EXPLOITATION OF OLIVE TREE PRUNINGS. EVALUATION OF AN INTEGRATED HARVESTING DEMONSTRATION IN CENTRAL GREECE

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ABSTRACT: The aim of the present paper is to evaluate the most extensive olive tree pruning (OTP) harvesting demonstration ever occurred in Greece. In Fthiotida region (NUTS 3, Central Greece), an integrated harvester/ shredder (FACMA COMBY TR 200) was used to harvest the local olive groves of Agios Konstantinos. The pruning value chain included: i) windrowing prunings in rows on the olive groves; ii) harvesting and shredding the prunings (leaves included) from the rows with the harvester; iii) discharging prunings on platforms and finally iv) transporting prunings to a storage site where the loads were weighted via a weighbridge. The harvesting demonstration lasted for 14 days where around 54 ha of olive groves were harvested that amounted to 232 wet tons of harvested prunings (25% w/w average moisture content). The harvesting cost resulted to 58 €/harvested dry ton of pruning and produced emissions calculated at 36 gCO_{2eq}/kg of dry harvested pruning. Aim of the current paper is to evaluate the whole pruning value chain during the harvesting demonstration in terms of biomass productivity (tons of prunings per ha), performance of harvester (working times, fuel consumptions) and transportation of prunings (fuel consumptions) into nearby storage area. Furthermore, an economical evaluation of the whole demonstration is performed along with a cost-breakdown of the pruning logistics. The costs include cost of the harvester, fuel costs of the harvester and the transportation platforms, renting costs of tractors and platforms, and labor and driver costs.

Finally, samples of harvested prunings were collected for key fuel properties analysis. Harvested olive prunings were analyzed in order to investigate their potential for energy use and examine how has the harvesting methodology influenced their fuel properties. The fuel characterization was performed by applying established standards and the results will be presented on the current paper.

Keywords: olive tree prunings, harvesting, agricultural residues, solid biofuel, demonstration

1 INTRODUCTION

Olive tree groves are a typical crop of the Mediterranean landscape that generate substantial amounts of residual biomass. Prunings (branches and shoots of fruit trees) produced from the Southern European Countries amount to around 8 Million dry tons [1]. Until now, the management of pruning residue has generally represented a disposal problem, rather than an opportunity for additional revenue. Prunings are either mulched, or in the majority of cases, piled and burned in open-fires. However, olive tree prunings (OTP) represent an abundant source of energy biomass, or raw material for added value products, still largely unexploited due to the lack of cost-effective harvesting technology. Prunings can be used as solid biofuels in chip or pellet form for heating applications or as feedstock in power plants [2-5]. In addition, they can also be feedstock for bio commodities (e.g. particle board by replacing wood, bioethanol, paper etc) [6].

Harvesting is a key stage that influences the product quality, the type of logistics chain and the economic sustainability of the pruning supply chain. Exploiting such residues entails creating a sustainable and cost-effective supply chain in which the harvesting and initial processing of the residues play a crucial role. Thus, the outcome of the present paper is to evaluate a real olive pruning harvesting value chain and export main results on the feasibility and performance of such configuration, along with the fuel analysis of harvested olive prunings.

2 HARVESTING DEMONSTRATION IN CENTRAL 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€ (2014) [7]. Greece is the third olive oil country in terms of olive oil productivity worldwide. 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 39,000 ha of olive groves [8]. The aim of the current paper is to evaluate a harvesting demonstration of olive prunings performed in Agios Konstantinos. Agios Konstantinos' agriculture depends mainly on olive tree production. Agios Konstantinos has around 750 ha [8] of olive groves producing two main edible olive varieties (Kalamon and Amfissis). Olive farmers in Agios Konstantinos prune their olive trees once every year. In comparison with other olive areas in Greece, Agios Konstantinos has olive groves with high biomass productivity [9]. The current common practice to deal with olive prunings in Agios Konstantinos, is that of mainly burning them in open fires inside the olive groves or mulching them on soil. The former practice is a threat for starting fires in the olive groves and the latter option consist a threat for transmitting soil diseases. Thus, Agios Konstantinos was considered an interesting case study for performing a harvesting demonstration of olive tree prunings for their exploitation.

