Energy Recovery of the Solid Waste of the Olive Oil Industries– LCA Analysis and Carbon Footprint Assessment

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Abstract: Renewable energy technologies contribute to the mitigation of climate change impacts through reduction in the emission of greenhouse gases (GHG) such as carbon dioxide. In this paper, a power plant located in Italy and fed with waste deriving from the olive oil industries is considered. The de-oiled pomace is characterised by lower caloric value equal to 4000 kcal/kg, by low content of nitrogen and sulphur and by the absence of heavy metals. A plant for the production of energy from biomass (de-oiled pomace and waste wood) is analyzed through a Life Cycle Assessment (LCA) approach. The carbon dioxide equivalent (kgCO_2eq) emitted into the atmosphere is equal to 0.0597 kgCO_2eq /kWh. The GHG emissions have been compared with those of a plant for energy production that uses refuse derived fuel (RDF) and with those of one that uses coal. The environmental benefits are quantified and the possibilities to develop the use of the pomace-to-energy at national level are estimated.

Keywords: LCA, Biomass, GHG balance, Bioenergy, Carbon footprint.

1. Introduction

In order to limit climate warming on Earth, industrialized nations promise to reduce their greenhouse gas (GHG) emissions but energy demand will grow in the next few years due to the development of emerging countries and the increase of the world population.

Environmental effects of uncontrolled use of energy resources are a problem greater than the availability of energy resources. The dissemination of renewable energy sources is an obvious choice for countries with advanced economies as well as emerging countries. Olive trees represent a constant 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 individual regions, particularly in the south of Italy, is of extreme importance in terms of employment and of both 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, which are the most productive regions.

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]. The material input percentages, from the oil mill, are illustrated in Figure 1.

Pomace is a by-product of the extraction process of olive oil made from the skins, pulp residues and fragments of peanuts. Pomace is used today to produce pomace oil; as a fertilizer in the agricultural sector; as fuel for heating. Virgin pomace is transformed in de-oiled pomace after drying and extracting pre-treatments.

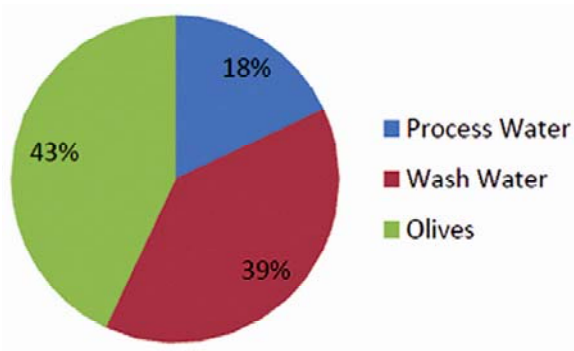

Figure 1. Input of the oil mill.

This study, aims to analyse the environmental advantages (in terms of GHG emissions) deriving from the use of de-oiled pomace (60%) and waste wood (40%) in the energy plant based on site-specific data and information, comparing its environmental impact with that generated by the recovery of RDF and of coal combustion.

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.

Energy recovery from biomass produces several advantages:

- the energy source is renewable over time;
- carbon dioxide emitted by thermal plants fuelled with biomass is the same as that absorbed by vegetables to produce an equal amount of biomass. In the biomass energy cycle, the carbon dioxide is in balance;
- liquid fuels produced from biomass contain small amounts of sulphur so there is a reduction in SO_2 emissions leading to less acid rain;
- NO_x emissions can be reduced through lower combustion temperatures and the use of modern technologies for pollution control.

In the literature there are several studies on de-oiled pomace: Tekin and Dalgıç (2000) investigated the biogas production from a slurry obtained by mixing finely ground olive pomace in water; Miranda et al. (2007) studied the viability of the combustion of this semi-liquid by-product, using the support of one or several dry fractions from the two-phases of Olive

Mill Solid Waste treatment; Miranda et al. (2010) analyzed the pyrolysis process of a series of pellets with different contents of olive waste and forest residues; Roig et al. (2006) provides a summary of updated information on research work that propose different valorization methods based on scientific studies [4-7].

In particular, Masghouni et al. (2000) and Caputo et al. (2003) analyzed the use of the olive oil industry waste as fuel to obtain thermal or electric energy through combustion [8-9].

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. Therefore with the present study we intend to evaluate the environmental consequences of the energy production from de-oiled pomace in each stage of the cycle, utilizing the LCA methodology.

