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Article

Energy Requirement of Extra Virgin Olive Oil Production

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Abstract: The scope of this chapter is to calculate the net energy of the production chain for virgin olive oil. Therefore, the determination was carried out for the direct and indirect energy inputs and the energy present as feedstock in the outputs (products and by-products). To perform this analysis, all of the production processes for olives and for oil extraction were studied. For the agricultural phase, three systems of cultivation were taken into consideration: the centenary olive grove (COO), the "intensive" olive grove (HDO) and, the more recently introduced, "super-intensive" olive grove (HSDO). The last two models are distinguished by the high number of trees per hectare and by an intense mechanization of agricultural practices. Regarding the oil extraction phase, four different technologies were compared: the pressure system (PS), the two-phase system (2PS), the three-phase (3PS), and the system, called "de-pitted", which provides for the separation of the pits before the oil is extracted (DPS). The analysis showed that the production of olives needs more than 90% of energy requirements, much of which is met by non-renewable sources of energy. The production of fertilizers, and also irrigation, are the production factors that require a considerable amount of energy. Among the three agricultural systems analyzed, the COO system of cultivation is the one that requires less energy as compared to the other systems. The scenario that enables the most energy return, however, is the SHDO system of cultivation, due to the greater amount of pruning residues that can be obtained.

Keywords: olive oil chain; energy demand; net energy; life cycle thinking

1. Introduction

The evidence of the increasing scarcity of fossil fuels for energy production poses important challenges for the future. Along with measures to promote the production of energy from renewable sources, energy consumption must be reduced, starting with improving the energy efficiency of production processes. To this end, it is important to have an accurate account of the energy used for each activity, in order to seek ways to reduce their use or identify alternative sources, which present fewer problems in supply, in price instability and environmental impacts. Among different methods of assessing the quality of a source of energy is the Net Energy Analysis, which compares the energy obtained from a given resource and the one required, direct and indirect, to make it available to the final consumer. Until now, many studies concerning "net energy" or "EROI" (Energy Return On Energy Investment) have been conducted on renewable energy and on several agricultural and agro-industrial products, primarily to evaluate the opportunity of using these as sources of energy [1–3].

In this study, however, the virgin olive oil production chain was analyzed; a product intended for human consumption, since it is of considerable economic importance in Mediterranean countries (the average annual production of virgin olive oil, in the period from 2007–2013, was approximately 2.9 million tons) [4] and also because it is the source of many materials for which it is possible to imagine a simpler use for energy purposes. The study is part of a vaster research, which tends to assess the "net energy" resulting from the production of edible oils and fats. This research will be extended to other agro-industrial productions in the future, in order to compile the information required to create comparisons among the different food chains in terms of net energy. The calculation was then carried out for the energy required to produce one liter of virgin olive oil and for the energy contained in the product and in the various by-products [5–11]. The data relating to agricultural practices and the inputs for the production of olives and of the oil extraction processes were collected in several farms and oil mills in Apulia region (Italy). Where primary data were not available, Ecoinvent v.2.2 [12] and PE-International (updated March 2014) [13] databases were used. This analysis has lead to suggested solutions that can allow us to reduce the energy consumption of the process as a whole.

