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Comparative studies on energy efficiency and GHG emissions between conventional and organic olive groves in Greece and Portugal

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Abstract

Nowadays, traditional farming based on achieving high yields using high inputs, shifts gradually towards maximum possible crop yield using minimal inputs in an optimized way or towards organic farming. This is usually accomplishing by low yield of high quality products without using conventional agrochemicals (i.e. fertilizers, pesticides). In general, this last approach leads to lower energy consumption per unit area of land, therefore lower cost and reduced greenhouse gas (GHG) emissions. However, in a global perspective it has the risk of significant total production reduction. Hence, it is vital to consider energy efficiency improvement, namely the decrease of primary energy consumption for the production of a unit of agricultural product (expressed in weight or volume units), within the farm boundaries. Improvement of energy efficiency is a key parameter affecting positively the overall efficiency of crop farming systems in terms of energy and GHG emissions. In the present paper, two show cases of olive groves in Greece (“Sterea Ellada” region) and Portugal (“Alentejo” region) were compared to illustrate the effect on energy efficiency and GHG emissions when moving from conventional to organic olive grove cultivations in these different locations. The analysis was based on two simple framework models using information provided by farmers and literature data regarding the inputs and outputs of each olive grove. The models were adjusted according to the olives’ variety, the agricultural practices followed and the location of the production system. Considering the specific energy consumption per unit of product, in the case of the Greek olive grove, organic farming reduces energy consumption by 13.9%, while the final yield is reduced by 30%. GHG emissions are reduced by 58%. In the case of the Portuguese olive grove, organic farming significantly reduces crop yield (54.5%), while, energy efficiency is improved by 9.7% and GHG emissions are reduced by 26%.

Keywords: energy, GHG emissions, olive groves, organic

1. Introduction

Agriculture as a primary production sector relies very much on the use of energy. Even if the agricultural sector accounts for 3.7% of the total energy use in EU-27 (EEA, 2012), which seems insignificant, it should be noted that in many countries national statistics record as energy use in agriculture only direct energy inputs, during the cultivation period. On the other hand, energy use for the production and transportation of input materials (indirect energy use), such as fertilizers, pesticides and plastics, is recorded under the industrial sector and fuel in the transport sector.

If both direct and indirect energies are considered in an agricultural production system, then it becomes clear that a significant amount of total energy is required for the production of agricultural products and that energy savings should also be considered in this sector, as in most energy consuming sectors (e.g. electrical appliances, automobiles, buildings, etc.). The best way to save energy is to improve the energy efficiency of the whole system.

According to the Energy Services Directive 2006/32/EC, there is a need for improve energy end-use efficiency in all energy consuming systems. In Article 3 of the same Directive, energy efficiency is defined as the ratio between an output of performance, service, goods or energy, and an input of energy.

There are three ways to obtain higher energy efficiency: either by reducing energy input or increasing yield or a combination of both. Thus, improved energy efficiency can be realized with either increased or decreased energy inputs depending on the input-output relationship.

Conventional farming systems target on high yields (high profit) without considering the amount of inputs used during the cultivation period. However, this practice has been the subject of strong questioning as the negative environmental and public health impacts of such farming systems are very high. Therefore, new farming systems have been adopted. Among them, organic farming is associated with lower yield and better quality, which excludes or strictly limits the use of synthetic fertilizers and pesticides.

Organic farming seems to be an ideal farming system on a land area basis (lower energy consumption per unit area of land), but in most cases this is not the case on a yield basis. In a global perspective it has the risk of significant reduction of total agricultural production.

Olives are one of the most important perennial crops for Greek and Portuguese agriculture. In general, olive groves are cultivated using the conventional farming concept of attaining the maximum possible yield. Organic farming is not widely applied yet as farmers believe that high chemical inputs ensure high yields and profits. However, there is a tendency recently to switch to organic farming as a result of higher product prices, especially for high quality exported certified olive oil. Productivity reduction is expected, but net return could be satisfactory since the market prices are higher.

