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Life cycle assessment (LCA) of an energy recovery plant in the olive oil industries

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Abstract
To reduce the GHG emissions in the UE and to increase the produced energy it is important to spread out decentralized technologies for renewable energy production. In this paper a power plant fed with biomass is studied, in particular the biomass considered is the waste of the olive oil industries. This study focuses on the possibility of using the de-oiled pomace and waste wood as fuel. A life cycle assessment (LCA) of a biomass power plant located in the South of Italy was performed. The global warming potential has been calculated and compared with that of a plant for energy production that uses refuse derived fuel (RDF) and that of one that uses coal. The LCA shows the important environmental advantages of biomass utilization in terms of greenhouse gas emissions reduction. An improved impact assessment methodology may better underline the advantages due to the biomass utilization.

Keywords: LCA; De-oiled pomace; GWP.

1. Introduction

Renewable energy sources are an obvious choice for countries with advanced economies as well as emerging countries. Biomass is one of the cheapest forms of renewable energy. Olive trees represent a characteristic element in the Italian countryside landscape as they are cultivated in 18 regions out of 20 [1]. The contribution of olive trees to the economy of entire regions, particularly in the south of Italy, is of extreme importance in terms of employment as well as soil and environmental protection. Italy is the second largest world olive oil producer after Spain and it is the highest consumer country. Since consumption is higher than production, Italy is also the country which imports the most olive oil.
On average, olive production represents around 4.2% of the value of national agriculture (production at base prices 2000/2001). This percentage rises to 10% in Sicily, 25 % in Calabria and 35% in Puglia, the most productive regions. All together, they reach almost 70%. Overall, the olive sector makes up around 1% of the total value of agricultural production in the north and the centre of the country.
The life cycle of extra virgin olive oil is described briefly as follows: olive trees are planted [2]. The soil around the roots of the trees is periodically ploughed, irrigated and fertilized and the trees and olives are also protected from pests. It is important to prune the trees regularly and allow them to adjust to the climatic conditions of the area in order to increase their productivity. Once a year, olives are harvested and transported into the processing unit where they are washed, milled and finally olive oil is extracted through centrifugation. The traditional pressing system generates olive oil and two kinds of by-products: vegetable water and pomace (olive husk) [3].

Pomace is commonly used for extracting crude olive-pomace oil for producing fodder, for thermal energy recovery or as a fertilizer. With the extracting phase the de-oiled pomace is produced and burned in the furnaces.
This study aims to analyse the environmental advantage (in terms of GWP, Global Warming Potential) deriving from the use of de-oiled pomace (60%) and waste wood (40%) in an energy plant based on site-specific data and information, and to compare its environmental impact with that generated by the recovery of RDF and of coal combustion.
In the literature there are several studies on the de-oiled pomace.
In particular, [4] and [5] analyzed the use of the olive oil industry waste as fuel to obtain thermal or electric energy through combustion.
Russo et al. [6], showed that the recovery of olive pit and solid wastes offers environmental advantages with respect to other alternative fuels, in particular with wood pellets.
The interest in understanding comprehensively the environmental costs and benefits of biomass use is increasing and for this reason several studies based on the life cycle assessment (LCA) approach have been published. But to our knowledge no-one of them gives results for olive waste to energy recovery comparing the plants we have compared. Therefore with the present study we intend to evaluate environmental consequences of the energy production from de-oiled pomace in each stage of life cycle, utilizing the LCA methodology.

2. Biomass energy and GHG

Biomass means the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste [7]. A wide range of biomass sources can be used to produce bioenergy in a variety of forms. For example, food, fibre, and wood process waste from industrial sectors, agricultural waste and forest waste can be utilized to generate electricity and heat.
EU–27 installed capacity for electricity generation from renewable sources increased by 54 % from 1997 to 2007 [8]. This increase was mainly due to wind capacity, which recorded a twelvefold increase over this period. Wood capacity and the capacity of other renewable sources – geothermal, photovoltaic, municipal solid waste and biogas – exhibited an almost threefold and a fivefold increase respectively. In 2007, 58 % of the total EU-27 renewable capacity was concentrated in four countries (Germany, Spain, France and Italy).
In Italy, the national overall target for the share of energy from renewable sources in gross final consumption of energy in 2020 is 17% [7].
Biomass is usually fed into the system as chips, pellets or briquettes [9]. Biomass can also be burned with coal in a boiler of a conventional power plant to yield steam and electricity. Co-firing biomass with coal is currently the most cost-efficient way of incorporating renewable technologies into conventional power production because much of the existing power plant infrastructure can be used without significant modifications.
Biomass for bioenergy purposes can be obtained in two ways: from residues and from dedicated energy crops. In this context, the concept of multifunctionality in agriculture, which introduces other roles for the primary sector than those strictly related to food production, allows farmers to enter a new market, agro-energy market, through the creation of chains designed to meet energy demand (see Figure 1).