2. The pomace supply

In order to analyze the availability of pomace in Italy, it is necessary to work out national production of olive oil. The pomace that comes from the olive oil extraction process consists of rinds, pulp residues and core fragments. The pomace production cycle from olive oil production is estimated assuming an average production index equal to 0.75 $t_{virgin\ pomace}/t_{olives}$, in the two-stage traditional mill [10]. If we consider a moisture elimination rate in the virgin pomace equal to 50%, the de-oiled pomace national productions are as shown in Table 1 [11].

In Italy 1.2 million tonnes of de-oiled pomace is produced in one year. The regions in the south are the main producers of oil. They could be the strategic areas where biomass energy plants, either large or small could be built. 60% of all olive oil production occurs in the Puglia and Calabria Regions.

In general, biomass could give an increasing contribution to the energy mix, allowing a partial replacement of fossil fuels with a renewable resource.

3. Biomass energy and GHG

Biomass means the biodegradable fraction of products, waste and residues of organic origin from agriculture (including vegetable and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste [12]. A wide range of biomass sources can be used to produce bioenergy in a variety of forms. For example, food, fibre, and wood processing waste from industrial sectors, agricultural waste and forest waste can be utilized to generate electricity and heat.

Installed capacity in Europe for electricity generation from renewable sources increased by 54% from 1997 to 2007 [13]. This increase was mainly due to wind capacity, which recorded a twelvefold increase over this period. Wood capacity and the capacity of other renewables (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).

Table 1. Annual Production from olive oil industries – 2008 per region.

Region	**Olive**		**Oil**		**Virgin Pomace (production rate 75%)**	**Dry pomace (production rate 50%)**	**De-oiled pomace (production rate 93%)**
	Total area (hectare)	Production (tonne)	Production rate (%)	Total production (tonne)	Total production (tonne)	Total production (tonne)	Total production (tonne)
Piemonte	99	67	16	11	50	25	23
Valle d'Aosta	0	0	0	0	0	0	0
Lombardia	2401	4976	14	711	3732	1866	1735
Liguria	17350	21307	16	3117	15980	7990	7431
Trentino-Alto Adige	384	1450	17	244	1088	544	506
Bolzano/Bozen	0	0	0	0	0	0	0
Trento	384	1450	17	244	1088	544	506
Veneto	4917	7673	19	1416	5755	2877	2676
Friuli-Venezia Giulia	105	205	14	29	154	77	71
Emilia-Romagna	3407	7234	16	1130	5426	2713	2523
Toscana	96589	124488	14	17266	93366	46683	43415
Umbria	27837	67755	17	11821	50816	25408	23630
Marche	9341	32531	15	4729	24398	12199	11345
Lazio	88106	222807	17	36974	167105	83553	77704
Abruzzo	44757	144445	15	22030	108334	54167	50375
Molise	13621	36781	16	5720	27586	13793	12827
Campania	72219	256375	17	44096	192281	96141	89411
Puglia	376826	1091164	18	190337	818373	409187	380543
Basilicata	31354	36233	18	6533	27175	13587	12636
Calabria	192405	1049430	19	200826	787072	393536	365989
Sicilia	158537	311890	18	49670	233917	116959	108772
Sardegna	40220	56768	18	10119	42576	21288	19798
Italy	**1180475**	**3475028**	**17**	**607021**	**2606271**	**1303136**	**1211916**

In Italy, the national overall target for the share of energy from renewable sources in the gross final consumption of energy in 2020 is 17% [12].

Biomass is usually fed into the system as chips, pellets or briquettes [14]. 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 that of agro-energy, through the creation of chains designed to meet energy demand (see Figure 2).

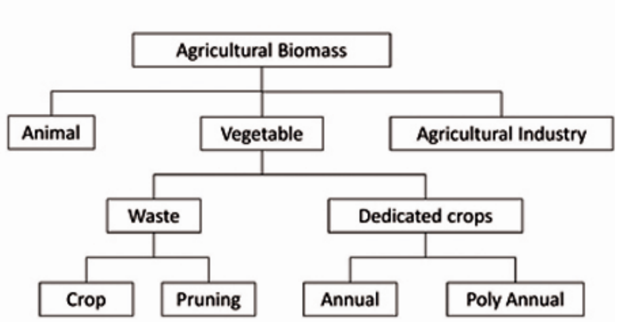

Figure 2 Scheme of the agricultural biomass

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.