Organic farming relies on a number of practices designed to minimize the impacts on the environment, while ensuring that the agricultural system operates as naturally as possible. Typical organic farming practices in olive groves include the limitation in the use of synthetic pesticides and fertilizers and takes advantage of on-site resources, such as livestock manure for fertilizer and possibly sheep for weed control. In addition, organic farming could help to conserve water (Altieri, 1992) in arid and semi-arid areas like many regions in Southern European countries as Greece and Portugal, and reduce GHG emissions (Dalgaard et al., 2001).

In this work the conventional farming of an olive grove located in the “Sterea Ellada” region, Greece and an olive grove in the “Alentejo” region, Portugal, was compared against the respective organic farming in terms of energy efficiency and respective GHG emissions.

2. Materials and methods

Apart from productivity, energy consumption is also directly related to environmental impacts and especially to GHG emissions. Therefore, it is worth considering both aspects when a new production system is proposed to replace an existing one. The energy efficiency improvement and the environmental analysis in this work are based on a “cradle to farm gate” analysis, taking into account all inputs used and emissions released to produce the agricultural products. The analysis of the olive groves in the Greece and Portugal were based on information provided by farmers and data found in literature.

In order to model potential trade-offs between energy savings and GHG emissions it was necessary to model the new production system (organic farming) with simple spreadsheet based models. Their frameworks were constructed based on selected showcases for typical olive grove cultivations in the two countries. The models were modified according to the olive variety and the agricultural practices followed in each case study and the location of the production system.

Instead of modelling only the production systems, the show case models were studied within a farm level framework, thus relating energy and GHG emission with final yield. In order to provide consistent results, the same system boundaries for all energy and environmental assessments were selected. The farm gate was considered as the ultimate boundary of the analysis of the trade-offs (Figure 1), because the show case analyses processes on the farm may differ. The calculations of the energy savings and GHG emissions with the energy efficiency measures were based on assumptions drawn, if not stated otherwise, from the Biograce database (www.biograce.net).

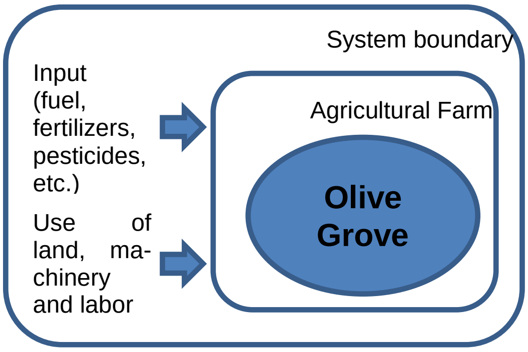


Fig. 1 System boundary of energy and environmental assessments

2.1 Case studies for olive groves

The first step regarding the case studies for olive groves in both countries was to develop records of the conventional agricultural practices and total inputs using data from personal interviews with the owner farmers.

2.1.1 Conventional olive grove in Greece

The conventional production system olive grove has a mean plant density of 250 plants/ha (compass of 6 x 6 m). The olive grove life time was assumed to be 100 years, with the first 15 years counting as installation period of low yield.

The olive grove installation is initiated with several operations for the soil preparation (plough for deep ploughing, heavy cultivator, light cultivator), followed by a fertilization using 5.5kg/ha/yr N, 7.5 kg/ha/yr P and 7.5 kg/ha/yr K. Soil is marked and holes are open for the olive trees. These operations are considered for the first year of installation.

The first 15 years, olive trees are sprayed with insecticides (dimethoate or fenthiol with 0.3%) 2-4 times/yr. Weed control is obtained using light cultivator 4 times/yr. Three to five irrigation applications using drip irrigation systems are applied (total water quantity 120 m^3/ha/yr). Fertilization is applied every second year using 11-15-15 fertilizer type. The quantity required is 0.2 kg/tree for every year of the tree growth.