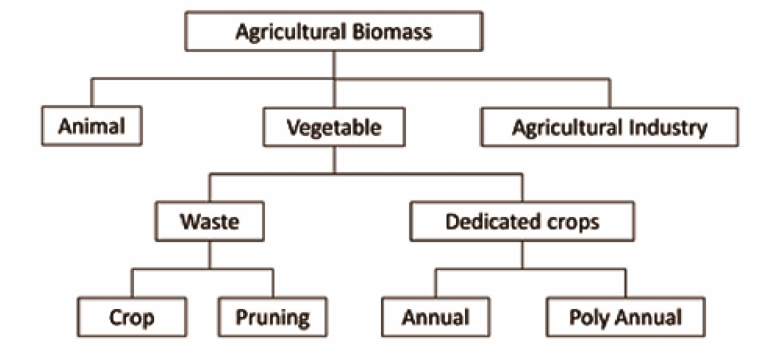

Figure 1. Scheme of the agricultural biomass

The source of biomass has a big impact on GHG balance outcomes. Biomass residues are not produced specifically for use as an energy resource. They are the result of economic activity and production of goods in almost all economic sectors, so their utilization as energy sources does not usually increase environmental pressures.

3. LCA methodology

The potential environmental benefits, in terms of GHG savings that can be obtained from replacing fossil fuels with biomass sources, are one of the main driving forces for the promotion of bioenergy. Life Cycle Assessment (LCA) is considered to be the appropriate method for evaluating the GHG performance of bio-energy compared to that of fossil alternatives. The GHG balance of bio-energy systems differs depending on the type of feedstock, carbon stock changes due to land use change, transport, processing of the feedstocks and conversion technologies to produce heat or electricity.

In this study, the methodology used is the LCA technique, based on ISO 14040 [10] and ISO 14044 [11]. This assessment methodology is based on the identification of energy and materials used and emissions released to the environment. The core of the concept is the assessment of the impacts at each stage of the product life cycle [12].

An LCA study consists of four phases:

1. goal and scope definition: define and describe the object of the analysis, establish the context in which the assessment is developed, discuss assumptions and data quality, identify system boundaries and environmental effects. The object of study is described in terms of a so-called functional unit;
2. inventory analysis: data collection and modelling must be related to the functional unit defined in the goal and scope definition;
3. impact assessment: assessment of the potential impacts associated with the identified forms of resource use and environmental emissions;
4. interpretation: interpretation of the results from the previous phases of the study in relation to the objectives of the study.

The general framework of a Life Cycle Impact (LCI) Assessment method is composed of mandatory elements (classification and characterisation) that convert LCI results into an indicator for each impact category, and optional elements (normalization and weighting) that lead to a unique indicator across impact categories using numerical factors based on value-choices [13].

In most LCA studies, assumptions are made and the system boundaries are modified in order to leave some elements out. Results of the LCA are often used for process optimisation. The applicability depends greatly on the model of the process that has been adopted at the beginning of the study, which is frequently too simplified.

3.1 LCA application to the specific case

The goal of this LCA study is to compare the Global Warming Potential over 100 years (both direct and indirect impacts) of the energy plant fuelled by vegetal biomass with the energy plant fuelled by RDF or coal. The considered energy plant is a thermal power plant that produces only electricity sold directly to the national transmission system using as fuel biomasses, de-oiled pomace and wood waste. The existing plant, located in Italy, produces a gross electrical power equal to 12 MWe and the exhaust gases are utilized for the production of the steam in the closed cycle.

