus of elasticity, moisture resistance and formaldehyde emission, in accordance with the current European standards, and compared with the same values of reference associated to particleboards produced from conventional wood material.


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Figure 15. Particleboards produced (UF resin) from reference wood (a), particle boards produced with 40% (b) and 100% (c) substitution from harvested with integrated mulcher/harvester prunings, 40% substitution with prunings with leaves, separated manually (d), and 40% substitution with firewood (thick olive prunings, e)

The evaluation of the results has led to the conclusion that it is possible to produce panels with up to 100 % substitution of the conventional wood with olive pruning materials. Based on the results achieved, a maximum substitution level of 40 % of the conventional wood with pruning material can be applied. The mechanical properties of the panels are reduced by increase of the substitution level. This may be attributed to the higher amount of bark compared to the conventional wood chips, which are produced from debarked wood logs. On the other hand, particle board properties such as the formaldehyde emissions of the boards (along with the thickness swelling) are reduced by increase of the substitution level, which makes the panels safer in terms of indoor pollution and human health and more consumer friendly and attractive.

The use of biomass from olive tree (and possibly other species too) pruning may be one of the solutions to tackle the problem of timber shortage and the growing cost of it, due to the shrinkage of forests and the growing demand for wood to produce products and energy.

4.2.2 Extraction of phenolic compounds from olive oil sector residues

The cultivation and processing of the harvested olive fruits yields various by-products such as field residues (leaves, prunings) and mill residues (pomace, exhausted olive cake), that consist an interesting source of phenolics. Olive leaves (OL) are known to be rich in polyphenols which may vary by cultivar, season or geographical location. Olive pomace and especially two-phase pomace (TPOMW) are also rich in phenolics.

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The total polyphenols market was estimated in 2010 to about 2.2k t of polyphenols (Frost and Sullivan) whereas, it is calculated that Greece has an annual discharge of polyphenols of about 2.4k t polyphenols. That implies a huge resource for polyphenols extraction that remains unexploited.

However, the options for integration of phenol extraction technology in the olive mill facilities needs further evaluation as the volume of the market for specific extracts is not yet known. Protocols for extraction of (poly)phenolic components (such as oleuropein, hydroxytyrosol, chlorogenic acid or verbascoside) have been described in literature.

In the frameworks of AGROinLOG, extraction tests were performed on various olive mill waste residues with different solvents. Quantitative analysis showed OL (olive leaves) and TPOMW (two-phase olive mill waste) contained the highest content of phenols compared to the other samples (exhausted olive cake, OTP, bark etc.), with a content of phenolics of 15.7 and 12.4 g of phenols/ dry kg solids of residue respectively. In addition, some of the phenolic components were identified in the extracted phenols such as oleuropein, hydroxytyrosol, 1,2 dimethoxy benzene, rutin and caffeic acid. By using different kind of solvent, not only the amount of phenolic compounds extracted was different but also the type of phenols extracted differed. In terms of quantity, methanol and ethanol resulted in higher amounts of total phenolics extracted than using ethyl acetate or butanol. Methanol and ethanol solvents had similar extraction results, however, methanol resulted in slightly higher extraction yields.

Recent biochemical, pharmacological and other studies have shown that (poly)phenols possess strong radical scavenging capacities and can play an important role in for example protecting against oxidative damages and cellular aging. Some of the phenolic extracts have been patented leading to commercial applications. In the market study developed, different valorization route concepts, regarding the extracts from the AGROinLOG tests, were designed. Extraction methodologies, the form of the final extraction and the content of the target compounds were taken into account. Considering the outcomes of the aforementioned tests, extracts of olive leaves and TPOMW may be used for cosmetic, nutraceutical and food applications, but again further treatment and/or clarification is advised to increase the possibilities of finding applications on the food sector. In one of the extraction tests performed, a concentrated liquid of 50 mL was obtained from 200 g olive leaves using 3 L MeOH. This concentrated liquid contained oleuropein, caffeic acid, rutin and 3-hydroxytyrosol; compounds that can be used for cosmetic applications as described above. If drying is possible, the final product could reach a value of 3.62 € / kg. Moreover, in another extraction test with TPOMW, a concentrated liquid was obtained using MeOH. This concentrated liquid contained 3-hydroxytyrosol and 2(4-hydroxyphenyl) ethanol, compounds that can be used for cosmetic applications as described above. If drying is possible, the final product could reach a value of 2.86 € / kg. Apart from the market values of the extracted phenolic compounds, an inventory was made for barriers and the effect of the National policy (Greece) for bringing olive mill processing by-products to the market.