During the regular period (next 85 years), the olive grove is sprayed with insecticides (dimethoate or fenthiol with 0.3%) 2-4 times/yr. For weed control, 3 light cultivations per year are applied, without chemical applications. Three applications of fertilizer are executed every second year (3 kg/tree). Every year, one to three irrigation applications using drip irrigation systems are applied (total water quantity 180 m^3/ha/yr).

Harvesting occurs from mid-November to late December (the first 15 years the mean yield is about 2.25 t/ha/yr while during the regular production period it reaches 6.5 t/ha/yr). Plastic olive mats are used for olives harvesting. The olive mats' fabric is woven PP cloth (100 g/m^2) with a minimum life span of 5 years. Several mats (depending on the grove area) are moved from tree to tree in order to collect the olives. The average olive mat surface is 50 m^2, in order to cover a surface larger than the canopy area of the tree harvested.

2.1.2 Organic olive grove in Greece

The organic olive grove results in 29% fuel consumption increase (Genitsariotis et al., 2000; Kaltsas et al., 2007). In the organic system, manure is spread using a trailed manure spreader (20 t/ha every second year). Then, one cultivation application is applied, followed by the sowing process for the installation of legumes (green manure of trifolium sp., vicia sativa). Sowing requires 135 kg seed/ha/yr. Finally, light cultivation is applied to incorporate the legumes at the end of their cycle (Kaltsas et al., 2007).

In addition, no chemical pesticides are applied, replaced by bait [Elcophon (plastic bottle)] or bait-pheromone [BIORYL (paper envelope)] and traps for the olive fruit fly (Genitsariotis et al., 2000; Kaltsas et al., 2007). The chemical fertilizers are substituted by sheep/goat manure that is spread in the olive grove using a manure spreader, as mentioned above. In addition, irrigation is not applied. The rest of agricultural practices are the same as in the conventional system. The average yield is assumed to be reduced by 30% mainly due to lower fertilizer inputs (Genitsariotis et al., 2000; Kaltsas et al., 2007; Guzman and Alonso, 2008).

2.1.3 Conventional olive grove in Portugal

The basic scenario is an olive grove in its full production stage, with a production of 8.8 t/ha olives for olive oil production. Mean plant density is 314 trees/ha (8 m x 4 m). The crop is irrigated by a drip irrigation system.

The installation is initiated with several operations regarding soil preparation. Soil is marked and holes are open for planting. The plant tutors and protectors are installed. These operations take place only in the first year and they were considered in this work in the total energy consumption and GHG emissions. The full production olive groves life time is assumed to be 30 years.

Olive groves cultivation techniques are mainly related with soil maintenance and weed control, fertilisation, irrigation, pruning, crop protection against pests and diseases and harvesting. Fertilization is approximately 72 kg/ha N, 16 kg/ha P and 70 kg/ha K. In early spring, a herbicide (glyphosate) is applied in the crop line and usually in the period May - September several pesticide treatments are applied, depending on climate conditions.

Trees are irrigated from May to October with an average annual water amount of 2000 m^3/ha, and with the application of a liquid fertilizer. The amounts of applied water depend on each year specific meteorological conditions, but are mostly supplemental irrigation practices. Olives harvest is done from November to December.

This farm is equipped with all the necessary equipment, namely tractors, a vibrator with a collecting umbrella, sprays, cut grass, and trailer. Materials used in the farm include harvesting canvas, protectors and tutors used during the installation.

2.1.4 Organic olive grove in Portugal

The farm with organic production is an olive grove in its full production stage, with a production of 4.0 t/ha olives for olive oil production. Mean plant density is 286 trees/ha (7 m x 5 m). The crop is irrigated by a drip irrigation system.

The installation is initiated with several operations regarding soil preparation, followed by the application of organic fertilizer (4000 kg/ha of sheep manure). Soil is marked and holes are open for planting. The plant tutors and protectors are installed. These operations take place only in the first year and it was considered in the calculation of energy consumption and GHG emissions. The full production olive groves life time is assumed to be 30 years.