According to the standard ISO 14044, the functional unit is defined as the reference unit through which the system performance is quantified in an LCA. In this LCA study, the chosen functional unit is 1 kWh because the biomass is produced in the same site where the energy plant works.

Several industrial LCA studies have shown that the environmental load from the production of capital goods is insignificant when compared to their operation stage [14, 15].

The data collection has been performed on site, analyzed and completed with the direct involvement of the managers responsible of the different plant’s departments.

The method utilized to evaluate the environmental performance is global warming potentials (GWPs). GWPs for greenhouse gases are expressed as CO_2-equivalents and are developed by the IPCC (Intergovernmental Panel on Climate Change) for time horizons of 100 years [16]. Carbon dioxide equivalency is a quantity that describes, for a given mixture and amount of greenhouse gas, the amount of CO_2 that would have the same global warming potential (GWP), when measured over a specified timescale (generally, 100 years).

The system boundaries take into account the phases of treatment and processing of fuel burned into the energy plant (see Figure 2).

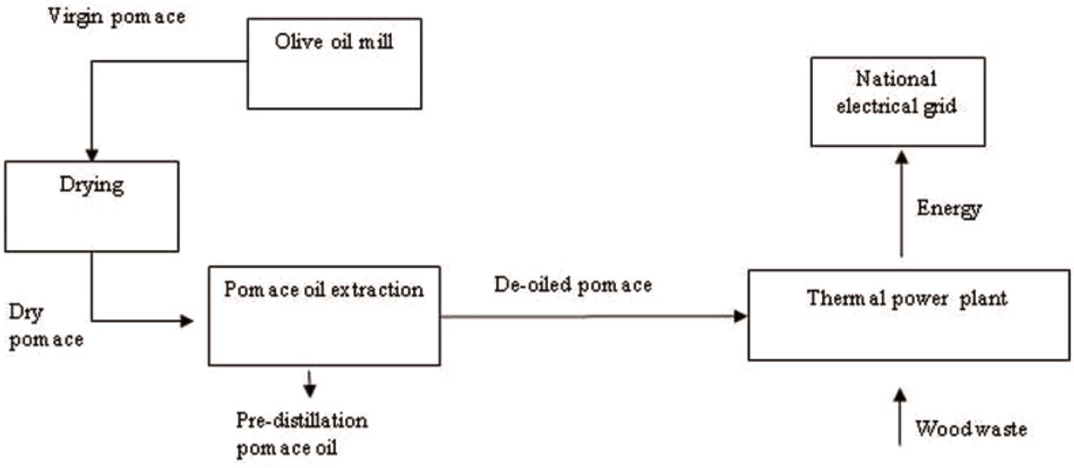

Figure 2. Scheme of the energy plant under analysis

The system boundary is defined knowing that the input of recycled materials to a product system is included in the data set without adding the data on environmental impacts caused in earlier life cycles. In the waste case the environmental impact connected to the treatment of wastes rests with the generator of the waste whereas the environmental impact connected to the processing of the waste into a resource for a subsequent user rests with the user of the resulting resource. The delineation between two product systems is considered to be the point where the waste has its "lowest market value". This means that the generator of the waste has to carry the full environmental impact until the point in the product´s life cycle where the waste is transported to a scrap yard or gate of a waste processing plant (collection site). This approach is called the "Polluter-Pays (PP) allocation method" [17] and this is what we used in this work.
The inputs are allocated on the various production steps according to defined procedures. Where possible, the allocation is avoided or at least follows a procedure based on the mass criteria. Allocation should reflect the physical relationship between the environmental burdens imposed, and the functions delivered by the system.
SimaPro 7.2.3 was used as a supporting tool in order to implement the LCA model and carry out the assessment [18]. The analysis uses the database Ecoinvent 2.2 [19].
The virgin pomace, waste of the olive oil mill production, undergoes drying and extracting pretreatment, is then transformed in the de-oiled pomace and qualifies as a renewable fuel in the Italian normative Decree 152/06. The virgin pomace is produced in the plant near the site of energy plant, so that the impact of the transport is zero.
With the extraction process of virgin pomace, the products are:

- olive-pomace oil obtained from olive pomace previously dried by extraction with solvent;
- exhausted pomace, which consists of dry pomace, residue of the extraction process of olive-pomace oil.