4. 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 possible to consider an appropriate method for evaluating the GHG performance of bio-energy compared to that of fossil alternatives [ref]. 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 feedstock and conversion technologies to produce heat or electricity.

In this study, the methodology used is the LCA technique, based on ISO 14040 and ISO 14044 (2006) [15-16]. 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 [17]. LCA evaluates all stages of a production chain and it is characterised by interdependent phases: one operation leads to the next. One of the main reasons why an LCA is applied is to make comparisons and choose among alternatives (e.g. comparison of electricity production from biomass and from coal).

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 [18].

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 Life Cycle Assessment method is already widely used in waste management systems [19-20]. The goal of this LCA study is to compare the Global Warming Potential over 100 years (both direct and indirect impacts) of an energy plant fuelled by vegetal biomass with an energy plant fuelled by RDF or coal. The considered energy plant is an existing 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 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. The functional units utilized in some studies to evaluate the bioenergy chain are: unit of biomass (kg), hectare of dedicated agricultural land (ha), kWh of electricity produced (kWhe) or km driven for transportation of biofuels (km) [21-23]. In this LCA study, the chosen functional unit is 1 kWh in line with the contents of the Product Category Rules document which provides basic rules for performing the LCA [24]. 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 [25-26].

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 consumables contributing less than 1% of the total environmental impact for the impact category have been omitted from the inventory (such as filters, detergents, etc.).

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 [27]. 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 GWP when measured over a specified timescale (generally, 100 years). In a GHG balance, emissions of the three most important greenhouse gases (CO_2, CH_4 and N_2O) are accounted for over the entire life cycle of the bioenergy system. These gases can be emitted directly (i.e. biomass combustion and decrease of organic carbon pools) or indirectly (i.e. combustion of auxiliary energy inputs, production of auxiliary materials and indirect land-use change).

The system boundaries take into account the phases of treatment and processing of fuel burned in the energy plant (see Figure 3), including all the phases from the virgin pomace (waste of olive oil mill) to energy production. 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 case of waste the environmental impact connected to the treatment of waste 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" [28] and this is what we used in this work. The processes of construction (infrastructure and equipment) of the plant are excluded.

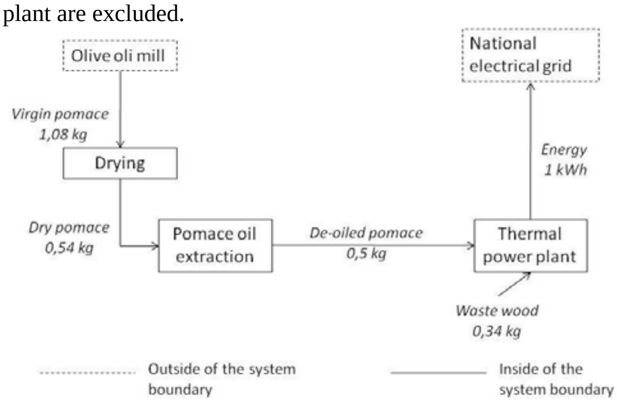

Figure 3. Scheme of the energy plant.

The inputs are allocated at the various production steps according to defined procedures. The allocation follows a procedure based on the mass allocation in function of the output products in each phase.

SimaPro 7.2.3 is used as a supporting tool in order to implement the LCA model and carry out the assessment [29]. The analysis uses the database Ecoinvent 2.2 [30].

The virgin pomace, waste of the olive oil mill production, undergoes drying and extracting pre-treatment, and is then transformed into de-oiled pomace and qualifies as a renewable fuel in the Italian normative Decree 152/06. The virgin pomace is produced near the site of the energy plant so that the impact of transporting it is zero.

The products of the extraction process of virgin pomace are**:**

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

5. From residues to energy

5.1 The pomace drying

The pomace-drying process reduces the humidity to about 10% by applying a current of hot air. The objective of the drying is to block the fermentation processes of the virgin pomace and further allow the extraction of pomace oil. In Table 2 the inventory per 1 kg of the dry pomace is illustrated.

Table 2. 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

5.2 The oil extraction process

Hexane is used for the extraction of oil contained in dry pomace. After the extraction process, the process of distillation purifies the pomace oil and eliminates the hexane for to sale the pomace oil in the economic market. In Table 3 the inventory for 1 kg of the finished product is illustrated.