In this organic olive grove, the cultivation techniques main difference comparing with the conventional practices is the exclusive use of organic fertilizers and the non-use of synthetic pesticides. Sheep manure (100 kg/ha/yr) and vegetal compost produced in the farm (5000 kg/ha/yr) are applied as fertilizer. Diseases and insects are controlled with cupper, sulphur and summer oil.

Trees are irrigated from May to October with an average annual water amount of 500 m^3/ha. The applied water quantity depends on each year specific meteorological conditions and is mostly supplemental irrigation practices. Olives harvest is from November to December. This farm is equipped with all the necessary equipment, namely tractors, a vibrator with a collecting umbrella, sprays, cut grass, and trailer. Materials used in the farm include harvesting canvas, protectors and tutors used during the installation.

3. Inventory

3.1 Inputs

A spreadsheet was prepared with an inventory of the olive grove cultivation inputs in Greece and Portugal (Table 1).

Table 1. Inventory of the conventional olive groves

Inputs	Unit	Greece*	Portugal**
Plants	n./ha	250	314
Materials		-	
Fertilizers (synthetic)			
Nitrogen	kg/ha/yr	40.7	72
Phosphorus	kg/ha/yr	55.6	16
Potassium	kg/ha/yr	55.6	70
Pesticides			
Herbicides	kg ai/ha/yr	4	2.7
Fungicides	kg ai/ha/yr	-	7.7
Insecticides	kg ai/ha/yr	3.5	1.23
Irrigation			
Electricity use	kWh/ha/yr	99	
Water	m3/ha/yr		2000
Field operations			
Diesel use	l/ha/yr	22.5	194
Olive mats	kg/ha/yr	2.75	-

(*) olive grove life time: 100 years

(**) olive groves full production life time: 30 years

3.2 Outputs

Table 2 shows the production yield of the Greek and Portuguese olive groves.

Table 2. Annual production yield of the conventional olive grove

Output	Unit	Greece	Portugal
Conventional Olive Grove			
Olives	t/ha/yr	6.5	8.8
Organic Olive Grove			
Olives	t/ha/yr	4.55	4

3.3 Data sources and main assumptions

The primary energy and the respective GHG emissions for each of the considered inputs are shown in Table 3.

Table 3. Primary energy of inputs

Input	Primary Energy	Unit Primary Energy	Total GHG Emission	Unit GHG Emission
Plant[1]	2.61	MJ/kg	0.276	$kgCO_2eq/kg$
N fertilizer[1]	48.99	MJ/kg	5.880	$kgCO_2eq/kg$ N
P_2O_5 Fertilizer[1]	15.23	MJ/kg	1.010	$kgCO_2eq/kg\ P_2O_5$
K_2O Fertilizer[1]	9.68	MJ/kg	0.576	$kgCO_2eq/kg\ K_2O$
Pesticide[1]	268.40	MJ/kg	10.970	$kgCO_2eq/kg$
Diesel Fuel[1]	49.99	MJ/kg	3.640	$kgCO_2eq/kg$
Electricity (GR)[2]	4.53	MJ_pNR/MJ	2.086	$kgCO_2eq/MJ$
Electricity (PT)[3]	2.44	PE/GWh	0.500	$kgCO_2eq/MJ$

[1]Biograce V4 (2012), [2]Ecoinvent (2007), [3]DGEG (data from 1990 to 2006)

Pesticides require the highest energy for their production, resulting in most of the GHGs produced. Diesel fuel and nitrogen fertilizers follow with minor difference between them.

Table 3 clearly shows that non-renewable energy required and GHG emissions for electricity production in Greece are very high. These figures are much higher than the EU average (Ecoinvent, 2007: UCTE average is 1.6 MJ_pNR/MJ and 0.125 $kgCO_2eq/MJ$ respectively), as the electricity grid in Greece is mainly supported by low efficiency coal (lignite) and oil production units, which result in high energy input and GHG emissions.