4. From residues to energy

4.1 The pomace drying

The pomace -drying process reduces the humidity rate to about 10% by applying a hot air current. The objective of the drying is to block the fermentation processes that happened in the virgin pomace and further allow the extraction of pomace oil. In Table 1 the inventory per 1 kg of the dry pomace is illustrated.

4.2 The oil extraction process

Hexane is used for the extraction of oil contained in dry pomace. Before the extraction process, the process of distillation of the pomace oil separates the hexane from the oil and allows the sale of the pomace oil in the economic market. In Table 2 the inventory for 1 kg of the finished product is illustrated.

Table 1. Input-output table of the drying process per 1 kg of the dry pomace

Input	Unit	Quantity
Virgin pomace	kg	2
Fuel	kg	0.15
Electricity	kWh	0.0325896
Output		
Steam	kg	1
Exhaust gases	kg	0.144
Ash	kg	0.006
Dry pomace	kg	1

Table 2. Input-output table of the oil extraction process per 1 kg of the finished product

Input	Unit	Quantity
Dry pomace	kg	1
Heat	kWh	0.179183
Electricity	kWh	0.03259
Hexane	kg	0.001
Output		
Pomace oil	kg	0.07
Exhaust gases	kg	0.001
De oiled pomace to energy plant	kg	0.78
De oiled pomace to pomace drying	kg	0.15

The environmental impact of the distillation phase has been added to the environmental impact of the pomace oil production. The distillation phase generates 72.8 g CO_2 per kg of pomace oil.

4.3 The energy plant

The biomass energy recovery plant includes some non-hazardous waste. In particular energy recovery (heat or electricity) from residues of oil production represents a step towards to the environmental objectives of reducing wastes of the agriculture sector. The exhausted pomace is characterized by a low calorific value of 4000 kcal/kg and by a low content of nitrogen and sulphur. The advantages of products with high energy content are: the reduction of mass and volume of solid waste, the reduction of pollutants and the potential recovery of energy that can be sold.

The process of recovering wood waste is taken from the Ecoinvent Database. In this case the impact of the procurement has been measured. In one year the number of travels is equal to 1335 with an average distance equal to 100 km. In Table 3 the inventory of 1 MWh of produced electricity is illustrated.

Table 3. The input/output of the biomass energy recovery plant of 1 MWh of produced electricity is illustrated

Input	Unit	Quantity
De oiled pomace	t	0.540975
Waste wood	t	0.342315
air	Sm^3	4224
urea	t	0.001
water	m^3	0.1
transport	km	1.35
Output		
Electricity	MWh	1
exhaust gases	t	0.796465
water	m^3	0.097561
ash	t	0.088329

In the energy plant, the low process temperature avoids the post-heating of the exhaust gases.

4.4 RDF production and combustion

The RDF production consists of a sorting process, which produces RDF bales and ferrous materials, and a biological treatment process which produces a stabilized organic fraction (SOF) [20]. Mixed waste, delivered by garbage trucks, is dumped on the tipping floor of the storage building where any unwanted items can be removed. A flail mill provides for the bag opening and for a size reduction of the input material. The oversize fraction is then sent to a magnetic separation, and finally, to a manual screening. A secondary screening is performed on the undersize fraction and allows the separation of a fraction larger than 60mm and a finer fraction which is sent for biological treatment. The production of 1kg of RDF is obtained with an overall efficiency of 40% and an electric energy consumption of 0.083 MJ (Table 4).

Table 4. Inventory of the production of 1 kg of RDF

Input	Unit	Quantity
Waste	kg	1 kg
Water	kg	0.088 kg
Metals	g	0.3
PE	g	0.16 g
Diesel	MJ	0.01 MJ
Electricity	MJ	0.083 MJ
Output		
CO_2	g	200 g
Waste	kg	0.05 kg
RDF	kg	0.4 kg
SOF	Kg	0.37
Metals	kg	0.05

The stage of RDF combustion is composed of three sections: combustion, energy recovery and gas treatment. For each section several technologies and design layout are possible. The plant under analysis has three parallel lines, each with a capability of 27t/h and characterized by a mobile grate, consisting of a series of alternate fixed and mobile bars where the fuel undergoes the primary stages of combustion. Table 5 shows the inventory of direct environmental burdens related to the combustion of one kg of RDF.

