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Possibilities of Energy Generation from Olive Tree Residues, by-products and Waste in Crete, Greece

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Abstract

The objective of the current work is the investigation of the current utilization of olive tree residues, by-products and waste for energy generation in Crete and their future prospects. The quantity of olive tree biomass in Crete has been estimated and its potential for energy generation has been calculated. Possibilities for using it for heat production, power generation, biogas production, pellet manufacturing and fermentable sugar production have been investigated. Experiences in other olive oil producing countries have been recorded together with the technologies used or experimented with so far. The energy potential of olive tree biomass in Crete has been estimated at 24.05 % of the TPES supply in the island. The only highly utilized olive tree by-product for heat generation by combustion in Crete is the olive kernel wood. Olive tree pruning have the highest energy content but they are underutilized in Crete. Their successful utilization in other countries for pellet manufacturing and power generation indicates that their exploitation should be promoted in Crete. The results of this study indicate that olive tree cultivation in Crete, apart from producing a high nutritional edible product, generates residues, by-products and waste which if properly utilized could contribute in the reduction of fossil fuels used and the carbon footprint due to energy use in the island.

Keywords: Biogas, by-products, Greece, energy generation, olive tree, pellets, residues, waste.

1. Introduction

Olive trees have been cultivated in Crete like in other Mediterranean territories since ancient times. During the 20th century olive tree was massively cultivated in the island and currently olive oil comprises the most important agricultural product generating significant income in agricultural communities. It is also the most important exported agricultural product in the island. Olive tree cultivation in Crete has been reported by ***Mavrakis, 2014***. The author presented the current data regarding the number of olive trees in Crete, the cultivated area and the quantity of the olive oil produced in the island. ***Alexakis, 2014*** has reported on the energy consumption in Crete stating that the electricity consumption in the island during 2014 was 2,837.8 GWh. The total primary energy sources (TPES) supply in Crete is 2.12 toe per capita **(*IEA, Energy indicators for Greece, 2014*)** and the total population in Crete according to a recent census in 2011 was 623,025 inhabitants (*www.statistics.gr*). Therefore the TPES supply in Crete is 15,362,041 MWh. Agrochemical characterization of "alperujo", a solid by-product of the two-phase centrifugation method for olive oil extraction, has been presented by ***Alburquerque et al, 2004*.** The authors described the differences between the two-phase and the three-phase centrifugation technologies. They also stated the characteristics and the chemical composition of the two-phase olive mill cake called "Alperujo". An overview of olive mill wastes and their valorization methods has been presented by ***Roig et al, 2006***. The authors stated that olive mill wastes have high phenol, lipid and organic acid concentration which turn them into phytotoxic and polluting materials. However they also contain some valuable compounds which could be recovered with appropriate processes. They reported on various proposed technologies for the valorization of these wastes including second oil extraction, combustion, gasification, anaerobic digestion, composting and solid fermentation. The authors concluded that the adoption of the two-phase centrifugation technology has significantly reduced the volume of the liquid wastes produced. They also reported that there is no unique solution for the treatment of those wastes but the optimum way of treating them depends on the specific needs of each area.