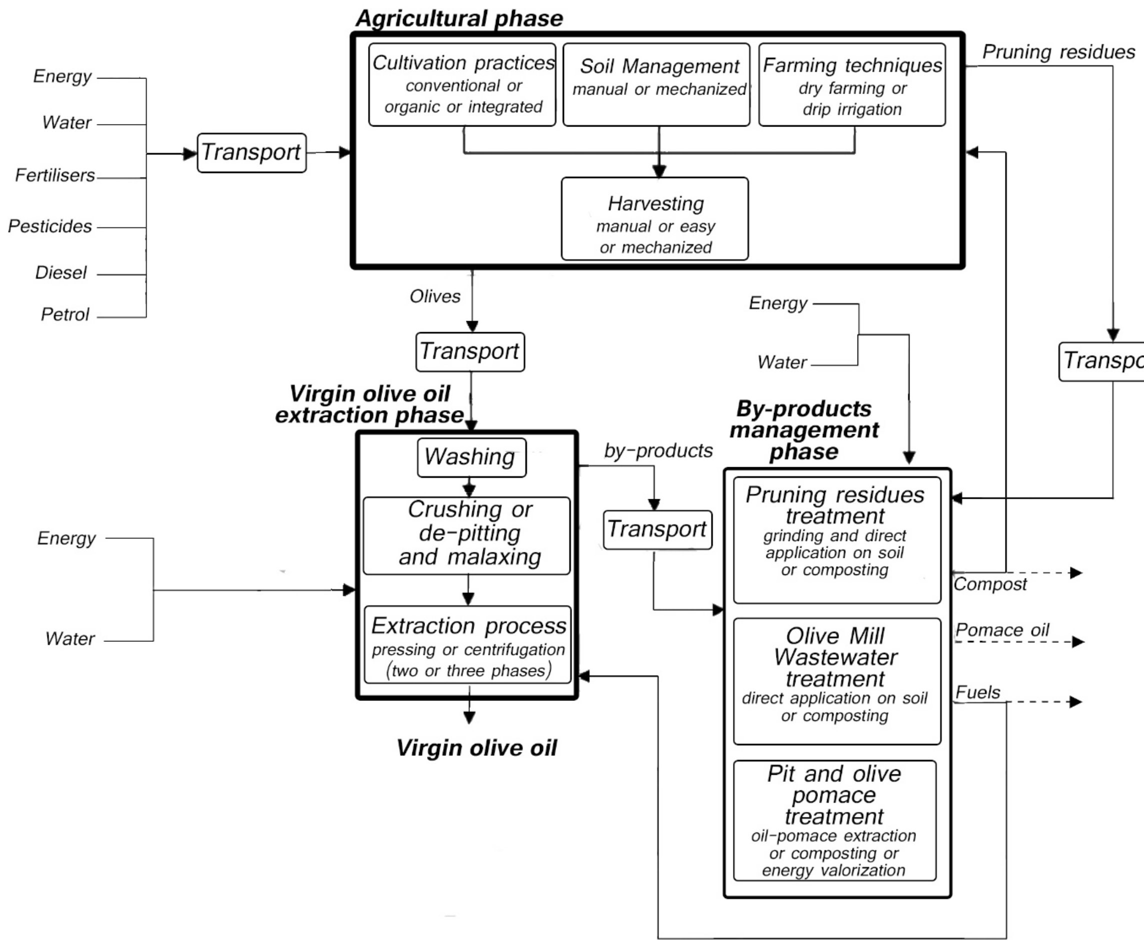
2. Methodological Approach

In this study, the net energy was calculated for the olive oil production chain (cultivation of olives and their transformation into edible oil) [14] (Figure 1).

Direct energy inputs were considered, along with the energy associated with the input materials in the supply chain. As output, the energy value of the product and the energy obtainable from by-products of the production chain were considered. The inputs and outputs of energy and materials referred to the production of 1 L of virgin olive oil (approximately 920 g). With regards to the production of the olives, three types of cultivation systems were analyzed: the secular system, (COO), the intensive system (HDO), and the super-intensive system (SHDO). With regards to the process of transformation of olives into oil, four different types of technologies were analyzed: discontinuous pressure system

(PS), two-phase continuous system (2PS), three-phase continuous system (3PS), and the system that provides for the separation of the pits before extracting the oil from the olive pulp (DPS). Transport from the olive grove to the mill was also taken into consideration. The data, referring to the agronomic practices required to manage the three cultivation systems (soil management, fertilization, water management, adversity management, pruning, harvesting) were collected from local olive growers. The information regarding fuels, lubricants, equipment, and the manufacturing of fertilizers and pesticides were collected from the Ecoinvent v.2.2 database. The operations of renewal for the olive grove in the SHDO system were excluded from the analysis. All data related to the stage of cultivation of the olive grove are relevant to olive cultivation in the Apulia region (Southern Italy). As far as transportation is concerned, an average distance of 30 km was considered, along with the relevant use of fuel, calculated according to what was indicated in the PE-International database. All data relating to inputs and outputs for the four extraction processes researched were collected directly from the oil mills in Apulia region. The information relating to the structures and machinery of the plants was excluded. As for electricity, the Italian energy mix was taken into consideration [15].