Table 5. Inventory of the combustion of 1 kg of RDF

Input	Unit	Quantity
RDF	kg	1
Air	kg	10.6
Water	kg	0.158
CaO	kg	0.025
Sodium silicate	kg	0.0015
Urea	kg	0.003
Heat by methane	MJ	0.036
Output		
Electricity	MJ	4.09
CO_2	g	1515
H_2O	g	679
Oxygen	g	839
N_2	g	8249
NO_x	mg	3335
SO_2	mg	333
HCl	mg	167
Dust	mg	83
TOC	mg	4
CO	mg	167
PCDD/F	mg	0.0000017

5. Impact assessment

The phase of life cycle impact assessment aims to quantify the relative importance of all environmental burdens contained in an LCI and at aggregating them to a single indicator, GWP100.

On the types and quantities of gases emitted into the atmosphere, expressed in terms of emissions of greenhouse gases, it is possible to determine the environmental effects of the different production phases of the considered case by using conversion factors expressed in. For the production of 1 kWh in the plant under analysis 0.0597 kgCO_2eq/kWh are given out and for the production of 1 kWh by combustion of RDF 1.61 kgCO_2eq/kWh. The process impact distributions are showed in Figures 3 and 4.

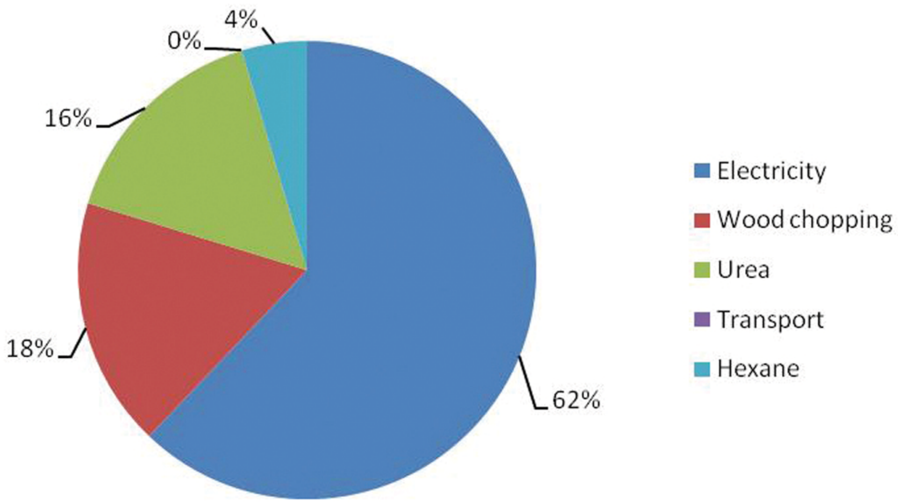

Figure 3. The process impact distribution for 1kWh of electricity by energy plant (60% de-oiled pomace and 40% waste wood)

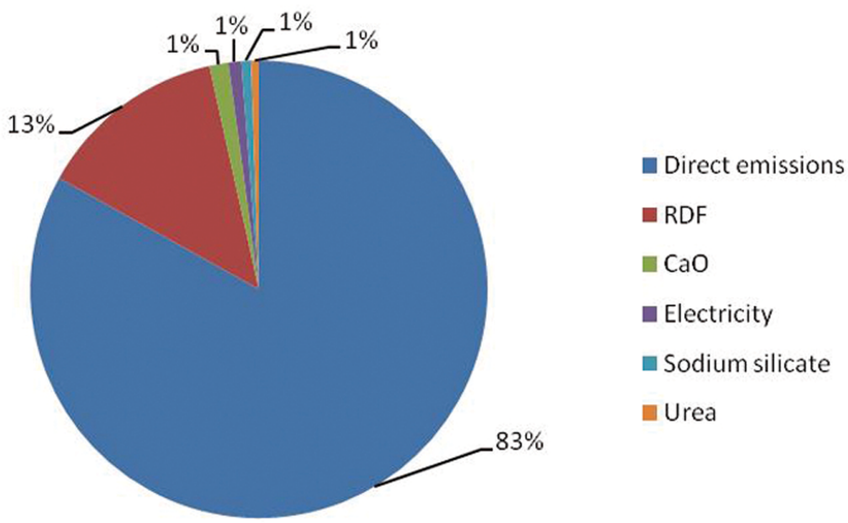

Figure 4. The process impact distribution for 1kWh of electricity by RDF

The first observation by the analysis of the plant under consideration is that the heat for the pomace oil extraction does not generate an environmental impact because the heat is produced by the recovery of the hot exhaust gases in the energy plant. Therefore there is a saving equal to 0.05 kgCO_2eq per 1 kg of de-oiled pomace produced.