1.1 Heat and power generation from olive tree biomass

The possibility of using olive kernel wood for co-generation of heat and power in Crete, Greece has been studied by ***Vourdoubas, 2015*.** The author investigated the possibility of creating a 1 MW_{el} co-generation plant in Crete, Greece using olive kernel wood as fuel. The generated electricity would be fed into the grid and the co-generated heat would be used by local large heat energy consumers. The disposal of by-products in the olive oil industry for energy generation has been reported by ***Caputo et al, 2003*.** The authors studied the thermal disposal of liquid and solid by-products and the waste from the olive tree combined with energy recovery. They concluded that collecting olive husks and olive mill wastewaters from 200 olive mills and processing them thermally in a centralized plant combined with energy recovery could be profitable. Analysis of olive grove residual biomass potential for electric and thermal energy generation in Andalucia, Spain has been presented by ***Garcia-Maraver et al, 2012*.** The authors stated that in Andalucia, olive tree residues and by-products are broadly used for heat and power generation. According to them Andalucia had 19 power plants using mainly olive biomass. It also had 13 industrial pellet production plants utilizing olive tree pruning as raw material. The same region, they reported, also uses olive kernel wood for heat generation. ***Solino, 2010*** has studied the external benefits of electricity generation from biomass in Spain. The author using appropriate questionnaires found that citizens were willing to pay a higher price for electricity generated from biomass taking into account that the use of biomass decreases greenhouse gas emissions, reduces the pressure on non-renewable resources, lowers the risk of summer fires and creates employment in rural areas. ***Celma et al, 2007*** studied the possibility of using waste from olive and grape processing for energy generation in Extremadura, Spain. The authors studied the use of various olive by-products and waste together with the waste from grape processing. Power generation was achieved with the well proven technology of biomass direct burning combined with a steam cycle. The authors concluded that plants with a power capacity of approximately 20 MW_{el} were profitable in Extremadura. A study concerning combustion and gasification of solid biomass for heat and power generation in Europe has been presented by ***Obernberger et al, 2008***. The authors stated that combined heat and power technologies based on biomass combustion and gasification have been developed intensively over the past ten years. They also reported that biomass combustion technologies have reached a high level of development. In parallel biomass gasification technologies are not currently used commercially but their future prospects are attractive. According to them electricity cost from biomass combustion varies from 0.13-0.22 € per KWel. ***Dornburg et al, 2001*** reported on biomass-based heat and power generation with combustion and gasification technologies. The authors stated that the economic performance of the plant is seriously influenced by its size. Other factors affecting its profitability are biomass costs and logistics and the degree of utilizing the co-generated heat. A techno-economic analysis of the energy exploitation of biomass residues in Heraklion, Crete (Greece) has been reported by ***Boukis et al, 2009***. The authors investigated the feasibility of a biomass-fired plant in Heraklion taking into account the high biomass residue potential in this area including residues and waste from olives, grapes and vegetables grown in greenhouses. They studied the viability of an 8 MWel combustion plant concluding that the total investment cost varies between 1,600-1,700 €/KWel and the total operating cost is 5.6 Eurocents per KWel. Taking into account that 40 % of its capital cost could be subsidized the plant could be profitable with a pay-back period of its own capital in 6.7 years. A techno-economic analysis of small-scale biomass-fuelled combined heat and power systems for community housing has been reported by ***Wood et al, 2011***. The authors stated that the economic performance and the profitability of such systems depend on the capital subsidies offered, the electricity feed-in tariffs and the amount of co-produced heat sold on-site. Energy applications of olive oil industry by-products have been reported by ***Masghouni et al, 2000***. The authors studied the use of the exhaust foot cake from the olive pomace industry as a combustible fuel in brick manufacturing in Tunisia. They concluded that the replacement of fuel oil with the foot cake from olive mills resulted in many environmental benefits.

1.2 Gasification of olive tree biomass

Skoulou et al, 2008 investigated the fixed-bed gasification of olive kernels and olive tree cuttings at a lab scale at 750-950 ^oC and atmospheric pressure. The authors found that in the gas phase, CO, CO_2, H_2 and CH_4 were present. They also found that gasification with air at high temperatures, 950 ^oC, favored gas yields. ***Vera et al, 2011*** studied the gasification of olive industry wastes in a small scale system. The authors stated that produced gas had low calorific values between 4,35 MJ/kg to 5.20 MJ/kg. They also found that the co-generation system was generating 70 KWel and 150 KWth with biomass consumption at 80-85 Kg/h, having electric efficiency of 20% and overall efficiency of 65%. ***Borello et al, 2015*** reported on the thermo-economic assessment of an olive pomace gasifier for co-generation applications. The authors studied a co-generation plant with thermal power of 800 KWth and electric power of 200 KWel. They stated that although the conversion efficiency was low, in the case that the co-generated heat was sold, the economics of the gasification-cogeneration plant were attractive. ***Vera et al, 2014*** reported on an experimental and economic study of a gasification plant fueled with olive industry waste. The authors studied a pilot plant converting olive tree pruning and olive pits to electric and thermal power. After gasification the produced gas had a lower calorific value in the range of 4.8-5.4 MJ/kg. The plant achieved acceptable efficiencies, 15 % for electricity and 50 % for CHP. The payback period of the investment was found to be 5-6 years which was believed to be satisfactory. Existing work on gasification of olive tree biomass and use of the produced gas for CHP indicates that the processes would be profitable in the near future.

1.3 Pyrolysis of olive tree biomass

Hani et al, 2016 reported on the production of bio-oil from the pyrolysis of olive biomass with and without a catalyst. The authors investigated the pyrolysis of olive oil cake after the removal of the olive oil contained in it. They found that the use of catalysts increased both the bio-oil and the gas yields. ***Al. Farraji et al, 2017*** reported on the pyrolysis of olive kernel biomass in fluidized and fixed bed conditions. They investigated the pyrolysis on a lab scale at a temperature range of 300-660 ^{o}C. They stated that the pyrolysis in a fluidized bed reactor better represents the conditions encountered in large scale systems.