Figure 1. Virgin Olive oil chain.



The twelve consequent systems are illustrated in Figure 2, where the inputs and outputs relating to the production of olives and the extraction of virgin oil are also indicated. It is clear that among the three olive grove management systems, the COO is the one that requires lesser amounts of inputs per hectare of olive grove. Instead, the complete mechanization of the SHDO system involves a greater use of energy and material resources. This, however, allows to obtain higher yields as compared to the other olive production systems.

With regards to the extraction phase, the PS system uses lesser amounts of energy than other inputs, while the continuous systems (2PS, 3PS, DPS) require greater quantities of water and electricity. With regards to the quantity of oil extracted from olives, it is noted that the differences between extraction systems are minimal. The energy value of the olive oil and the lower calorific value of the pruning residues and by-products from the oil extraction were included in the analysis, since it is intended to quantify the energy yield that olive cultivation and oil production allow to obtain.

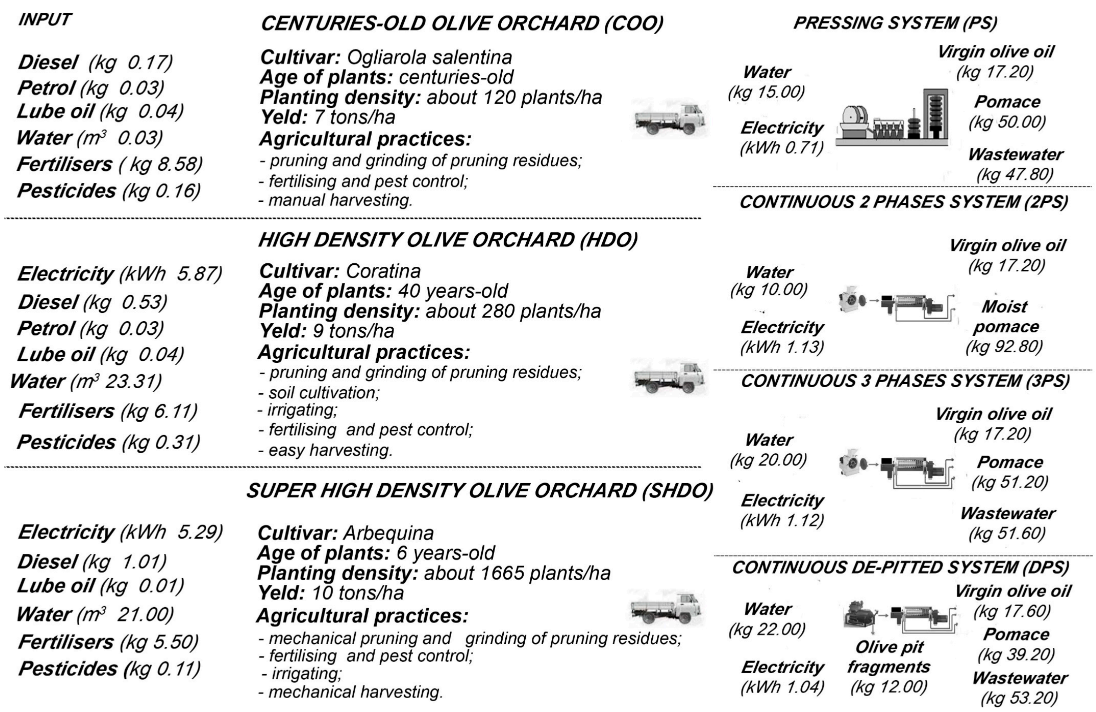
For the calculation of the energy contained in the products and by-products of each system, the following data were considered:

- virgin olive oil for food consumption: Energy value—34.5 MJ/L [16];
- lower calorific value of by-products:
    - pruning residues—18.3 MJ/kg (dry substance) [17];
    - olive pomace—20.3 MJ/kg (dry substance) [18];
    - pits—19.0 MJ/kg (dry substance) [19];
    - pulp—21.2 MJ/kg (dry substance) [19].