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.

Table 3. 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
De oiled pomace	kg	0.93

5.3 Biomass combustion in the energy plant

The de-oiled pomace is characterized by a low calorific value of 4000 kcal/kg and by a low content of nitrogen and sulphur.

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 journeys of trucks to plant is equal to 1335 with an average distance equal to 100 km. In Table 4 the inventory of 1 MWh of produced electricity is illustrated.

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

Table 4. 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

5.4 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) [31]. 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 separator, and finally, for a manual screening. A secondary screening is performed on the undersize fraction and allows the separation of a fraction larger than 60 mm 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 5).

The stage of RDF combustion is composed of three sections: combustion, energy recovery and gas treatment. For each section several technologies and design layouts 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. The grate is cooled by water and in the combustion zone the alternate movement of bars allows a good mixing of waste that is exposed to flame radiation for a time suitable to guarantee very high combustion efficiency. The grate is inclined at 10° in order to ensure a continuous movement of the waste. The combustion process is regulated by taking into account: the steam mass flow; the oxygen and carbon monoxide concentrations in the flue gases; the primary combustion temperature; and the flame length over the grate. Table 6 shows the inventory of direct environmental burdens related to the combustion of 1 kg of RDF.

Table 5. 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

Table 6. Inventory for the production of 1 kWh of the energy by the combustion of RDF.

Input	Unit	Quantity
RDF	kg	0,88
Air	kg	9,33
Water	kg	0,14
CaO	kg	0,02
Sodium silicate	kg	0,00
Urea	kg	0,00
Heat by methane	MJ	0,03
Output		
Electricity	kWh	1,00
CO2	g	1333,50
H2O	g	597,65
Oxygen	g	738,48
N2	g	7260,73
NOx	mg	2935,45
SO2	mg	293,11
HCl	mg	146,99
Dust	mg	73,06
TOC	mg	3,52
CO	mg	146,99
PCDD/F	ng	1,50

6. Impact assessment

6.1Comparison between RDF and de-oiled pomace

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 in a single indicator, GWP_{100}.

From 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 IPCC 2007 [27]. 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 shown in Figures 4 and 5.

The first observation from 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 production purposes instead of being disposed of in a landfill.

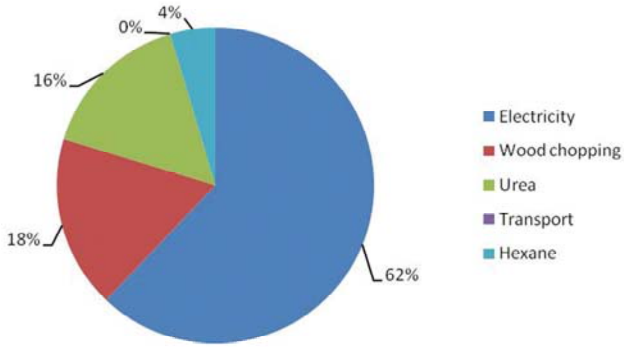

Figure 4. The process impact distribution for 1kWh of electricity by energy plant (60% de-oiled pomace and 40% waste wood).

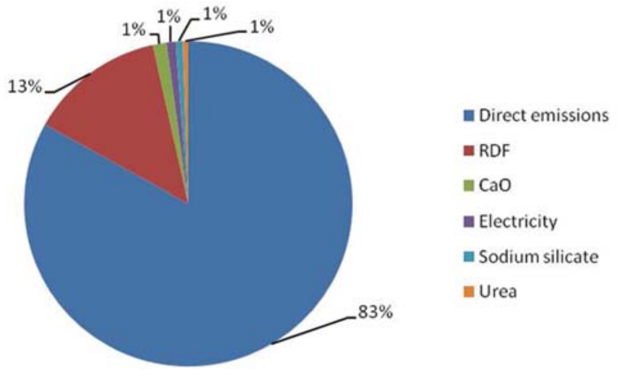

Figure 5. The process impact distribution for 1kWh of electricity by RDF.

6.2 Fuel mix analysis

The effect of the variability of the fuel mix was analysed. The lower calorific value of the RDF is 4060 kcal/kg, the lower calorific value of the de-oiled pomace and of the waste was 4000 kcal/kg and the energy efficiency in the power-plant is 3539 kcal/kWh. The production of electricity and the $kgCO_2eq/kWh$ are shown in Table 7.