1.4 Pellet production

Pellet production from olive tree by-products and residues in Crete, Greece has been reported by ***Vourdoubas, 2008.*** The author stated that the chemical composition of olive kernel wood does not qualify it for the production of premium quality wood pellets. He also reported that the production of wood pellets in Crete from mixtures of olive kernel wood and olive tree pruning could be profitable under some conditions. A review of the agricultural residue pellet market in Greece has been presented by ***Karkania et al, 2012***. The authors stated that the amount of agricultural residues in Greece is high but their use is rather inefficient. They concluded that the pellet market in Greece is not well developed buy its growth potential is high. However the legislative aspects of pellets must be solved in order to increase their utilization in Greece. ***Molina-Moreno et al, 2016*** studied the creation of pellets from olive and almond trees analyzing their combustion efficiency and their CO and NOx emissions. The authors concluded that the combustion of pellets obtained high efficiencies, at approximately 86-88 %, and that their CO and NOx emissions were below the legally established levels.

1.5 Biogas production from olive tree biomass

Anaerobic treatment of olive mill waste in batch reactors has been presented by ***Erguder et al, 2000***. The authors stated that liquid waste can be treated anaerobically with high efficiencies producing 57 l of biogas per l of treated wastes. Olive oil mill waste treatment has been reported by ***Rincon et al, 2012*****.** The authors stated that olive mill liquid wastes from two-phase and three-phase centrifugation plants are promising substrates for anaerobic digestion. Although this microbial process has been successfully used in many agro-industrial residues, it has not been used commercially yet for olive mill liquid wastes. They also reported that currently olive mill liquid wastes are disposed either in evaporation ponds or they are used for the co-generation of heat and power. Enhancement of biogas production from olive mill effluents by co-digestion has been reported by ***Azbar et al, 2008*****.** The authors investigated the co-digestion of olive mill effluents with poultry litter and cheese whey. They stated that co-digestion with poultry litter increased the biogas production by 90 % and with cheese whey by 22 %.

1.6 Bio-ethanol production from olive tree biomass

Production of fuel ethanol from olive tree pruning treated with steam explosion has been reported by ***Cara et al, 2008***. The authors used olive tree pruning as raw material for ethanol production. Biomass was submitted to steam explosion pre-treatment in temperatures of 190-240 ^{o}C with or without previous impregnation with water or sulphuric acid solution. They reported ethanol yield at 7.2 g ethanol per 100 g of raw materials. ***Cara et al, 2008*** have reported on the conversion of olive tree biomass into fermentable sugars by diluting acid pretreatment and enzymatic saccharification. The authors stated that soft pretreatment with dilute sulphuric acid resulted in a sugar-rich prehydrolysate. A maximum value of 36.3 g sugar per 100 g of raw materials was achieved by the two-stage process representing 75 % of all sugars present in olive tree biomass. Acid hydrolysis of olive tree biomass has been reported by ***Romero et al, 2010***. The authors investigated the first stage of bio-ethanol production from olive tree pruning, the hydrolysis of the solid biomass to sugars. They stated that this could be an alternative to the current practices of grinding and burning olive tree pruning on the field. The authors found that during hydrolysis with sulpuric acid at temperatures of 60-90 ^{o}C a large fraction of hemi-celullose was transformed to fermentable sugars. The possibility of microbial production of ethanol from sugars has been reported by ***Martinez-Patino, et al, 2015***. The sugars were produced by diluting phosphoric acid hydrolysis of olive tree pruning and they were afterwards fermented by *E. coli*, producing an ethanol solution. A hemi-celullosic sugar recovery in the liquid fraction near 70 % was obtained as well as an ethanol yield of 0.46 g ethanol per g sugars consumed.

The main aims of the current work were: a) to estimate the energy content of the olive tree by-products, residues and wastes in Crete, Greece, b) to present the current uses of those biomass sources for energy generation in Crete, and c) to investigate the current status and the prospects of other promising technologies which could be used in the future for generation of heat, power and energy products from olive tree biomass. A mapping of olive tree cultivation in Crete has been made followed by a literature review regarding the exploitation of olive tree by-products and residues for energy generation in various countries together with a review of new innovative energy technologies utilizing olive tree biomass for energy generation. The results of the current study indicate that the energy potential of the olive tree residues, by-products and waste in Crete is high at 24 % of the TPES in the island. It is also concluded that olive tree biomass which is currently underutilized in Crete compared with other territories could be used in the future for pellet production and power generation.