The analysis took into consideration the three olive plant cultivation systems in full production. Actually, these all have a different life span: the intensive and centuries-old olive groves can respectively exceed fifty and one hundred years, the super-intensive, however, last for a limited time that does not generally exceed twenty years. For this analysis, the replanting of the super-intensive olive grove was not taken into consideration.

Furthermore, the analysis did not take into consideration the energy input from human labour.

Figure 2. Input and output referred to 100 kg of processed olives by distinguishing among the analyzed systems.



3. Results

Table 1 shows the energy inputs for the production of 1 L of virgin oil for all the production systems considered, distinguishing between olive production, transportation, and oil extraction. The total quantity of energy varies from approximately 9 MJ of the COO-PS, COO-2PS, COO3-PS and COO-DPS systems to the over 11.5 MJ of the HDO-2PS, HDO-3PS, SHDO-2PS and SHDO-3PS systems. It is also noted that in the twelve systems analyzed, the production of olives requires over 90% of total energy consumption (from about 90% of the COO-PS system to about 94% of the HDO-PS and SHDO-PS system). Analyzing the energy inputs of only one phase of transformation of the olives into oil, although they represent an unsubstantial quota of the total, several differences among the four different extraction techniques were detected. The continuous systems (in particular, the 3PS system) demand an energy requirement of up to 50% higher as compared to the PS discontinuous system, characterized by a greater intensity of manual work.

Table 1. Energy needed to obtain 1 L of virgin olive oil.

		Olives Production		**Transport**		**Virgin Olive Oil Extraction**		**Total**	
		MJ	**%**	**MJ**	**%**	**MJ**	**%**	**MJ**	**%**
COO	**PS**	8.4	92.8%	0.1	1.6%	0.5	5.5%	9.1	100.0
	2PS	8.4	90.7%	0.1	1.3%	0.7	8.0%	9.3	100.0
	3PS	8.4	90.4%	0.1	1.6%	0.7	8.0%	9.3	100.0
	DPS	8.2	91.2%	0.1	1.6%	0.6	7.2%	9.0	100.0
HDO	**PS**	10.7	94.2%	0.1	1.3%	0.5	4.4%	11.3	100.0
	2PS	10.7	92.5%	0.1	1.3%	0.7	6.2%	11.5	100.0
	3PS	10.7	92.3%	0.1	1.3%	0.7	6.5%	11.6	100.0
	DPS	10.3	92.9%	0.1	1.3%	0.6	5.8%	11.1	100.0
SHDO	**PS**	10.6	94.2%	0.1	1.3%	0.5	4.5%	11.2	100.0
	2PS	10.6	92.5%	0.1	1.3%	0.7	6.2%	11.5	100.0
	3PS	10.6	92.2%	0.1	1.3%	0.7	6.5%	11.5	100.0
	DPS	10.3	92.9%	0.1	1.3%	0.6	5.8%	11.1	100.0

Table 2 shows the distinct energy requirement for the different factors of the production of 100 kg of olives from the three agricultural scenarios. In particular, the datum relevant to the production of fertilizers (about 102 MJ for COO, about 73 MJ for HDO, and about 67 MJ for SHDO) should be noted. This energy input is particularly relevant in the COO system, due to the lesser density of plants per hectare and, therefore, lesser productivity. For the same reasons, the energy relevant to the production of pesticides (in particular, organophosphates) amounted to about 27 MJ for the COO system (19% of the total energy required by the system). This contribution is lower in the HDO system (12%) and the SHDO (8%) system. Furthermore, the three agricultural scenarios consider different typologies and quantities of pesticides. In particular, in the COO and SHDO is relevant the use of insecticides (organophosphates), while in the HDO the copper is used in high quantity (almost 4 times higher than the quantity used in the COO). Indeed, despite of the great amount of total pesticides employed in the HDO due to the high use of copper, the energy required to their production is lower than in the COO system.

The consumption of diesel referred to cultivation procedures in the HDO and SHDO systems results as being greater (respectively 0.5 kg and 1 kg) than that of the COO system (0.17 kg). Weed control is the agricultural practice that requires more fuel. This is conducted by mowing in the COO system, harrowing in the HDO system, and the application of chemical herbicides in the SHDO system.

