Olive grove residues and olive extraction process solid biowaste streams management via thermo chemical valorization

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Abstract

Olive oil production is a significant economic activity in the Mediterranean basin and a considerable employment source. Nevertheless, the environmental pressures associated with the olive tree farming and olive oil extraction are remaining of note. Olive farming and olive oil processing are generating large quantities of solid wastes the disposal of which is still considered as a major problem for the farmers and the mill operators. The commonly used management practice of combustion is not in line with the terms of sustainability, thus, different waste management techniques should come into scene. In this respect the thermochemical valorization via pyrolysis seems to be a promising alternative as it generates both energy carriers (biomass and bio-oil) that can be utilized in the olive grove and the olive mill, and bio-char that could be efficiently used as a soil amendment. Taking into consideration the size of a typical olive grove and an olive mill, the valorization of the solid wastes in this route, could produce enough energy and materials to cover its own needs.

This work investigates the above scenario for an olive grove of 10 hectares. A pyrolysis of the solid wastes from the olive tree pruning and the kernels from the olive mill was contacted. The results shown that the produced electricity is not only sufficient enough to cover the energy requirements for the operation of the mill but in the same time it is producing a surplus that can be sold to the grid and provide an extra income to the farmer ensuring the economic viability of the project.

Keywords: Bio-waste; pyrolysis; Bio-char; Olive Oil; Energy; Waste Management

Introduction

The olive tree is inextricably linked to the Mediterranean regions and olive farming is a typical activity in the Mediterranean basin. Almost the whole of the global olive oil production is done in this part of the world while Spain, Italy and Greece cover the three quarters of the total production. Olive farming is an important part of these countries culture and heritage and together a significant economic activity and a conspicuous employment source, especially in the rural territories. The nutrition value of olive oil is well entrenched and the last years more consumers include olive oil consumption in their diet. This is represented in the increased olive oil production tense during the last decades, fig 1, [1].

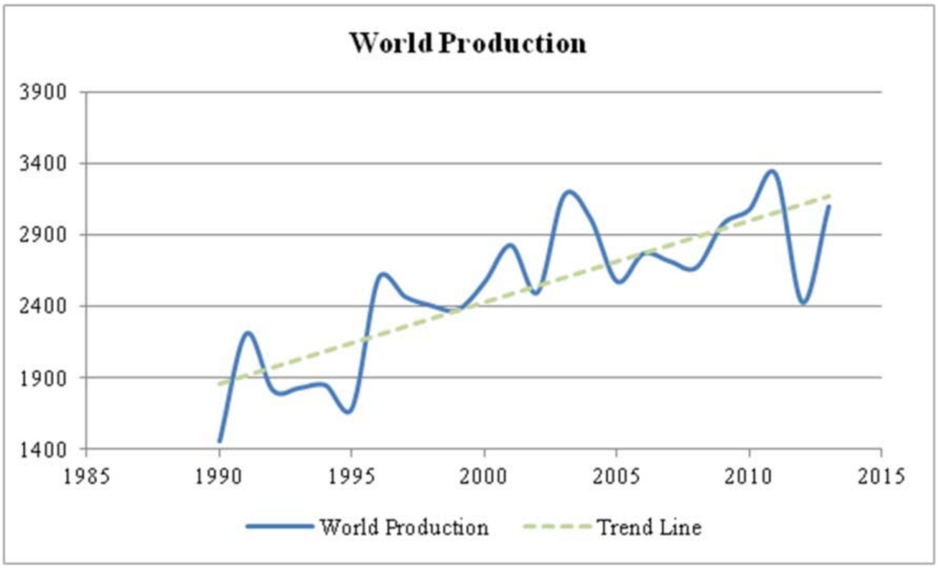

Fig. 1 Global Olive oil production

The cultivation of the olives could be considered as environmental friendly procedure. The use of large quantities of chemicals and fertilizers is not necessary compare to other crops and the use of energy is limited to its use in tractors, diesel saws and electric peaveys, [2]. In addition the energy use related to the olive oil production is not considered as a major issue, [3]. In this respect the olive oil extraction could be considered to have a minor environmental impact itself. Nevertheless, the olive farming and the olive mills are generating large quantities of solid and semi solid wastes and wastewater, the handling of which is a major task for the majority of the olive processing facilities. The disposal of these residues is a one of the biggest environmental problems that Europe is facing today and the olive oil industry is considered one of the most heavily polluting food industries, [4, 5].