4. Results and Discussion

4.1 Current Energy and GHG emissions profile

Figure 2 shows the energy and GHG emissions profile of the conventional olive groves in Greece and Portugal. In Greece, the highest energy consumer and GHG emission source are the fertilizers (39.16%), because it is the main input of the plantation as it is shown in Table 1. The second most important energy consumer is the pesticides (23.9%), followed by electricity for irrigation (18.94%) and fuel (15.16%). As for GHG emissions, fertilizers count for almost half of the total GHGs of the system (45.67%) followed by electricity for irrigation (29.14%). Fuel and pesticides are on the same level.

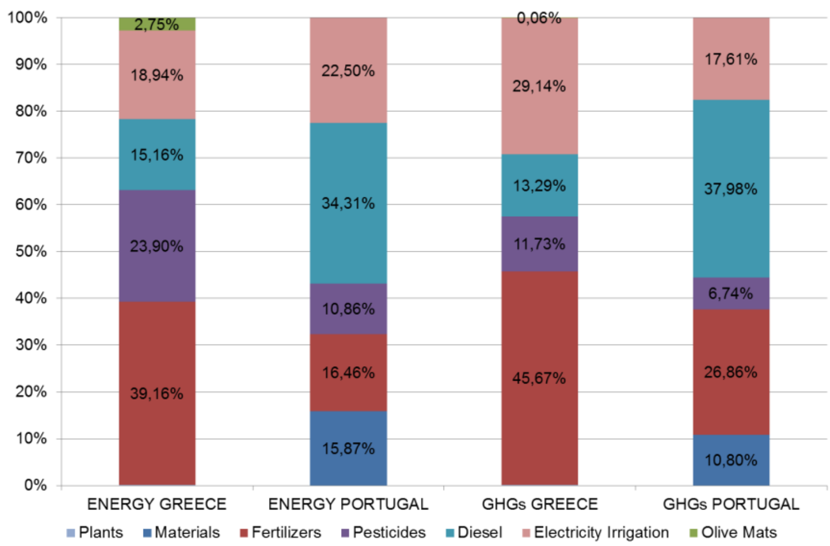
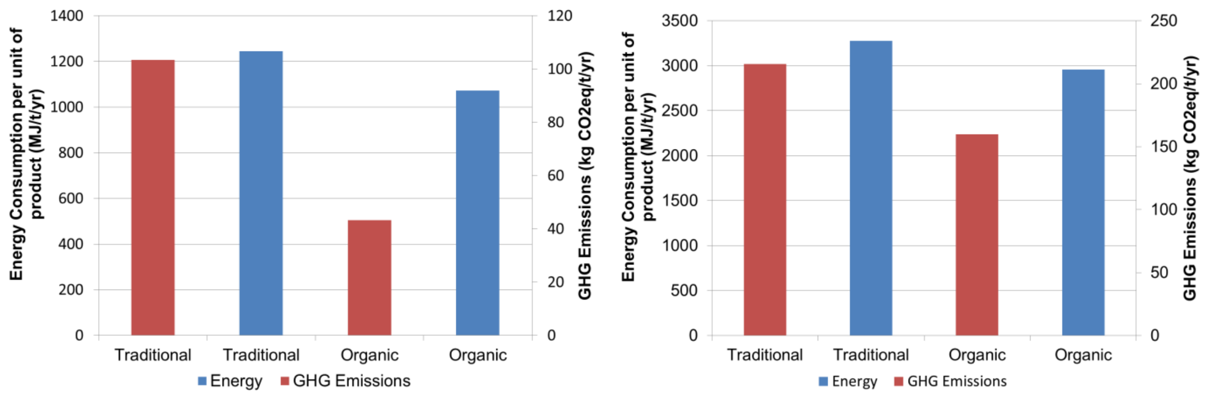