Table 2. Energy demand of 100 kg of olives obtained from the three olive-growing models, by distinguishing among the sub-phases.

	COO		**HDO**		**SHDO**	
	MJ	**%**	**MJ**	**%**	**MJ**	**%**
Fertilisers	102.5	72.4	73.2	40.8	67.0	37.5
Soil cultivation	8.8	6.2	12.6	7.0	12.2	6.9
Irrigation	0.0	0.0	55.1	30.7	49.6	27.8
Pesticides	27.1	19.1	21.7	12.1	13.7	7.7
Pruning	3.3	2.3	2.5	1.4	2.2	1.2
Harvesting	0.0	0.0	14.3	8.0	33.7	18.9
Total	141.7	100.0	179.4	100.0	178.4	100.0

Fuels and lubricants employed in the pruning process make up over 2% of the total energy requirement for the COO production system while, in the other two systems, the contribution is lesser. This is due to the fact that systems that are mostly mechanized allow to perform pruning procedures more efficiently. In particular, in the SHDO system, a cutting blade applied to the tractor replaces scissors and chainsaw commonly used for the HDO and COO manual pruning systems. Irrigation is carried out only in the HDO and SHDO production systems. This practice, in particular, demands a considerable amount of electricity (about 55 MJ for HDO system and about 50 MJ for SHDO), needed to extract from artesian wells the considerable volumes of water required (approximately 2000 m^3 per hectare, from wells 60 m to 150 m deep). With regard to the sources of energy, it appears that over 90% of the total energy used is produced from non-renewable sources. That produced from renewable sources is represented only by the quota relevant to the mix of national electricity. By analyzing the different types of non-renewable energy resources, excluding transportation for obvious reasons, higher consumptions are related to natural gas. During the production of olives, this consumption mainly concerns the production of fertilizers and pesticides, while for the HDO and SHDO systems, these also refer to the consumption of electricity for irrigation. The SHDO system is one that requires greater quantities of crude oil, since it is a fully mechanized and, therefore, requires a higher consumption of fuel and lubricants for machinery.

Figure 3 shows the potential energy that can be recovered from by-products, net of the energy used for the production of 1 L of virgin oil (obtained from the various systems of olives production and oil extraction). Among the various agricultural systems, the SHDO system returns the greatest amount of energy, since the higher plant density allows to obtain a larger quantity of plant biomass (pruning residues). From the oil mill operations aimed at obtaining 1 L of virgin olive oil, similar quantities of by-products are produced, regardless of the extraction system used.

Figure 3. Net energy of 1 L virgin olive oil.

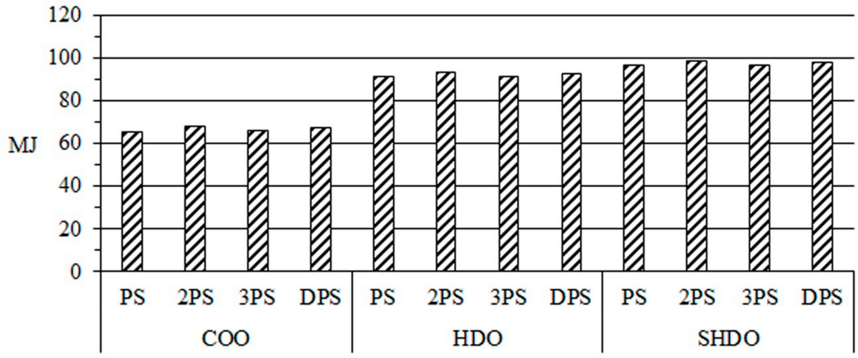
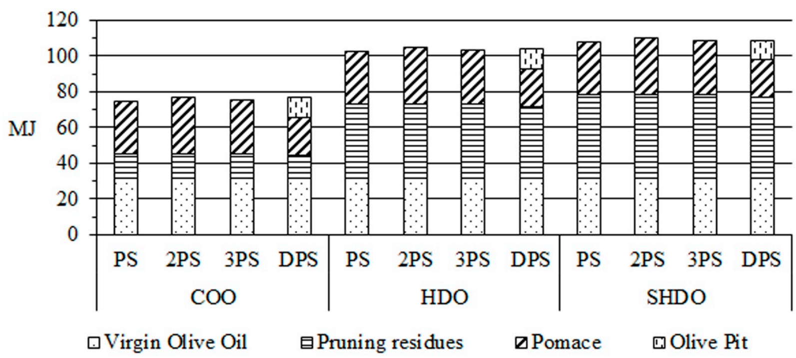