Besides the type and special characteristics of the wastes itself, the situation is intensified by the nature of the olive mills and the characteristics of the olive tree farming. The majority of the olive mill is family owned business with limited financial resources, relatively small at size and scattered all over the olive farming territory or located inside the olive grove. Moreover, the olive tree production follows a biennial cycle as it grows the first year and produces more olives the second, [2, 6], resulting in erratic waste production. The above facts are introducing economic, technical and organization constrains that make it difficult to establish a centralized waste treatment facility.

Traditionally, the dominant solid waste management strategy was its combustion for heat or electricity, [7]. However, the combustion is inefficient and often incomplete and emits a thick smoke rich in carbon and carbon monoxide. In addition, the proposed use of incineration, as an alternative, is raising concerns associated with its impact to the environment and to public health, [8, 5]. Thus, the waste management in a sustainable and economically viable manner is an emerging task and good environmental practices should be organized. Emphasis should be given into the aspects of efficient and effective use of energy, the preservation of the natural resources and the mitigation of air, water and soil pollution.

In this respect, a promising waste management practice of the olive farming solid wastes is their thermochemical treatment via pyrolysis. The advantage of this route, compared to the commonly used combustion, is that besides the energy carriers (SynGas and Pyrolysis Oil), the process is producing the bio-char. As the soil erosion is considered as the most serious environmental problem associated with olive farming, [9], bio-char could be efficiently used as a soil amendment of a great potential that could be used in olive grove to preserve soil fertility, [10, 11, 12, 13].

The current work investigates the potential of the reuse of the solid wastes from olive farming and olive milling (kernels) through the pyrolysis route and the contribution of this alternative valorization method to the development of an environmental efficient bio-energy system and compares pyrolysis benefits with gasification. Taking into consideration that the average size of olive groves and olive mills in the EU countries is relatively small, the appropriate management of olive farming wastes could develop an energy self maintained autonomous system that contributes to the conservation of natural resources and together is in line with the principles of ecology and sustainable agriculture (use of bio-char). The proposed solid waste valorization scheme is represented in fig. 2.