Fig. 2 Energy profile and GHG emissions of the conventional olive grove

On the other hand, in Portugal the main energy consumer is the fuel (34.31%), which could be explained due to the mechanisation of the majority of operations realised throughout the year. Electricity for irrigation comes second (22.5%) and fertilizers are in the same level as the total materials used in the orchard. Regarding GHG emissions, fuel remains in the first place (37.98%) and fertilizers come second (26.86%). Electricity for irrigation contributes in GHG emissions in a lower percentage (17.61%) than in energy (22.5%) because the ratio between energy and GHGs for electricity production in Portugal is in favour of GHG emissions. Materials (10.8%) and pesticides (6.74%) contribute to the total GHG emissions less than in energy (ratio energy/GHGs is in favour of GHG emissions).

4.2 Energy efficiency and GHG emissions impact (conventional - organic)

Energy efficiency comparison of the two olive grove farming systems in both countries is shown in Figure 3a. Organic farming in the Greek olive grove results in (an assumed) significantly lower olive yield (30%), however the impact on the final energy efficiency was positive. In fact, energy efficiency (t/MJ/yr) was improved by 13.9%, due to the fact that total chemical inputs (fertilizers, pesticides) were zeroed. Energy consumption per unit of product was decreased from 1,244 MJ/t of olives to 1,072 MJ/t of olives. The increase of fuel consumption was not as important as the chemical inputs in terms of energy. Regarding organic farming in the Portuguese olive grove, the yield is also reduced significantly (54.5%). However, energy efficiency was improved in comparison to the conventional production (9.7%) as the energy consumption per unit of product was decreased from 3,275 MJ/t of olives to 2,957 MJ/t of olives. It can be seen that, in line with the Greek olive grove, zero use of chemical fertilizers and pesticides makes a significant change in the energy input that compensates positively with the effect of lower yield.



(a) (b)

Fig. 3 Energy consumption per unit of product alteration (MJ/t/yr) and GHG emissions alteration ($kgCO_2eq/t/yr$) from conventional to organic olive groves in Greece (a) and Portugal (b)

Figure 3b shows the GHG emissions impact for both case studies of Greece and Portugal. In Greece, GHGs are reduced by 58% (103.5 $kgCO_2eq/t$ vs. 43.3 $kgCO_2eq/t$), following the same trend as in energy efficiency in a higher rate. This reduction is significantly higher than the energy reduction, as the chemical fertilizers applied in the conventional farming system are substituted by manure in the organic farming system. Another reason is that chemical pesticides are substituted in the organic system by paper traps (bait pheromone) and baits associated with insignificant amounts of GHG emissions.

In Portugal, GHG emissions are reduced by 26% (215.7 $kgCO_2eq/t$ vs. 159.7 $kgCO_2eq/t$), which in line with the Greek case; it comes in higher rate than the energy efficiency improvement. The main reason for that is the use of manure and vegetal compost instead of chemical fertilizers yield decrease.

5. Conclusions

An energy efficiency comparison, based on the energy consumption per unit product and the respective GHG emissions, is presented between conventional and organic farming of two olive groves located in the “Sterea Ellada” region of Greece and the “Alentejo” region of Portugal. In both countries, yield was decreased significantly (30% in Greece and 54.5% in Portugal). In Greece, swift from conventional olive production to organic farming gives improves energy efficiency (13.8%) and reduces GHG emissions (58%), as chemical fertilizers and pesticides are replaced by less GHG productive inputs. In the case of Portugal, organic farming results in improved energy efficiency by 9.7% and reduced GHG emissions by 26%.

The introduction of organic production system affects significantly energy efficiency and GHGs in both countries. It has advantages and it should be considered as an alternative option. Future studies should seek to find adapted varieties with high productivity and improved technologies for organic farming that could help obtain better results. The challenge for the future in both countries will be to achieve better productivities for organic olive groves while maintaining high quality olive products (olives, olive oil).

6. Acknowledgements

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