Table 7. $kgCO_2eq$/kWh per 1 kg of fuel (de-oiled pomace, waste wood and RDF).

Fuel	kWh per 1 kg of fuel	$kgCO_2eq$ per kg of fuel	$kgCO_2eq$/kWh
De-oiled pomace	1.13	0.11	0.097
Waste wood	1.13	0.015	0.013
RDF	1.14	1.83	1.61

The plant under analysis is the reference scenario. The different input mix is analyzed and alternative scenarios are evaluated to produce 1 kWh of electricity. In the comparison analysis is evaluated the contribution of the virgin pomace transport. Because this energy technology from pomace is justified only if it is present in an area with a high presence of oil olive companies, we supposed the average distance to supply to be about 100 km using vehicles with capacity of 4 t, as in the case study.

The first alternative is a mix input equal to 60% de-oiled pomace, 10% waste wood and 30% RDF. The system boundary is composed of the fuel production lines and of the energy plant.

The GHG performance is equal to 0.617 $kgCO_2eq$ for 1.132 kWh. Thus it gives out 0.545 $kgCO_2eq$ for 1 kWh.

The second alternative is a mix input equal to 70% de-oiled pomace and 30% RDF. The system boundary is composed of the fuel production lines and of the energy plant.

The GHG performance is equal to 0.621 $kgCO_2eq$ for 1.132 kWh. Thus it gives out 0.55 $kgCO_2eq$ for 1kWh.

The third alternative is a mix input equal to 50% de-oiled pomace and 50% RDF. The system boundary is composed of the fuel production lines and of the energy plant.

The GHG performance is equal to 0.96 $kgCO_2eq$ for 1.133 kWh. Thus it gives out 0.847 $kgCO_2eq$ for 1kWh (see Table 8).

This evaluation of different fuel mixes underlines the GHG reductions wich are possible from the de-oiled pomace use to produce green energy.

Table 8. $kgCO_2eq$ of the alternatives.

The alternatives	Fuel	Quantity (kg)	kWh	$kgCO_2eq$
Case a	De-oiled pomace	0.6	0.678	0.066
	Waste wood	0.1	0.113	0.002
	RDF	0.3	0.341	0.549
	Total	**1.00**	**1.1318**	**0.617**
Case b	De-oiled pomace	0.7	0.791	0.077
	RDF	0.3	0.341	0.544
	Total	**1.00**	**1.1318**	**0.621**
Case c	De-oiled pomace	0.5	0.565	0.055
	RDF	0.5	0.568	0.906
	Total	**1.00**	**1.133**	**0.961**

7. 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.

When the bioenergy pathway delivers some co-products able to replace existing products (thus saving GHG emissions), the reference substituted products should be defined in the fossil reference system and emissions for their production accounted for in the GHG balance.

Energy plants fuelled by RDF, waste wood and de-oiled pomace are compared in terms of GHG emissions with energy plants fuelled by coal.

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 $kgCO_2eq$ (Nomisma Energia, 2008) [32]. 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 (APAT, 2007) [33]. The coal extraction phase emissions by underground mines in Italy are estimated to BE 0.05995 kgCO2eq/kWh.

If we compare the plant under analysis with the coal energy plant there is a net saving equal to 0.94 kg CO_2eq for each kWh produced (see Table 9).

If we compare case C with the coal energy plant there is a net saving equal to 0.042 kg CO_2eq for each kWh produced (see Table 10).

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 saving a net saving equal to 0.404 kg CO_2eq for each kWh produced is achieved.

Table 9. $kgCO_2eq$ 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	0.072	0.0634
coal + extraction coal	0.382	2.624	1.0039

Table 10. $kgCO_2eq$ per each produced kWh.

Fuel	kg/kWh	$kgCO_2eq$/kWh
case c	0.87	0.961
coal + extraction coal	0.382	1.003

7.1 Bioenergy national projection

Agricultural residues are of a wide variety of types, and the most appropriate energy conversion technologies and handling protocols vary from type to type.

Biomass residues and waste are materials of biological origin arising as by-products and waste from agriculture, forestry, forest or agricultural industries, and households [34].

The results of this study can be utilized to estimate the national possibilities of the pomace-to-energy development. This opportunity facilitates an increment in the percentage of the national renewable energy. The regional and national energy production and CO_2 saved (with respect coal derived energy) are illustrated in Table 11.