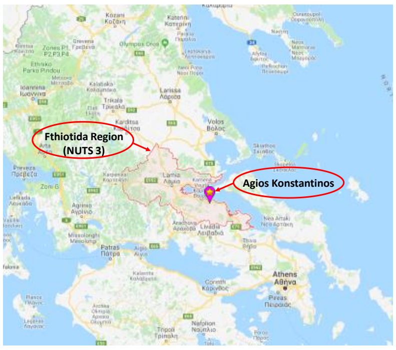

Figure 1: OTP harvesting demonstration in Agios Konstantinos, Fthiotida, Central Greece

For the harvesting needs, an integrated harvester/ shredder Comby TR200 (**Figure 2**) was used which is manufactured by the Italian company FACMA. The harvester, attached to a 125 hp tractor, drives over the aligned olive prunings (**Figure 2**) and harvest them by shredding them and keeping them in its automated lifting bin. The produced material (**Figure 5**) is an inhomogeneous material that its size varies and can be labeled as “hog fuel”. Furthermore, the produced material includes the woody part of the prunings along with the leaves.

Figure 2: Left: Alignment of olive tree prunings before harvesting; Right: FACMA Comby TR200 harvester used in the demonstration

The value chain of the harvesting demonstration of olive prunings is depicted in **Figure 3**. 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 be dried more and be separated from as many leaves as possible. 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 m^3 volume). After the bin gets full of harvested prunings, the harvester discharges the prunings onto platforms (attached to tractors) waiting at field side (**Figure 4**). After the platform is fully loaded with harvested material, it is sent to a storage area of an intermediate biomass logistic centre in Agios Konstantinos (**Figure 4**). All harvested olive groves are within a radius of 3km from the storage area. During the demonstration, two platform trailers were used for biomass haulage from the fields to the storage area in order not to have idle time while harvesting. In this light, while a platform was full and on its way to the storage area, the harvester continued harvesting and discharging the chipped prunings on the second platform waiting on the field. By the time this platform got full of harvested prunings, the first platform would have returned from the storage area. Every platform, before discharging its load on the storage area, it measured its net weight of harvested prunings on a weighbridge of a company next to the storage area. Both harvesting of prunings with FACMA and the biomass haulage were performed by the members of the local Agriculture Co-operative of Agios Konstantinos- Lokridas.

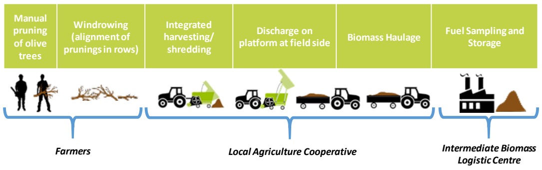

Figure 3: OTP harvesting demonstration value chain in Agios Konstantinos, Fthiotida, Central Greece

Figure 4: Left: Discharging harvested prunings on platform; Right: Storage area of harvested prunings

Figure 5 illustrates the harvested olive prunings. The shredded material has an inhomogeneous character and its particle size varies, with over 75% of the harvested OTP to have a particle size between 45mm to less than 3.15mm.

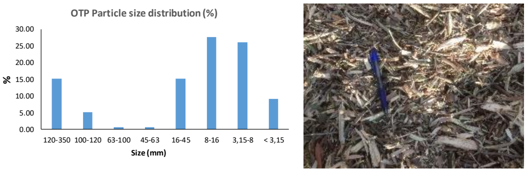

Figure 5: Left: OTP Particle size distribution (mm) as produced from harvester; Right: Harvested olive prunings

3 Harvesting Demonstration Results

The most extensive harvesting demonstration of olive prunings so far in Greece was performed in April- May 2018. The aim of this paper is to evaluate a real pruning value chain in terms of performance (times, weight of harvested material) and economics (fuel consumptions, logistics costs) and environmental impact. The full extent of the harvesting demonstration will be analysed in order for it to consist a stepping-stone for establishing such value chains for pruning exploitation.

3.1 Harvesting Results

The harvesting demonstration lasted for 14 days where 232 wet tons or 174 dry tons (25% w/w average moisture content) of prunings were harvested from 53.8 ha of olive groves, resulting into an average of 4.3 wet tons of prunings harvested per hectare. The olive groves harvested in Agios Konstantinos are depicted in **Figure 6**.

Figure 6: Harvested olive groves in Agios Konstantinos, Fthiotida region.