In the RDF combustion the fossil composition (plastics) of the RDF is the major cause of the GHG impacts. However, it is important to consider that the energy recovery via RDF closes the waste cycle, the waste is used for energy purpose instead of being disposed of in a landfill.

6. Interpretation of the results

In the assessment of the GHG savings of the bioenergy system, the definition of the fossil reference system is very important. For instance, fossil-derived electricity can be assumed to be produced from oil, natural gas, coal or other sources, all of which have different GHG emission factors. In order to compare the bioenergy system with the best available fossil technologies, the coal thermo plant is compared with the energy plant under analysis and the RDF recovery plant.

Knowing the production of electricity per kilogram of fuel, it is possible to determine the emissions of CO_2eq per 1 kWh of energy produced.

The CO_2eq emissions per kg of coal are assumed to be equal to 2.624 kgCO_2eq [21]. A lower calorific value of coal equal to 6728 kcal / kg and a value of electrical efficiency in a solid fuel power plant equal to 2574 kcal/kg are considered [22]. The coal extraction phase emissions by underground mines are estimated in the Italian area equal to 0.05995 kgCO_2eq/kWh.

If we compare the plant under analysis with the coal energy plant there is a net saving equal to 0.9497 kg CO_2eq for each produced kWh (see Table 6).

Table 6. kgCO_2eq saved from the energy plant (60% de-oiled pomace and 40% waste wood)

Fuel	kg/kWh	kgCO_2eq per kg of fuel	kgCO_2eq/kWh
Mix actual plant	0.885	0.0612	0.0542
coal + extraction coal	0.382	2.624	1.0039

If we compare the case c with the coal energy plant there is a net saving equal to 0.163 kg CO_2eq for each produced kWh (see Table 7).

Table 7. kgCO_2eq per each produced kWh

Fuel	kg/kWh	kgCO_2eq per kg of fuel	kgCO_2eq/kWh
case c	0.87	0.96	0.8439
coal + extraction coal	0.382	2.624	1.003

If other alternatives are considered, for instance the sending to disposal, the valorisation of the RDF contributes to avoid 290g of CO_2eq per 1 kg of RSU to disposal. Knowing that 1 kg of RDF is produced by 2.5 kg of urban waste, the GHG saved is 725 gCO_2eq per 1kg of RDF. Summarising the quantity of the saving by avoided disposal and avoided coal energy, a net saving equal to 0.5225 kg CO_2eq for each produced kWh is achieved.

At last, the co-product of the extraction phase, the pomace oil, is utilized as palm oil. If we evaluate the avoided emissions from the production of the palm oil, the GHG reduction increases by 0.0587 kg CO_2eq for each produced kWh. The total reduction is 0.584 kg CO_2eq/kWh.

6.1 Dedicated energy crops vs renewable energy from waste biomass

One of the major justifications for bioenergy systems is their low greenhouse gas emissions compared to fossil energy ones. The biomass to energy conversion is accomplished throught three principal routes:

- Thermochemical (combustion, gasification and pyrolysis);
- Biochemical (anerobic digestion and fermentation);
- Physiochemical (mechanical and chemical extractions).

The ideal crops for biofuel production are only suitable for cultivation in the hotter climate of tropical regions, such as bioethanol from sugar cane [23] and biodiesel from palm oil [24]. In colder climates where these optimal crops are unable to grow, more appropriate alternatives such as rapeseed [25] may be considered.