2. Olive oil production in Crete

The current number of olive trees cultivated in olive groves in Crete, is estimated at 33 mils and the total cultivated area is 190,000 Ha, which corresponds to 25 % of the total area in the island. Average annual olive oil production in Crete during the period 2010-2013 was 98,600 tons **[Mavrakis, 2014].** There are currently 543 olive mills operating seasonally from November until March in Crete. Each one of them produces on average 181.6 tons of olive oil; therefore they are very small-size processing plants. Although in the last decades the three-phase centrifugation system was the predominant technology for olive oil production in Crete, in recent years the two-phase centrifugation technology has dominated. The main drawback of the old three-phase centrifugation technology is related with the production of large amounts of liquid wastes in a short period during the winter. Those liquid wastes have a high organic content and high BOD_5 and COD values. The proposed methods regarding their processing have not given satisfactory results taking into account the small size of the olive mill plants and their seasonal operation. The main methods for their processing include storage in evaporation ponds and their direct disposal in agricultural soils as fertilizers. When disposed in evaporation ponds the water evaporates during the summer and a small quantity of sludge remains. However the long period of their stay in the evaporation ponds results in the creation of bad odors due to anaerobic digestion of the organic matter. The two-phase centrifugation system has been developed in the last twenty years in Crete in order to cope with the problems created by the previous technology. The two-phase centrifugation produces less liquid waste and it requires less water and energy compared with the three-phase system. Therefore the new two-phase technology is considered environmentally friendly. The production of various products, by-products and waste by the two-phase and three-phase centrifugation systems is presented in Table 1.

Table 1. Production of olive oil, by-products and waste with the two centrifugation technologies used in olive mills

	Units	Two-phase centrifugation	Three-phase centrifugation
Olives	Tons	1,000	1,000
Hot water	M^3	0	0.6-1.3
Washing water	M^3	Small quantities	Small quantities
Olive oil	Tons	200	210
Olive paste	Tons	800	550
Liquid waste	M^3	0.2	1-1.6

Source: Alburquerque et al, 2004.

The average moisture content of the olive cake produced by two-phase centrifugation plants is 64 % of fresh weight and it varies between 55.6-74.5 % of fresh weight [**Alburquerque et al, 2004].** Data on the production of olive cake, olive kernel wood and liquid waste in Crete with the use of two different technologies of two-phase and three-phase centrifugation olive mills are presented in Table 2.

Table 2. Annual production of olive oil, olive cake, olive kernel wood and liquid waste in Crete with the use of two different technologies of two-phase and three-phase centrifugation olive mills

	Units	Two-phase centrifugation	Three-phase centrifugation
Olives	tons	500,000	500,000
Olive oil	tons	98,600	98,600
Olive cake	tons	400,000	275,000
Liquid wastes	M^3	100,000	500,000-800,000
Olive kernel wood (after the removal of moisture and the residual oil from the olive cake)	tons	155,000	152,000

Source: Own estimations

Assuming that each Ha of olive groves produces annually 3 tons of olive pruning [**Garcia-Maraver et al, 2012**] the total annual production of olive tree pruning in Crete is 570,000 tons. The moisture content and the lower heating value of olive tree pruning and olive cake produced in the two-phase olive mills and the olive kernel wood are presented in Table 3.

Table 3. Moisture content and heating values for various olive tree by-products and residues

	Units	Olive tree pruning	Olive cake produced in the two-phase olive mills	Olive kernel wood
Moisture content	% weight	10.95	55.29	13.12
Lower heating value	Kcal/kg dry weight	4,300	4,250	4,500

Source: Garcia-Maraver et al, 2012

3. Energy content of the olive tree by-products, residues and waste in Crete

The energy content of olive tree pruning, olive kernel wood and olive mill liquid waste produced annually by two-phase centrifugation plants in Crete has been estimated and presented in Table 4. The energy content of olive tree pruning is approximately three times higher than that of olive kernel wood and seventy times higher than olive mill liquid waste.