Figure 7 and **Figure 8** present the harvested prunings for each demo day in correlation with the harvested area of olive groves and the fuel consumption of the harvester. The harvester consumed 17.2 litres of diesel per hectare harvested and resulted into 5.3 litres of diesel consumed per dry ton of harvested prunings. Regarding the biomass haulage, 8.8 litres of diesel per harvested hectare were consumed resulting to a consumption of 2.7 litres diesel per dry ton of harvested prunings. In total, during the whole harvesting demonstration, 1402 litres of diesel were consumed (927 litres by the harvester and 475 litres for the biomass haulage from the fields to the storage area by the two platforms), or 8 litres per dry harvested ton.

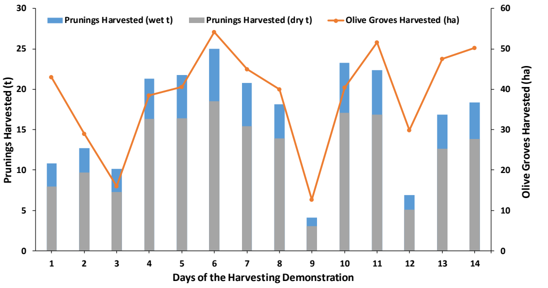

Figure 7: Harvested prunings (wet and dry tons) and total harvested olive groves (hectares) for each demo day

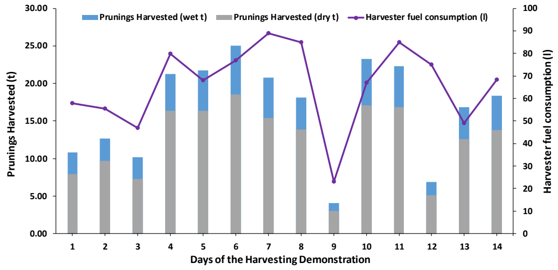

Figure 8: Harvested prunings (wet and dry tons) and harvester's fuel consumption (litre) for each demo day

The whole harvesting demonstration lasted for around 78 hours of net harvesting time (without considering breaks or machine failures) that accounted to 0.69 hectares of olive groves harvested per hour.

Figure 9 presents the net harvesting efficiency of the harvester along each day during the demonstration. The harvesting efficiency is calculated as the dry tons of prunings harvested per hour. The average net harvesting efficiency during the demonstration was at 2.2 dry tons per hour. From the following graph, it can be seen how local actors improved during the duration of the demonstration in terms of harvesting efficiency. As it was the first time that harvesting of olive prunings was performed, harvesting efficiency started from a low efficiency of 1.6 dry t/hr and increased every day to reach an average value of 2.2 dry tons per hour. This was due to the fact that every day, the participating local actors (farmers, machine operators etc.) acquired experience based on their roles in the harvesting OTP value chain.

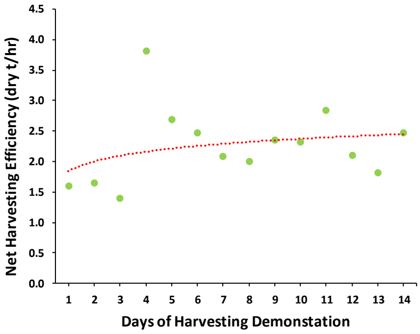

Figure 9: Net Harvesting efficiency of the demonstration (dry tons of prunings harvested per hour) along each harvesting day

3.2 Economical Results

Apart from the harvesting results recorded during the demonstration, the costs of such harvesting value chain were calculated. **Figure 10** presents the cost- break down of the olive pruning harvesting scheme. All costs are expressed in € per dry ton of harvested pruning.

The cost break down includes the fuel cost (diesel) of FACMA harvester and that of platforms needed for the biomass haulage (1.35 €/ litre diesel). Furthermore, it includes the cost for the harvester's driver and the cost for renting a 125 hp tractor to be attached to the FACMA harvester (250 €/day for the needs of the demonstration). Likewise, the biomass haulage cost include the costs for renting the platforms (capacity of platforms at 5 wet tons) and the costs of their drivers (price for one platform and its driver: 120 €/day). Moreover, the personnel costs include the costs for having two workers working with the harvester and aligning olive prunings if not harvested with the first pass of the harvester (100 €/day including a person for supervising the demonstration). Finally, the annualized harvester cost is calculated at 1.87 €/ dry ton OTP by assuming a harvester lifetime of 10 years, 500 working hours per year, a harvesting efficiency of 2.2 dry tons per hour and a purchase cost of 21,000 €, excluding VAT. Finally, by taking into consideration the costs of the above mentioned value chain steps, the total cost for harvesting one dry ton of olive prunings was calculated at around 58 €. The lion's share (34.5% of the harvesting cost) belongs to the harvester driver cost and the renting of the harvester's tractor. Moreover, another major contributor to the harvesting cost is the renting cost of the platforms and their drivers cost needed for the biomass haulage, consisting the 28.6% of the total harvesting cost.