As noted in Table 11, the Puglia region is one of the most suitable for the development of the energy plant under study and so it is important to evaluate the possibility of burning biomass from agricultural residues, in additional to de-oiled pomace and waste wood.

The following crops were taken into consideration [35]:

- herbaceous: wheat (hard and soft), barley and oats. Other crops have been excluded because it is very difficult to recover waste;
- woody trees: olive, almond and vine.

The only byproduct of herbaceous crops is the straw while for the woody trees two byproducts were considered:

1. primary byproduct, S1: pruning of the almond trees and vines, and branches of the olive treeS;

2. secondary byproduct, S2: the wood which from the vines and almond trees. The wood resulting from olive trees has not been evaluated because their life cycle is usualy over a century.

The energy content of the agricultural and forest residues are:

- wheat (hard and soft), barley and oats : 4197 kcal/kg (dry);
- olive: 4200 kcal/kg (dry);
- almond: 4187 kcal/kg (dry);
- vine: 4447 kcal/kg (dry);
- forest: 4500 kcal/kg.

Information on production and consumption are extracted from bibliographic studies [35-36].

The productivity of herbaceous matter is about 1.5 t/ha and the diesel consumption for agricultural processing is about 2400 MJ/ha. The productivity of woody trees is about 6.7 t/ha and the diesel consumption for agricultural processing is about 1900 MJ/ha.

Figure 6 illustrates the emission comparison among herbaceous matter, de-oiled pomace and woody trees (including N_2O from land). The woody trees are a low impact in respect to the other residues because their energy consumption is low.

By considering the data in Table 12, it is possible to estimate that if all production of pomace were used for energy purposes then the amount of energy produced from biomass would increase by 20% [37].

7.2 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 through three principal routes:

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

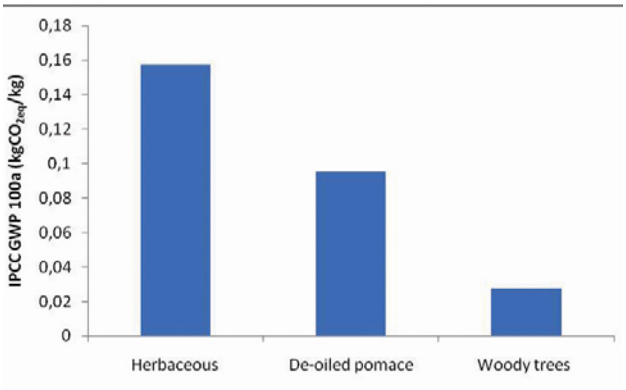

Figure 6. Comparisons among herbaceous, de-oiled pomace, woody trees.

Table 11. Regional and national energy production and CO_2 saved by biomass use.

Region	**De-oiled pomace**	**Energy**	**CO_{2eq} saved** (respected coal energy)	**CO_{2eq} saved** (respected natural gas energy)
	Total production (tonne)	MWh/year	tCO_2eq/year	tCO_2eq/year
Piemonte	23	27	27	11
Valle d'Aosta	0	0	0	0
Lombardia	1735	1961	1990	847
Liguria	7431	8397	8521	3627
Trentino-Alto Adige	506	571	580	247
Bolzano/Bozen	0	0	0	0
Trento	506	571	580	247
Veneto	2676	3024	3069	1306
Friuli-Venezia Giulia	71	81	82	35
Emilia-Romagna	2523	2851	2893	1232
Toscana	43415	49059	49785	21194
Umbria	23630	26701	27097	11535
Marche	11345	12820	13010	5538
Lazio	77704	87806	89105	37932
Abruzzo	50375	56924	57766	24591
Molise	12827	14495	14709	6262
Campania	89411	101034	102529	43647
Puglia	380543	430014	436378	185766
Basilicata	12636	14279	14490	6168
Calabria	365989	413567	419688	178661
Sicilia	108772	122912	124731	53098
Sardegna	19798	22371	22703	9664
Italy	**1211916**	**1369465**	**1389733**	**591609**

Table 12. The national renewable energy production

Energy (GWh)	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Hydro	46810	39519	36669	42337	36066	36994	32815	41623
Wind	1179	1404	1458	1847	2343	2971	4034	4861
Photovoltaic	5	4	5	4	4	2	39	193
Geothermal	4507	4662	5341	5437	5325	5527	5569	5520
Biomass	2587	3423	4493	5637	6155	6745	6954	7523
Total	55088	49013	47967	55263	49893	52239	49411	59720

The ideal crops for biofuel production, such as bioethanol from sugar cane [38] and biodiesel from palm oil [39], are only suitable for cultivation in the hotter climates of tropical regions. In colder climates where these optimal crops are unable to grow, more appropriate alternatives such as rapeseed [40] may be considered.