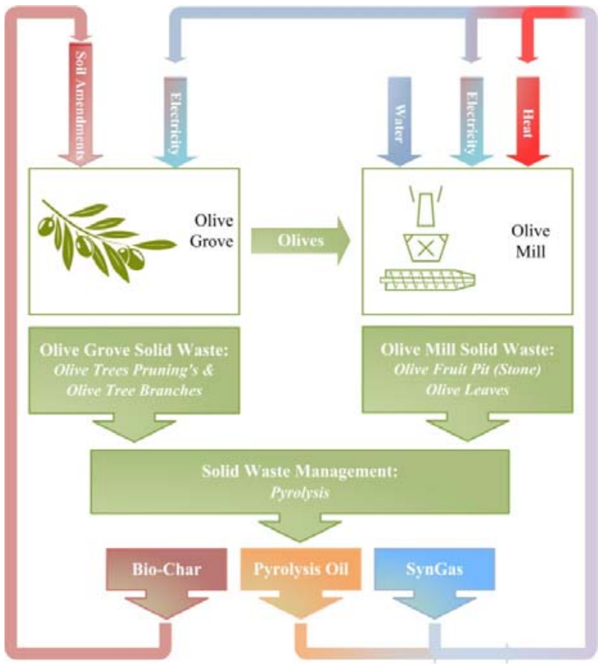

Fig. 2 Waste management via Pyrolysis and the products utilization

Olive Farming and Olive Milling Residues

The olive tree cultivation in Mediterranean region is considered as an important part of the agriculture and as estimated over 700 million olive trees are grown in Spain, Italy and Greece. Spain is the main olive oil producer country followed by Italy and Greece. Despite the decline in olive tree cultivation during the 70's and the 80's the last decades an expansion of new olive trees plantations occurred, especially in Spain and Greece. In late 60's, in Spain there was reported 2.4 million hectares (ha) of olives. Nowadays, 2.1 ha and over 300.000 trees are devoted to olive oil production, the majority of which are located in the area of Andalusia. In Italy most of the Olive oil production is happening at the regions of Puglia, Sicily and Sardinia, while the total area of the olive groves is estimated at 1.4 million ha that represents a 40% increase since the early 90's. In Greece, olive farming covers 60% of the country's cultivated land. The area of olive groves in Greece has increased constantly during the last 25 years as a result of the plantation of new groves with high-density plantings. Currently in Greece, there are more than 132 million trees, mostly located in Peloponnese and Crete, [9, 14].

The olive grove solid wastes are mostly twigs and leaves generated during the pruning of the trees. Pruning also generates and larger logs that usually used as firewood. On average an olive ha could produce 1.2 t of pruning annually, [15]. Nevertheless, this could not be used as a general principal. Although, regular pruning is a measure to prevent the growth of certain pests and fungus and to maintain the trees health, there is not a common pruning practice. Trees may be pruned every year or every two or more years, depending on the specific characteristics of the region, the olive tree variety or the farmer's tradition. Further to this the density of the olive grove clearly affects the pruning yield. According to the mentioned figures olive groves are generating large quantities of solid wastes the disposal of which is still considered by farmers as problem rather than a productive operation and a potential income.

The last decades there have been significant changes in production methods. The traditional (batch) process gradually was replaced by the continuous process that is further divided in the two-phase and three phase processes, depending on the olive oil separation method used. In the traditional process the olive oil is extracted by pressure after the grinding of the olive fruit while the continuous process uses centrifugal decanters. Most of the world's oil is extracted by the continuous process and the current trend is towards the two phase process. The advantages of this process, which is also called as "ecological" process is that it requires less quantities of water, uses less energy and does not generate any olive mill waste water (vegetable water), which is the major pollutant in the three phase decanter process. The byproduct is a residue of high humidity, the virgin oil pomace, which besides water contains fractions of the olive kernel, the olive pulp and olive oil. The kernel deriving of wet pomace is generally obtained at the mills themselves and used in the oil processing plant as an alternative fuel. The average kernel fraction included in the wet pomace reaches the 15 wt%, [16].

Case Study of a 10 Hectare Olive Farm

Olive grove production and Olive mill operation

The olive grove covers an area of approximately 10 hectares and on average it produces yearly 40 t of olives and generates 25 t of twigs (32 wt% of humidity) and 10 t of wood (40 wt% of humidity) as pruning residues. Inside the olive grove is operating a modern two phase mill that produces approximately 4 t of "extra-virgin" olive oil and 36 t of wet pomace of 60 wt% humidity. The energy used for the operation of the olive mill was calculated at 0.8MWh/kg of produced oil, 70% of which is electricity for the operation of the machinery and 30% is heat used for the fruit washing and in the malaxation process. The extraction process of "extra-virgin" olive oil is following the four basic steps:

Feeding, leaf removal and washing: After their collection from the grove, olives are placed in large containers and via a moving belt they are transferred to the olive mill. After they are processed in a vibrating sieve they are washed in order to remove the olives leafs, twigs and all the particles that could bite the machinery or contaminate the final product.

Crushing: The olives are poured into large "vessels" in which two or three heavy wheels rotate at high speeds, crushing the fruits and producing the olive paste.

Slow Mixing (Malaxing): The paste yield, is mixed slowly and constantly (malaxed) for about 30 minutes. The purpose of this operation is to help small oil drops coalescence in larger and thus to increase the percentage of extracted oil. This step takes place in a horizontal container made of stainless steel to avoid oxidation. A rotating helix with several wings mixes the paste slowly (20-30 rpm) for 20–30 minutes. The containers body has double walls where hot water is circulating in order to provide the required heat for the process. The temperature of the water is limited at 30°C to prevent the destruction of volatile constituents, the change of oil color to reddish and an increase of its acidity.