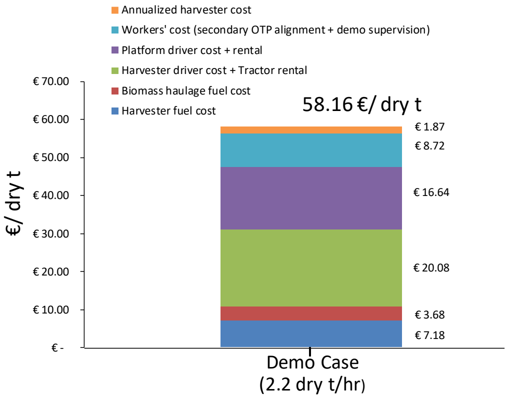

Figure 10: Cost- breakdown of harvesting olive prunings value chain (average values from harvesting demonstration with 2.2 dry t/hr net harvesting efficiency)

The above harvesting cost is not the ideal cost for such harvesting scheme. It was calculated based on the recorded values of the whole harvesting demonstration. It should be also considered that it was the first implementation of such harvesting value chain, thus the harvesting performance and economics can be further improved. For example, harvesting efficiency was lower during the first days of the demonstration which was later stabilized at higher efficiency, as the actors got used to operate such harvesting solution. In order to have a more realistic harvesting cost, a more improved case was taken into consideration by assuming a realistic 2.5 dry t/hr harvesting efficiency. This harvesting efficiency is realistic based on the experience that the local actors has acquired since the beginning of the demonstration. For the improved/ realistic case, apart from the higher harvesting efficiency, other changes in the costs were implemented. First of all, regarding the workers' cost, the supervision cost was not included. The workers' cost include the wage for having two workers while harvesting (60 €/day for both workers). Furthermore, the cost for renting the harvester's tractor and driver is considered at 200 €/day (lower than 250 €/day used in the demo) because, as the local actors mentioned, the harvester could work with a less powerful tractor (100 hp instead of 125) for which the renting price would be lower at 200€/day. Moreover, based on the local actor's opinion, the renting cost for one platform and its driver would also be lower at 100€/day compared to the 120€/day of the demonstration. Finally, by considering such alterations in costs and by applying a 2.5 dry t/hr harvesting efficiency, the harvesting cost lowers down to 44.5 €/dry t (**Figure 11**), 24% lower than the harvesting cost of the demonstration case.

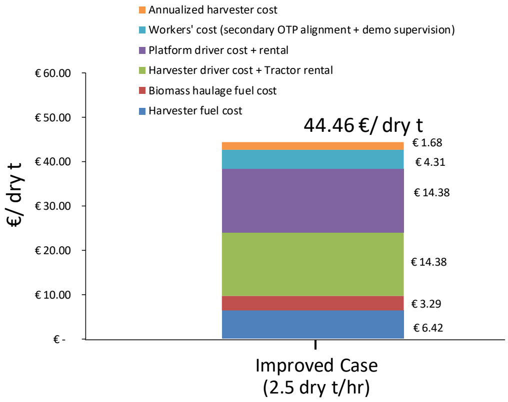

Figure 11: Cost- breakdown of harvesting olive prunings value chain (improved values from harvesting demonstration with 2.5 dry t/hr net harvesting efficiency)

3.3 Environmental Results

The environmental impact of the harvesting demonstration of olive prunings was calculated using a tool developed by CERTH during uP_running H2020 project [10]. Through the tool, GHG emissions are calculated as CO_2 equivalent emissions from each value chain step.