Figure 4 shows the data relating to energy that can be recovered, referred to single products and by-products deriving from the production of 1 L of oil. This demonstrates that the oil, despite being produced in smaller quantities than the other by-products (on average, approximately 17% of virgin olive oil), has a very high energy content. The DPS system allows for the separation of pit fragments from the pulp of olives prior to extraction of the oil. This allows us to obtain an additional by-product, the pits, much appreciated as a domestic fuel. Regarding the 2PS extraction system, it presents an energy recovery potential that is slightly higher. Since it does not generate vegetation waters, but only pomace (humidity from 65% to 70%), there is no loss of organic substance, which instead occurs in other extraction systems. To recover the energy contained in the wet pomace, however, it is necessary to remove a larger amount of water. Only if it is performed by evaporating the water without direct input of energy can it be possible, in this case, to consider all the energy potential of solid biomass available. Ultimately, the scenario which allows more energy return is the one that the SHDO agricultural system offers while, among extraction systems, there were no substantial differences. In the COO system, the energy recovered does not exceed 80 MJ/L of oil, while for the HDO it exceeds 100 MJ/L and for SHDO the value is about 110 MJ/L. These differences are mainly due to the different amounts of pruning residues that are generated in the three systems, since the methods with which pruning is carried out and the density of plants per hectare are different. Figure 4 also shows the energy input provided by the pomace, an average of approximately 30 MJ/L of oil. Therefore, it appears that the amount of energy returned from the 12 systems ranges from a minimum of 74.6 MJ, for the COO-PS system, to a maximum of 110.4 MJ, for the SHDO-2PS system.

Figure 4. Energy recovery, from pruning residues (Pr), virgin olive oil (O), virgin pomace (P) and pit, (Pt) referred to all the analyzed systems.



4. Conclusions

The analysis conducted, which represents only a first stage in a wider field of research regarding the Net Energy Analysis applied to the agricultural-food sector, involved the production chain for virgin olive oil.

This study highlights, despite many approximations, that the agricultural phase requires more than 90% of the total demand of energy required for the production of virgin olive oil. Among agricultural practices, irrigation, where applicable, requires a great deal of electricity, while the production of fertilizers is the activity that, by far, determines the most energy input. As sources of energy, more than 90% come from non-renewable sources (of which natural gas represents approximately 50%).

Furthermore, the study showed that the systems which require lower energy input are COO-PS and COO-DPS.

The study also estimated the energy that can be recovered from the virgin olive oil production chain. This varies from system to system, essentially dependent upon the amount of pruning residues obtainable. In particular, the SHDO system is, from this point of view, the most advantageous.

To achieve further energy returns, several strategies may be implemented:

- reduce the use of water to a minimum, using more efficient systems and irrigation practices;
- reduce chemical fertilizers and pesticides to a minimum and use these more efficiently, promoting organic fertilizers, minimum processing, and organic pest control.

For the olive oil sector, increased mechanization is expected for the future, especially for harvesting olives, since this activity is economically very burdensome. It is for these reasons that, in the next few years, the demand for energy in this sector is likely to grow.

It would be opportune to evaluate whether these innovations will also improve the energy efficiency, as well as the economic yield of the system. The challenge, according to some objectives of the Horizon 2020 program, will be to encourage researchers to find solutions to reduce the energy demand, optimize the supply from renewable energy sources, and recover potential energy along the entire virgin olive oil production chain.

Author Contributions

G.M. Nicoletti conceived and coordinated the study. G.M. Cappelletti and G. Ioppolo collected and processed the data. C. Russo elaborated and discussed the results. All authors prepared and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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