Centrifugation: The malaxed olive paste is then driven to a horizontal two phase centrifugal decanter in order to separate the oil from the olive paste. The decanters consist of a cylindrical conical container and a shaft with helical blades. The difference between the speed of the shaft and the container shell is moving the moist pomace to one end of the centrifuge, while the virgin oil is pushed to the other. The oily mixture (oil with a small fraction of water) passes through vertical centrifuges which operate at 6,000–7,000 rpm for the final separation of the oil.

The wet pomace is further treated to remove the olive kernels (5.0 t) and the stone free mixed waste is sent to a pomace treatment facility to extract the pomace olive oil after its treatment with hexane. The olive kernels and the pruning residues are used as a feed stock in the pyrolysis reactor. The characteristics of the olive wood (pruning and twigs) and the characteristics of the olive kernel are presented in Table 1.

Table 1 Elementary analysis of the Olive solid residues

Olive Branches		Olive Tree Pruning		Olive Kernel	
	wt% (daf)		wt% (daf)		wt% (daf)
Carbon	48.77	Carbon	46.92	Carbon	49.89
Hydrogen	5.98	Hydrogen	6.61	Hydrogen	6.32
Nitrogen	0.59	Nitrogen	0.68	Nitrogen	0.92
Sulphur	n.d.	Sulphur	0.08	Sulphur	0.07
Oxygen	44.55	Oxygen	47.23	Oxygen	43.79
LHV (MJ/kg)	18.00	LHV (MJ/kg)	18.00	LHV (MJ/kg)	20.00

Pyrolysis process, Materials flow and Energy balance

In pyrolysis, the decomposing of the large biomass molecules is occurring after the rapid heating of the feedstock producing smaller hydrocarbon molecules (liquids), non condensable gases and a solid residue rich in carbon, the bio-char. The liquid product of the pyrolysis is of primary interest, as it can replace diesel in an internal combustion engine. The nature and the yield of the pyrolysis products depends on several factors, including pyrolysis temperature, the heating rate, the experimental system, the pressure, the residence time, etc, [17]. In general, pyrolysis can be classified as slow, fast, rapid, flush, although that there are no distinct boundaries to determine the differences between the methods. In general, pyrolysis can be characterized as slow, when the time to heat the biomass to its pyrolysis temperature is much higher than the pyrolysis reaction time. In addition, pyrolysis can be classified according the type of the pyrolysis reactor, or pyrolyzer. The oldest pyrolyzer type is the fixed bed reactor that is operating in a batch mode, while the required heat is provided from an external source, e.g. an electric furnace.

In the analysis, data from previous work were used, [18, 19, 20, 21, 7]**.** The reactor is a tubular fixed reactor, which is surrounded by an electric furnace that supplied the necessary heat for start-up. The temperature of the reaction is measured with the use of a thermocouple vertically placed inside the reactor while the pyrolysis products determined by weighting. The pyrolysis temperature set at 600 ^oC, with an approximate heating rate of 200 $^oC/s$ under He atmosphere, [7]. The producer gas is a mixture of CO (99%) with minor fractions of CO_2 and CH_4, [7], resulting in a low enthalpy SynGas that is inefficient for use for energy production and apparently is considered as by product of the procedure. The pyrolysis also produces 7.4 t of bio-char with an average LHV of 29MJ/kg (our data) and 8.5 t of bio-oil with an average LHV of 31MJ/kg, [18, 22]. The energy balance of the system is presented in Table 3 while the energy balances at Table 4.

Table 2 Elementary analysis of bio-char

Bio-Char	
	wt% (daf)
Carbon	78.37
Hydrogen	2.485
Nitrogen	1.86
Sulphur	0.215
Oxygen	8.995
LHV (MJ/kg)	29.00

In order to produce the mass and energy balances several assumptions have been made. The temperature of the raw material before it enters the dryer is considered same as the average environmental temperature (15 ^oC) while the dryer's efficiency taken at 60% which is a typical average for drum driers, [23], and the electricity production engine's efficiency set equal to 30%. Tables 3 and 4 indicate the mass and energy balances.