The options for integration of phenol extraction technology in the olive mill facilities need further evaluation as the volume of the market for specific extracts is yet not known. Olive leaf products and extracts can be obtained commercially as health products from various suppliers to high value

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markets such as cosmetic, pharmaceutical, nutraceuticals, food & beverage industries. Suppliers can be found especially from USA and China. Up to now (April 2020), the olive polyphenols market is in its nascent stage, as the number of extraction plants is low and the demand for olive polyphenols has been limited by reduced market offer. However, this state of the market is about to change if more applications and sustainable solutions will be explored.


4.2.3 OTP pellets as animal bedding

An interesting possibility that can “revive” the pellet concept is to sell OTP pellets as an animal bedding material. Indeed, pellets from forest wood or “alternative” biomass feedstocks suggested for animal bedding can be found in various countries and it seems that straw pellets available in Greece are mainly targeting this market segment.



Figure 16. Use of OTP pellets as bunny litter

OTP pellet was used as a bedding in a bunny’s house. The pet owner highlighted her satisfaction for using the OTP pellets, commenting that they have better smell and their color is darker so the bunny’s house looks cleaner. In addition, the OTP pellets do not disintegrate into very fine dust when wet. Although extremely limited in scope, this activity indicated the potential of selling OTP pellets in the niche market of animal bedding. In fact, it seems that in this market, the OTP pellets may even be sold at a premium compared to wood pellets since their properties are better. Animal bedding appears to be an interesting market for already established agropellet producers in Europe or USA. However, there are many uncertainties regarding the actual size of the market in Greece or other European countries, since based on the knowledge achieved, there are no published market studies. It should also be noted that there may be additional, currently not foreseen costs related to marketing OTP pellets as animal bedding: for example, tests required to demonstrate that the material is non-toxic and suitable for animal use, more thorough cleaning to ensure very low levels of fines, distribution of smaller volumes for the pet market, etc.

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5 IBLC IMPLEMENTATION IN THE AGRO-INDUSTRY OLIVE SECTOR

5.1 Advantages and drawbacks


Each of the three concepts evaluated for NUTRIA has its own advantages and disadvantages. A comparison between the concepts as concerns different parameters of the value chain.

Table 11. Pros and Cons for each IBLC concept to be implemented by NUTRIA

Comparison of the different NUTRIA IBLC concepts				
		Hog Fuel (Concept A)	Pellet Plant (Concept B)	Power Plant (Concept C)
CAPEX requirements		Minimum to no additional CAPEX required	Small to medium CAPEX requirements (in the range of 0.6- 1 M€)	Very high CAPEX (in the range of 4-8M€)
Biomass mobilization & harvesting		Up to 2,500 t can be mobilized with existing equipment Up to 8,000 t can be reached with additional harvesting capacity Mobilization can be downsized in case of lack of demand	High amount of prunings to be mobilized (8,000 t), requires additional harvesting capacities	High amount of prunings to be mobilized (8,000 t), requires additional harvesting capacities Mobilization cannot be downscaled without significantly affecting the profitability of investment
Product quality		Low energy density Inhomogeneous particle size Worse fuel properties than wood chips	High energy density Homogeneous particle size Worse fuel properties than wood chips / improved fuel properties compared to other industrial solid biofuels	Not applicable