Thus, based on the demonstration results regarding the amount of biomass harvested and the amount of diesel consumed for harvesting and biomass haulage, the total amount of GHG emissions were calculated. The value chain steps that have an environmental impact is that of harvesting and biomass haulage. The GHG emissions are mainly calculated through the amount of diesel consumed for these steps. The harvesting step produced 4.7 tCO_{2eq} or 27.1 gCO_{2eq} per dry kg of harvested pruning (1.5 gCO_{2eq} /MJ). Regarding the biomass haulage step, it produced 1.6 tCO_{2eq} or 9.2 gCO_{2eq} per dry kg of harvested pruning (0.5 gCO2eq /MJ). Finally, the total amount of GHG emissions produced during the harvesting demonstration were calculated at 6.3 tCO_{2eq} or 36.3 gCO_{2eq} per dry kg of harvested pruning (2.0 gCO2eq /MJ). The calculated GHG emissions are in line with the typical & default values of RED II.

3.4 Fuel Characteristics of olive prunings

Olive prunings can be mainly used as solid biofuels for heating applications at industrial scale or for power generation in energy plants. In this sense, samples of harvesting prunings were collected from Agios Konstantinos in order to perform fuel analysis. The Fuel characterization was performed in CERTH/CPERI's laboratories in Ptolemaida by applying established standards (EN 14774 for moisture, EN 14775 for ash, EN 14918 for heating value, EN 15104 for ultimate analysis, EN 15290 for major elements, EN 15297 for minor elements). **Table 1** presents the fuel characterization of 30 samples of harvested olive prunings collected during the harvesting demonstration in Agios Konstantinos. One combined sample per harvested field was collected for the analysis.

Overall, an ash content of 4.5 w-% d.b. derived from the harvested olive pruning samples. The high amount of ash content appears due to the existence of leaves and due to the soil contamination that is unavoidable in mechanized harvesting. For the determination of the weight percentage of leaves in olive tree prunings, the former were separated manually from the woody part of the prunings. As it was expected, the results showed that the olive leaves are at 45-50 % wt d.b. of olive tree prunings depending on the olive variety (49.8% for Amfissis and 43.4% for Kalamon varierty). Furthermore, the fuel analysis showed an average HHV content of 19.53 MJ/kg d.b. and moisture content of 25 w-% w.b. The moisture content depends on how many days the prunnings 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 further drop from the prunings.

Table 1: Fuel characterization of harvested olive tree prunings (OTP) from 30 samples retrieved in Agios Konstantinos.

Property	Min	Max	Average
Moisture Content (w-% ar)	19.2	31.3	25.2
Proximate analysis			
Ash (w-% db)	2.9	5.8	4.5
Volatile Matter (w-% db)	77.2	79.7	78.4
Ultimate analysis			
Carbon, C (w-% db)	47.66	51.99	50.43
Hydrogen, H (w-% db)	5.61	8.38	6.79
Nitrogen, N (w-% db)	0.55	2.19	1.27
Sulphur, S (w-% db)	0.06	0.6	0.12
Chlorine, Cl (w-% db)	0.03	0.14	0.07
High Heating Value (MJ/kg db)	18.83	20.27	19.53
Bulk Density (kg/m^3 ar)	190	300	240

Moreover, **Figure 12** and **Figure 13** present the Major and Minor Elements found in the harvested olive prunings respectively. The appearance of calcium and silicon in the results is also due to the soil contamination due 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 is at 32.4 mg/kg d.b whereas the limit of class B wood chips is at 10 mg/kg d.b. The amount of copper that is found in the analysis is a result from the copper that is sprayed on olive trees as fungicide.

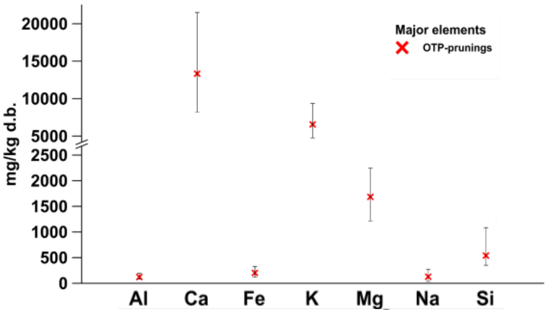

Figure 12: Major elements (mg/kg d.b.) of harvested olive prunings

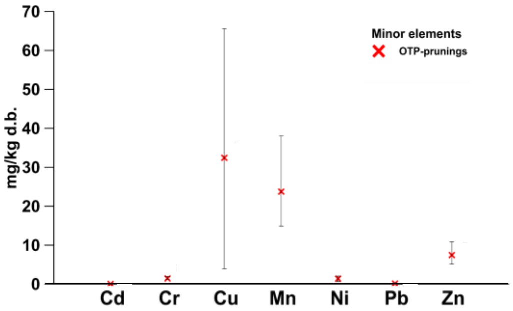

Figure 13: Minor elements (mg/kg d.b.) of harvested olive prunings

In general, olive prunings 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. Due to inhomogeneity, feeding issues may be expected in some systems. However, the upgrade of treated OTP into pellets could be considered an interesting option.