Table 4. Energy content of olive residues, by-products and waste produced annually in Crete

	Olive tree pruning	Olive kernel wood [1]	Olive mill liquid wastes [1]
Quantity	570,000 tons/year	155,000 tons/year	100,000 M^3/year
Energy value	4,300 Kcal/kg (4.99 KWh/kg)	4,500 Kcal/kg (5.23 KWh/kg)	[2] 0.4 MWh/M^3
Total energy content per year	2,844,300 MWh	810,650 MWh	40,000 MWh
% of the TPES consumption in Crete	18.52 %	5.28%	0.26 %

[1] produced in two-phase centrifugation plants

[2] Ergutter et al, 2000

The total energy content of the above-mentioned olive tree biomass in Crete is high at 3,695 GWh per year corresponding to 24.05 % of the TPES supply and 130.21 % of the electricity consumption in the island.

4. Current utilization of olive tree by-products, residues and waste in Crete and future prospects

Olive tree by-products, residues and wastes in Crete are utilized only for heat generation. Olive tree pruning are either burnt in the olive groves or ground on site and added into the soil to increase its organic matter. Its high potential in Crete and its near zero value makes its future prospects for production of pellets or for power generation very attractive. However the logistics regarding the transport of the pruning from the olive groves to the processing sites must be solved. Olive mill liquid wastes in Crete are disposed into evaporation ponds. However due to their anaerobic degradation in the ponds before their evaporation, undesirable odors are produced creating problems in nearby areas. Additionally the liquids occasionally pollute the surface and the underground waters since they overflow or penetrate the walls of the ponds. Anaerobic digestion of olive mill effluents for biogas production has not been used commercially so far in Crete. Olive kernel wood produced in olive kernel oil producing plants is used for heat generation. It is consumed partly inside the plants and the rest is sold to various heat consumers including residential buildings, greenhouses and various small and medium size industries. Olive kernel wood has very good burning characteristics and since its price (120 € per ton.) compared to its heating value (4,500 Kcal/kg d.w.) is very attractive compared to fossil fuels its current demand in Crete for heat generation is high. Past efforts for the production of wood pellets were not successful due to the high ash content of this biomass source. This did not allow the production of premium quality wood pellets. Currently some quantities of crude olive kernel wood in Crete are refined with mechanical processes using sieves and its burning characteristics are improved increasing its attractiveness as a renewable local fuel replacing heating oil. The current demand of olive kernel wood in Crete is higher than its supply. Past efforts for its use in electricity generation or co-generation of heat and power in Crete did not succeed since the profitability of the plant depends on the size, raw material price and logistics, capital subsidies and electricity feed-in tariffs. Utilization of olive tree pruning for production of fermentable sugars has not been studied so far in Crete and this process is not expected to be commercially viable. Gasification and pyrolysis of olive biomass for energy generation in Crete are not considered currently viable. Co-treatment of olive mill effluents with other agro-industrial residues and waste and co-treatment of olive tree pruning with other agricultural residues for pellet manufacturing in Crete should be further examined. Current uses and future prospects for olive tree residues, by-products and waste use for energy generation in Crete are presented in Table 5.

Table 5. Current uses and future prospects for exploitation of olive tree residues, by-products and waste for energy generation in Crete

	Olive tree pruning	Olive mill effluents	Olive kernel wood
Heat generation	No, It has been used in other countries after standardization	No	Yes
Power generation or CHP	No, It has been used commercially in other countries	No	No, It has been used commercially in other countries
Anaerobic digestion for biogas production	No	Only experimentally	No
Manufacturing of pellets	No, It has been used commercially in other countries	No	No, However refined olive kernel wood similar to pellets is produced.
Production of fermentable sugars	Only experimentally	No	No

5. Conclusions

The olive tree is extensively cultivated in Crete, Greece producing a high quality edible oil. It also produces various residues, by-products and wastes like olive tree pruning, olive kernel wood and olive mill liquid waste with high total energy content equivalent to 24.05 % of the TPES supply in the island. Among them olive kernel wood is highly utilized in Crete for heat generation in buildings, in agriculture and in industries. Olive tree pruning produced in large quantities have a high energy content, but they are not utilized currently in Crete, although in other countries they are used for pellet manufacturing and for power generation. The difficulties of transporting the olive tree pruning from olive groves to the processing site should be resolved. Olive mill liquid waste could be used for biogas production and subsequent energy generation. However commercial anaerobic digestion plants do not operate today. Olive tree biomass utilization processes like gasification, pyrolysis and hydrolysis for fermentable sugar generation could find commercial applications in the future. Successful utilization of olive tree biomass for energy generation in other countries indicates that it could also be exploited in Crete, increasing the share of renewable energies in the energy mixture in the island. The economics of various processes utilizing olive tree biomass for heat and power generation in Crete depend on capital subsidies and feed-in tariffs and they are sensitive to the cost of the raw materials.

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