A last aspect to consider is the use, in the other production chain, of the agricultural residues as livestock feed, which forms the basis for important protein in the human diet [26]. For example in the Netherlands about 70% of the concentrates fed to pigs, cattle and poultry originate from residues generated by the food processing industry. In the study of Nonhebel is compared the area required for these additional protein crops and/or feed crops with the area reduction in energy crops in the energy system. It is assumed that residues (oilseed cakes from vegetable oil production and molasses from sugar production) are fed to pigs. Using residues for non-feed purposes therefore requires adaptations in the food system to compensate for protein losses, i.e. growing beans or supplementary livestock feed crops. Land requirements for such adaptations are substantial and are larger than the area needed for energy crops that produce equivalent amounts of energy, leading to a net increase of the land requirements. From a land use perspective, therefore, using residues of the food system for livestock feed and generating bio-energy from dedicated energy crops is the most preferable option.

The results for apparently similar bioenergy systems may differ for several reasons: type and management of raw materials, conversion technologies, end-use technologies, system boundaries and reference energy system with which the bioenergy chain is compared [27].

The production of feedstock for bioenergy requires land that was previously used, and would otherwise be used, for a different purpose. Therefore, both direct and indirect land use change must be considered on the GHG balance.

For example, in the direct land use, the total soil carbon stock changes from tropical moist rain forest to palm oil is equal to -4 t C/ha. Indirect land use change (iLUC) occurs when land currently used for feed or food crops is charged into bioenergy feedstock production and the demand for the previous land use remains. The feedstock quantities for bioenergy can be obtained by biomass use substitution, by shortening the rotation length and by crop area expansion.

An example of one approach for calculating the indirect land use change and its influence on final results considers that use of arable land for additional biomass feedstock production will induce indirect land use change risks due to displacement, but that the risk is small and can be ignored for feedstock produced from wastes and on degraded land and also on set-aside and idle land, as well as biomass feedstock derived by increasing yields. Therefore in the case of de-oiled pomace and waste wood the effect of land use change can be ignored.

Finally, to complete the analysis, some case of life cycle GHG emissions of biofuels [28], where the iLUC factor is included, are reported:

- Rapeseed to fatty acid methyl ester, EU, equal to 188 gCO_2eq/MJ, medium value.
- Palm oil to fatty acid methyl ester, Indonesia, equal to 64 gCO_2eq/MJ, medium value.
- Sugarcane to ethanol, Brazil, equal to 42 gCO_2eq/MJ, medium value.
- Wheat to ethanol, EU, equal to 110 gCO_2eq/MJ, medium value.
- Short rotation crop to biomass to liquid, EU, equal to 75 gCO_2eq/MJ, medium value.

For a high level of the iLUC factor, only ethanol from sugarcane and second-generation Biomass to Liquid (BtL) technologies would still provide a GHG reduction.

GHG emissions of biofuels are significantly higher than the de-oiled pomace, equal to 5.7 gCO_2eq/MJ. The evaluation of environmental effects shows that the exploitation of agricultural residues seems to be preferable to energy crops, due to the energy consumption for ground preparation, plant establishment and cultivation and to the impacts of pesticides and herbicides production and spreading associated with energy crops.

One of the problems that has to be considered as well, though it is beyond the scope of this paper, is the fact that the demand for grain and corn as a source of biofuels has been a significant element of recent food price rises [29]. The US already spends $7 billion a year supporting ethanol [30]. This consumes 20 per cent of America's corn crop [31] – a figure likely to rise to 32 per cent by 2016. Looking ahead, the EU has a target for 10 per cent of its transport fuel to come from biofuels by 2020, while the US has proposed a target of 36 billion gallons of renewable fuel by 2022 [32]. Rising food prices will hit poor countries and poor people hardest, and will present an obvious impediment to achieving the Millennium Development Goal of halving hunger by 2015. The FAO has already announced that 36 countries are in crisis in terms of food security, and will need external assistance of these, 21 are in Africa (although not all of them have been affected equally) [33].

7. Conclusion

LCA methodology was applied to compare the environmental performance of the recovery of olive oil sector residuals and wood waste with that of RDF or fossil resources. The results showed that the recovery of de-oiled pomace and waste wood offers environmental advantages with respect to other alternative fuels.

Bioenergy chains which have residues as raw materials show the best LCA performances, since they avoid both high impacts of dedicated crop production and the emissions from waste management.

The problems of the pomace used in the energy plant are that it is only available for a few months of the year, that this period coincides with the period of olive-oil production, and there are different quantities each year due to different harvests of the trees. The best advantages are the limited costs of pomace as a raw material and the availability of a mature technology for biomass exploitation [34].

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