Table 3 Mass balance

Olive grove		
Outputs	*t*	*Moist. (wt %)*
Pruning	25	32
Twigs	10	40
Olives	40	-
Olive Mill		
Inputs	*t*	*Moist. (wt %)*
Olives	40	-
Water	4	-
Outputs	*t*	*Moist. (wt %)*
Olive Oil	6	-
Moist Olive pomace (pits included)	34	60
Olive pits	5	15
Drying Process (η=60%)		
Inputs	*t*	*Moist. (wt %)*
Olive Pits	5	15
Pruning	25	32
Twigs & Leaves	10	40
Outputs	*t*	*Moist. (wt %)*
Dried Olive Pits	4.9	10
Pruning	19.5	10
Twigs & Leaves	7.0	10
Pyrolysis reactor		
Inputs	*t*	*Moist. (wt %)*
Dried Olive Pits	4.9	10
Pruning	19.5	10
Twigs & Leaves	7.0	10
Outputs	*t*	
Pyrolysis Oil	8.5	-
Bio-Char	7.4	-
Pyrolysis Gas	9.9:	-

Table 4 Energy flows

Olive Mill	
Inputs	*kWh*
Thermal Energy	1,440
Electricity	3,660
Drying Process Olive Wood (η=60%)	
Inputs	*kWh*
Electricity	11,300
Pyrolysis reactor	
Output	*kWh*
Pyrolysis Oil	73,300
Bio-Char	61,000
SynGas	165
Oil Engine for Electricity (η=30%)	
Input	*kWh*
Pyrolysis Oil	73,300
Output	*kWh*
Electricity	22,000

Gasification for Power production

Gasification is considered as a mature technology as it was extensively applied in the town gas industry. Although the use of natural gas resulted in the decline of the technology, lately, gasification is having its own rejuvenation. The advantage of gasification is that could efficiently valorize a great number of feedstock including organic residues and biomass. Among the biomass types that can be used for energy production the agricultural and agro-food processing wastes are of great significance. The solid residues from olive farming and olive oil extraction process are among the most promising agricultural residues suitable for energy production via gasification. In this respect an alternative power production scheme is examined. The solid wastes that previously used as a feedstock in a pyrolysis reactor will be valorized in a series of bubbling fluidized bed gasifiers, [24]. The residues dried at 4.2 wt% humidity, producing 29 t of feedstock suitable for use in the gasifier. The gasification temperature is at 800 ^oC and the equivalence ratio is kept constant during operation at ER: 0.3 (50 t of air in gasifiers). The Syngas yield estimated at 63 t and its energy content at 88MWh. The producer gas is utilized for electricity production in a micro turbine (Brayton Cycle) of 37.5% efficiency, [25], producing $33MWh_{el}$. The electricity required for the drying and the operation of the olive mill and gasifier estimated at $24MWh_{el}$ resulting at a $9MWh_{el}$ surplus provided to the grid. The thermal energy for the malaxation process is provided as in pyrolysis scenario by the utilization of the waste heat that is recovered from the dryer. The mass balances and energy flows of the process are shown in Tables 5 and 6.

Table 5 Mass balance (Gasification)

Drying Process (η=60%)		
Inputs	*t*	*Moist. (wt %)*
Olive Pits	5	15
Pruning	25	32
Twigs & Leaves	10	40
Outputs	*t*	*Moist. (wt %)*
Dried Olive Pits	4.5	4.2
Pruning	18.0	4.2
Twigs & Leaves	6.4	4.2
Set of Gasifiers		
Inputs	*t*	*Moist. (wt %)*
Dried Olive Pits	4.5	4.2
Pruning	18.0	4.2
Twigs & Leaves	6.4	4.2
Air (ER=0.3)	50.00	-
Outputs	*t*	
Synthesis Gas	62.00	-

Table 4 Energy flows (Gasification)

Olive Mill	
Inputs	*kWh*
Thermal Energy	1,440
Electricity	3,660
Drying Process Olive Wood (η=60%)	
Inputs	*kWh*
Electricity	18,400
Pyrolysis reactor	
Output	*kWh*
Synthesis Gas	88,000
Micro Turbine for Electricity (η=37.5%)	
Input	*kWh*
Synthesis Gas	88,000
Output	*kWh*
Electricity	33,000

Results and Discussion

The current work presents an alternative waste management technique for the "disposal" of the solid residues generated from the olive oil farming and olive oil extraction process. The concept is shown in fig. 3, where the mass and energy balances are presented.