A last aspect to consider is the use of the agricultural residues as livestock feed, which forms the basis for important protein in the human diet [41]. 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. Nonhebel (2007) [41] compares 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 the reference energy system with which the bioenergy chain is compared [42].

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 change 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 changed 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 crop 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 [43]. 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 cases of life cycle GHG emissions of biofuels, 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 gCO2eq/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 from 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 [44]. The US already spends $7 billion a year supporting ethanol production [45]. This consumes 20 per cent of America's corn crop [46] – a figure likely to rise to 32 per cent by 2016. Looking ahead, the EU has a target of 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 [47]. 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) [48].

7.3 GHG emissions of the renewable and fossil system

Figure 7 shows the GHG emissions for the generation of electricity relative to 1MJ.

Results demonstrate that most current and advanced bioenergy systems release lower GHG emissions than fossil energy systems. If compared with other renewable sources, electricity from de-oiled pomace generally has higher emissions than hydro, wind and geothermal derived electricity, while it is comparable with photovoltaic power production systems. The GHG balance in this case depends from efficiency in the conversion process and from the degree to which biomass is used to fuel the process.

Figure 8 shows the GHG emissions for the generation of electricity by bioenergy system relative to 1MJ.

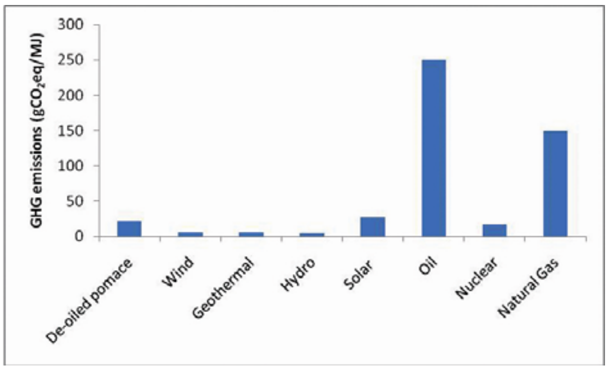

Figure 7. GHG emissions (gCO_2eq/MJ) (Cherubini et al, 2009).

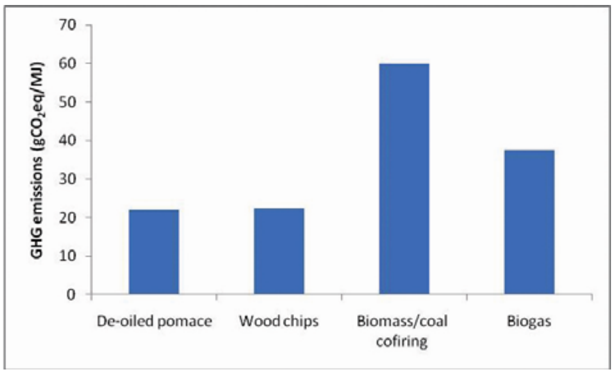

Figure 8. GHG emissions form bioenergy system (gCO2eq/MJ) (Cherubini et al, 2009).

The energy produced from de-oiled pomace is a third of the energy produced form biomass/coal firing and half of the energy produced from biogas.

The results of GHG emissions should always be assessed from a perspective of sustainability in an integrated analysis of environmental impacts. Apparently nuclear energy could be competitive but in reality the problem of nuclear waste is significant. Wind energy is profitability only if implanted in an area with strong winds. Geothermal energy can only be considered in areas with a layer of soil with high temperature, easily accessible through drilling.

8. Conclusions

LCA methodology is 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 show 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, coinciding with the period of olive-oil production, and that there are different quantities each year due to different harvests of the trees. The advantages are the limited costs of pomace as a raw material and the availability of a mature technology for biomass exploitation [49]. Finally, the development of olive residues -to -energy chains can provide solutions to olive solid waste management. The pomace is a suitable replacement for fossil fuels and a promising source for the creation of new job opportunities. Besides this, biomass is residual and available anyway and does not present the problems that may arise from energy crops and the need for food.

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