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Comparison of the different NUTRIA IBLC concepts				
	Hog Fuel (Concept A)	Pellet Plant (Concept B)	Power Plant (Concept C)	
Market demand & size	<p>One large industrial end-user in 30 km</p> <p>Two biomass power plants in 150 – 200 km</p> <p>Other potential end-users have to be further evaluated</p> <p>Local heating demand has to be created</p>	<p>Ability to transport OTP pellets to far-away industrial consumers</p> <p>Demand subject to fluctuations (e.g. competitive fuel prices, weather conditions, etc.)</p> <p>Residential sector cannot be targeted due to regulatory requirements</p>	<p>Guaranteed demand for renewable electricity, with fixed tariff for 20 years</p>	
Revenues	Up to 50 EUR/t of OTP hog fuel sold	Up to 150 EUR/t of OTP pellet sold	<p>185 EUR/MWh (gasification power plant) or 176 EUR/ MWh (combustion plant)</p>	
Storage requirements	Medium storage needs for the OTP hog fuel	Very high storage demands. Apart from the storage area for shredded OTP, indoor storage for the OTP pellets is required	High storage demands for the OTP hog fuel	
Job creation	Seasonal job creation	Many new job positions created	Many new job positions created, including permanent ones	
Air pollution	Avoidance of some open-field burning activities and reduction of local air pollution	Major contribution in the minimization of open- field burning activities and reduction of local air pollution	Major contribution in the minimization of open- field burning activities and reduction of local air pollution	
Rural community	Low impact on the local rural community (economically and environmentally)	High impact on the local rural community (economically and environmentally)	High impact on the local rural community (economically and environmentally)	

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Comparison of the different NUTRIA IBLC concepts			
	Hog Fuel (Concept A)	Pellet Plant (Concept B)	Power Plant (Concept C)
Other factors to be considered	<p>End users reap most of the economic benefits of pruning use</p> <p>Local demand (e.g. for heating boilers has to be created)</p> <p>Activity can be terminated if end-users lose interest</p>	<p>Need to secure the supply of feedstock. Value proposition is currently questionable</p> <p>OTP pellets are more expensive than other solid biofuels for industrial consumption. They are cheaper than the currently used biofuel in domestic boilers but present a reduced quality, additionally current national legislation forbids their domestic use.</p> <p>Creating demand for OTP pellets in new facilities would require a significant effort.</p>	<p>Need to secure the supply of feedstock.</p>

In short:

- Concept A offers limited risks due to lower level of investment. The concept is based on the assumptions that there are end-users willing to pay 50 EUR/t of OTP hog fuel (at NUTRIA's storage yard), going up to 60 EUR/t delivered at their plant. However, there are uncertainties that should be taken into account, since potential end-users have not yet confirmed their interest. In addition, there is always the possibility that other companies / actors will implement the same concept in closer proximity to the end-users, pushing NUTRIA out of this market.
- Concept B seems to be the most complicated business line to develop. It presents risks both on the side of raw material supply (sourcing of OTP biomass) as well as on the product demand side (market of OTP pellets). The profit margin does not seem sufficiently profitable to justify investing under the current market conditions.
- Concept C presents the same risk on the raw material supply as Concept B, however demand and prices are guaranteed. The investment level is quite high, so the investment risk is even higher.

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6 LESSONS LEARNED

Throughout the duration of AGROinLOG project several lessons learned were acquired regarding the implementation of an IBLC in the olive sector, and more specifically in NUTRIA.


Some general points and important factors to be considered, independently of the concept of IBLC to be implemented:

- The logistics of harvesting and transporting the olive tree prunings from the field to the storage area is one of the most crucial steps in such an IBLC, affecting the cost of the final product. Thus, much attention should be given to the design and implementation of the olive pruning value chain from field to the IBLC.
- The harvesting step affects not only the price of the end product but also its quality (e.g. the wrong pick-up system could lead to increased soil contamination or stones in the harvested material). Thus, the harvesting solution that is implemented should be chosen carefully.
- The vigorous varieties of olives around NUTRIA area and the, mainly, flat olive groves with long distances between trees are important parameters that facilitate the realization of a value chain that exploits olive tree prunings.
- The use of fleece seems a very promising option for maintaining the biomass quality under long-term storage.
- An important sensitization campaign in the area of the IBLC ensures social acceptance by local population and informs farmers for other treating methods of prunings than burning them. Farmers should be well informed and realize the cost savings that can be achieved by letting people, with access to mechanized equipment, perform the management of prunings.
- The IBLC should be in close communication with farmers and the local agricultural cooperatives in order to secure the feedstock supply. The implementation of an IBLC for the valorisation of olive tree pruning requires the active collaboration of farmers and cooperatives. It is necessary to develop alliances between the local authorities and the agricultural sector. All actors involved in the value chain, should have gains by implementing such pruning exploitation method.

Some lessons learned related to Concept A, OTP hog fuel sales:

- The most important parameter in this concept is the search and finding of end-users with appropriate feeding systems, able to consume OTP in hog fuel form.
- The target selling price of hog fuel (> 50 €/t at NUTRIA), and its fuel quality, makes it a promising biofuel for the industrial sector.
- The low bulk density ($\sim 230 \text{ kg/m}^3$) of hog fuel, does not facilitate the long distance distribution of the product. End users in close range from the IBLC should be targeted (less than 150 km distance).


Some lessons learned related to Concept B, OTP pellet sales:

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- The fuel properties of the OTP pellets are similar and, in some cases, even better than other industrial fuels. However, even though OTP pellets could compete with well-established industrial fuels, in terms of combustion efficiency and emissions, their selling price of 150 €/t and more, makes them an unattractive solution for substituting industrial fuels.
- Targeting the residential pellet market is not a viable possibility for NUTRIA. The OTP pellets produced are out of regulatory specifications as concerns the oil content, exhibit worse properties than wood pellets for most parameters (e.g. ash, nitrogen, chlorine, etc.) and would result in high emissions of NO_x in residential boilers (CO, OGC and dust emissions could be controlled through the use of efficient combustion systems and secondary measures).
- Investigation of alternative markets for OTP pellets, such as animal bedding, seems a promising alternative.

Finally, for Concept C, OTP biomass power plant:


- The current support scheme secures the revenues for 20 years for the IBLC; however, a high initial investment is needed.
- Securing stable OTP biomass consumption throughout the year is required. Apart from harvesting large volumes of biomass, storage should be carefully planned.

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7 CONCLUSIONS

In brief, the present report intended to analyse and summarize all the results obtained and reported in the different activities performed during the AGROinLOG project, towards the conversion of an agroindustry in the olive sector into an IBLC. The majority of activities in the AGROinLOG project, have been focused on the exploitation of olive tree prunings as a main activity of an IBLC. Based on the abovementioned concepts, different new products are obtained with different market potential: i) OTP hog fuel, ii) OTP pellet, iii) electricity. During the AGROinLOG project, activities have been performed to demonstrate / validate / prove the technical feasibility of each value chain step for the three main concepts, thus evaluating all possible pathways of NUTRIA towards its conversion into an IBLC.

Even though OTP pellets could compete with well-established industrial fuels, in terms of combustion efficiency and emissions, their cost is considerably higher, making them an unattractive solution for substituting industrial fuels. As a result, the concept where NUTRIA invests on a pellet line is slightly risky as their absorbance in the market is still questionable. On the contrary, the use of OTP in the form of hog fuel seems to be a promising solution. It is a more competitive biofuel due to its reduced fuel cost. However, it faces several challenges as well, as its need of a suitable feeding system to burn such fuel. Furthermore, OTP hog fuel has significantly lower (energy) density compared to pellets, thus increasing the transportation costs. In this light, its targeted end users should be in close range from the IBLC. Finally, the concept of power plant could be the most rational one when mobilizing high quantities of raw material, as the whole amount of harvested OTP would be consumed to generate power, thus securing the demand of the harvested OTP. In addition, with a guaranteed reference tariff for 20 years, the investment of NUTRIA in such IBLC concept, seems to be the most profitable.

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