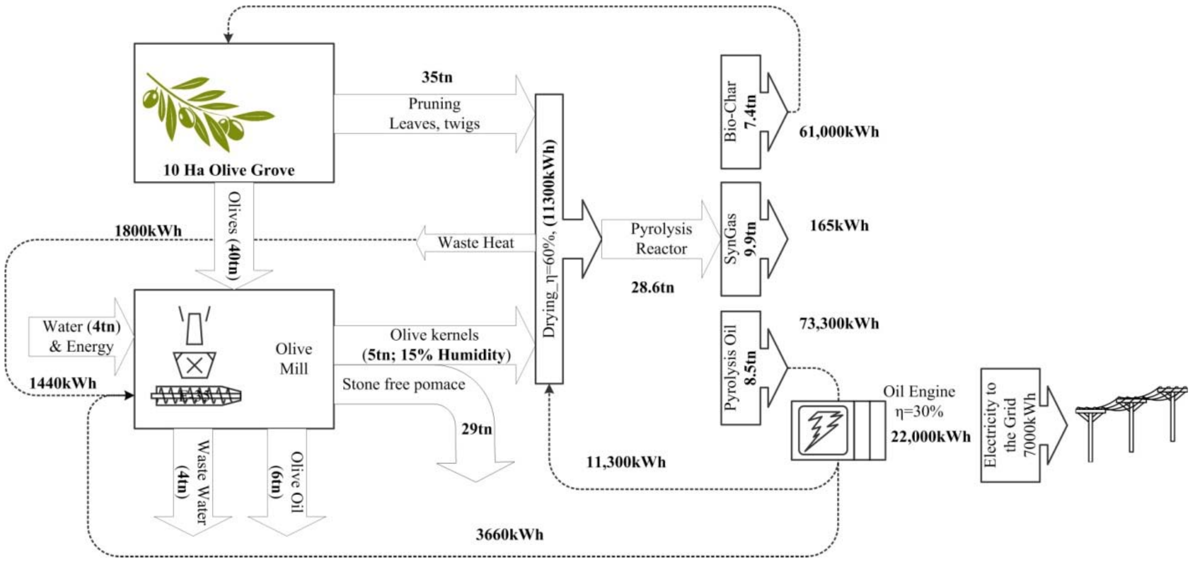

Fig. 3 Energy and Mass balances (Pyrolysis)

As it can be noticed, the valorization of the solid residues from the olive tree cultivation and the olive mill manages efficiently 40 t of woody biomass that up to date still remains a major waste problem for the olive farmers of the Mediterranean basin. In addition the waste management facility, (dryer and pyrolysis reactor) is located on the olive grove and by the olive mill. This eliminates the need of a central waste management facility as the wastes are treated on site and together the seasonality or the discontinuity of the waste generation is no longer a significant handicap. Moreover this practice incorporates the European Union Directive on the promotion of the use of energy from renewable sources (Directive 2009/28/EC of 23 April 2009).

The whole process requires additionally large quantities of energy but as it can be seen from fig. 3, this is not considered as a burden. The energy required for the drying of biomass is fully covered by the electricity produced. Further to the above, the produced electricity is enough to satisfy the energy needs for the machinery operation ensuring the olive mills energy autonomy. Together there is a surplus of 7.0MWh_{el} that can be provided to the grid. If the high sell prices of electricity from biomass are taken under consideration then the financial viability of the project could be easily met and in a best case scenario to provide an extra income to the farmer and the operator of the mill.

Besides the advantages of the waste management and electricity production the scheme is producing 7.4 t of bio-char that could be used in the olive grove as an amendment in order to preserve the fragile soil quality, a practice that is in line with the principles of ecology and sustainable agriculture.

On the contrary the SynGas produced from the pyrolysis could be characterized as a byproduct of the process. Although its yield is similar to the bio-char and the pyrolysis oil, its low heating value make it inefficient for use. Thus, the design of the pyrolysis reactor (heating rate, pyrolysis temperature, resistance time) should focus in the maximization of the solid and liquid yields over the Syngas production.