5 CONCLUSIONS

Aim of the current paper is the evaluation and detailed monitoring of the most extensive OTP harvesting demonstration held in Greece. Olive prunings' potential in Agios Konstantinos is estimated at more than 2.5 dry kt biomass annually from local trees that currently remain unexploited. The current paper evaluates the OTP harvesting value chain in terms of performance, economical feasibility and its environmental impact.

More specifically, during the monitored harvesting demonstration, 232 wet tons (174 dry tons) of olive groves were harvested from 54 ha of olive groves in 14 days. The average harvesting efficiency was at 3.2 dry tons/ha or 2.2 dry tons harvested per hour. The fuel consumption for the harvester was at 5.3 litres per dry ton harvested whereas for the biomass haulage to the storage area at 2.7 litres per dry ton harvested (olive groves in radius of 3km from storage area). The examined harvesting scheme, from the OTP harvesting to the biomass haulage to a storage area, has an average harvesting cost of 58 € per dry harvested ton and an environmental impact of 36 gCO_{2eq} per dry kg of harvested pruning. Improved results can be expected in future replications due to the gradual experience accumulation of the participating actors. Improved harvesting is expected to result in reduced costs by 24 % or around 33 €/ wet t, comparable with market price of sawdust.

The main exploitation method for olive prunings is that of solid biofuels. Either to be used as raw material for the production of pellets or briquettes or to be used directly in their chipped form (hog fuel or chips). In this light, olive pruning samples have undergone a fuel analysis in order to further investigate the energy exploitation of such biomass resource. From the fuel results, olive prunings have high energy content but with high ash content (4.5 w-% d.b.). Consequently, the olive prunings could find application as solid fuels at industrial level and compete industrial fuels such as sunflower husk pellets, exhausted olive cake etc.

6 REFERENCES

[1] CIRCE et al., Mapping and analysis of the pruning biomass potential in Europe. Deliverable report D3.1. EuroPruning project FP7312078. 2014.

[2] Martín-Lara MA, Ronda A, Zamora MC, Calero M. Torrefaction of olive tree pruning: Effect of operating conditions on solid product properties. Fuel. 2017;202:109-17.

[3] Picchi G, Lombardini C, Pari L, Spinelli R. Physical and chemical characteristics of renewable fuel obtained from pruning residues. Journal of Cleaner Production. 2018;171:457-63.

[4] Amirante R, Clodoveo ML, Distaso E, Ruggiero F, Tamburrano P. A tri-generation plant fuelled with olive tree pruning residues in Apulia: An energetic and economic analysis. Renewable Energy. 2016;89:411-21.

[5] Garcia-Maraver A, Rodriguez ML, Serrano-Bernardo F, Diaz LF, Zamorano M. Factors affecting the quality of pellets made from residual biomass of olive trees. Fuel Processing Technology. 2015;129:1-7.

[6] Requejo A, Peleteiro S, Garrote G, Rodríguez A, Jiménez L. Biorefinery of olive pruning using various processes. Bioresource Technology. 2012;111:301-7.

[7] inr.gr. Economic Data for industries in the olive sector 2014; Available from: http://www.inr.gr/?p=a2097.

[8] ELSTAT. Tree crops. Areas of continuous crops, by Region and Regional Unit 2015; Available from: http://www.statistics.gr/el/statistics/-/publication/SPG06/2015.

[9] Kougioumtzis M-A, Karampinis, E., Grammelis, P., Kakaras, E. Assessment of Biomass Resources for an Integrated Biomass Logistics Center (IBLC) Operating in the Olive Oil Sector. 26th European Biomass Conference and Exhibition; Copenhagen, 2018. p. 309 - 313.

[10] uP_running "Take-off for sustainable supply of woody biomass from agrarian pruning and plantation removal", H2020 Project, GA No 691748; Available from: https://www.up-running.eu/other-materials/.

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8 LOGO SPACE

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