Further to the aforementioned this work investigated the possible valorization of the solid residues via the thermochemical route of gasification in order to compare these results with the pyrolysis benefits. The mass and energy balances of the gasification process are presented in fig. 4.

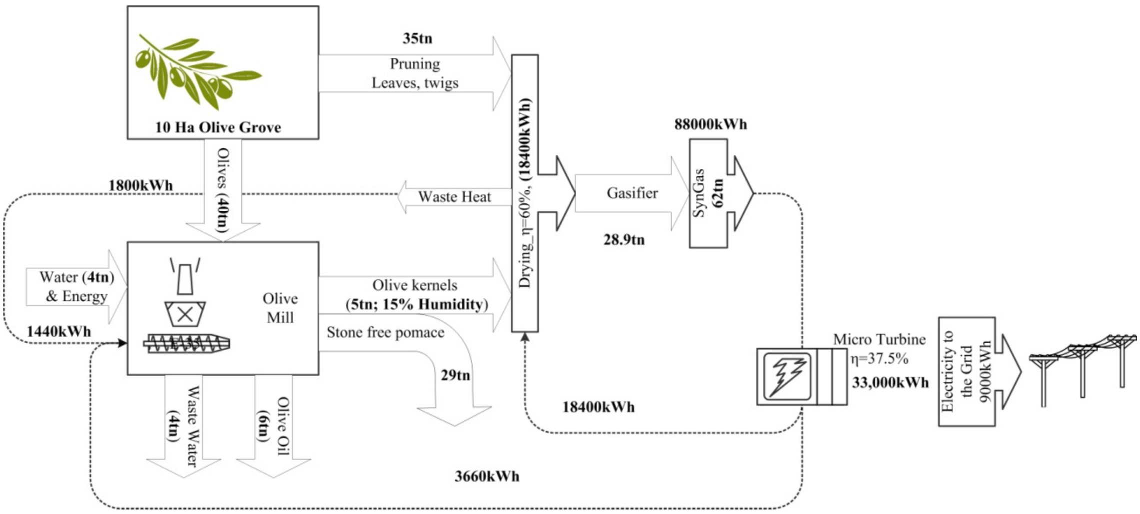

Fig. 4 Energy and Mass balances (Gasification)

The comparison of pyrolysis with gasification has shown that although the gasification scenario requires more energy for its operation than pyrolysis, on the contrary it generates an additional 2000kWh_{el} for the same input. If someone focuses just in power production then the gasification scenario seems to be the most suitable alternative. However, the pyrolysis is co-producing the bio-char that could efficiently be used as a soil amendment. The characterization of one of the above as the best practice is not straightforward as it is highly dependent on the specific characteristics of the olive grove and the farmer's needs. If the soils quality is quite poor and the potential erosion is obvious, then the pyrolysis route is imperative. Moreover, if the olive grove farming requires more energy, e.g. electricity for irrigation, then the best solution appears to be the gasification.

The proposed scheme manages the wastes in a manner aligned to the concept of sustainability. The system under study produces energy and/or a soil amendment material from a renewable feedstock that otherwise would considered as waste, preserving in this way the resources, it creates a new source of employment and enhances the social fabric of rural and agricultural areas and together it ensures its financial viability, as it eliminates the cost of the electricity formally used and simultaneously provides a new income to the farmer from the produced electricity provided to the grid.

Conclusions

In this work an alternative waste management scenario of the olive grove residues and olive extraction process solid biowaste streams is under investigation. The scope of the proposed scheme is to reuse the solid wastes through their valorization via pyrolysis in order to develop an environmental efficient bio-energy system and together attempts a comparison of the pyrolysis benefits with the ones of the gasification. The results of the analysis could be considered as encouraging.

- Both systems are producing enough electricity to cover the needs of the olive mill operation and together they are having a surplus that can be sold to the power corporation and provide an extra salary.
- Gasification is producing more electricity (9,000kWh) and is more suitable in energy intensive olive farms while pyrolysis is producing bio-char (7.4 t) that can efficiently used as a soil amendment and is more suited when the increase in production is in question.
- The proposed method managed 40 t of woody biomass generated from a 10 ha olive grove in an environmental align manner following the concept of sustainable development.

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