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Title: Comparative energy and environmental analysis of agro-pellet production from orchard woody biomass

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Cover letter

The Paper : Comparative energy and environmental analysis of agro-pellet production from orchard woody biomass is submitted to the journal "Renewable & Sustainable Energy Reviews"

Dear colleague Editor,

this submission is new, original and never published before.

Please take care.

The authors

Highlights

life cycle assessment (LCA) from grape and olive cultivation

Comparative analysis revealed that pellet production from both biomass is dominated by cultivation phase

Mechanization and biofuels production to Energy use

Comparative energy and environmental analysis of agro-pellet production from orchard woody biomass

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Abstract

Woody biomass has a considerable potential for energy purposes specially use in densification processes which convert these materials into solid biofuels with higher energy density. This study focuses on the energy and environmental assessment of pellet production system from vine and olive grove woody biomass. The life cycle assessment (LCA) from grape and olive cultivation up to packed pellet production, ready for delivery to final users was conducted to quantify the ecoprofile of agro-pellet production. The results of comparative analysis revealed that pellet production from both biomass is dominated by cultivation phase. Vine pellet production was more dependent on chemical fertilizers specially potassium sulfate, but olive pellet production was more dependent on copper oxide pesticide. Primary energy use per MJ energy of vine pellet was greater than that of olive pellet (0.6 vs .0.19). On the other hand, energy return ratio of olive pellet was three times of that of vine pellet (5.22 vs. 1.7). Nevertheless, olive pellet had higher environmental impacts in the forms of human toxicity, freshwater ecotoxicity and marine ecotoxicity. Consequently,sensitivity analysis investigatesthe impact of variation in input parameters of fertilizers, pesticides, machinery, diesel fuel, transport and pelletizing process onLCA results.

Keywords: LCA, Pellet, Energy return ratio, Sensitivity analysis, Woody biomass valorization

1. Introduction

The European Union's Renewable Energy Directive (RED) 2009/28/EC commits the EU to increase the share of renewable energy consumption in gross final energy consumption from 8.5% (in 2004[1]) to 20% by 2020 [1,2]. Following this directive, the

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[1] Source: Eurostat Database, Energy Statistics, https://ec.europa.eu/eurostat/data/database.

total contribution of biomass energy to the renewable energy resources' mix, is foreseen to represent 45.2% of renewable energy mix in 2020[3]. This represents an increase from around 3002 Petajoules (PJ) in 2010 to about 4636 PJ in 2020 [4].

Biomass has a fundamental role to develop renewable energy sources[5]. Nonetheless, there are a few environmental burdens of first-generation biofuels (the final output of biomass), such as: land use change and damage to biodiversity, impact on food availability and real global warming potential [6–8]. The use of more sustainable biomass, in particular agricultural residues such as pruning residues unravels these environmental burdens. In addition to the environmental benefits, the energetic use of agriculture residues, is also beneficial from the farmers' perspective[9]. Pruning residues represent in most situations a cost for farmers. The disposal of vineyard residues, for example, usually consists in shredding, burying or burning them.

The low bulk and energy densities of biomass persuade operators to conduct densification processes (pelleting and briquetting) prior to its energy use[10]. This process transfers biomass into homogeneous and automate solid biofuel that additionally has higher energy density.Agro-pellets are mainly used as fuels for heating and power generation and has become very attractive in the European market in the mid-2000s[11].

The largest national production markets of pellets are Sweden and Germany followed by Italy. The utilization rates of pellet plants in these three most important producers in 2008 were 64%, 56%, and 87%, respectively [12]. An important factor limiting the utilization of the pellet plants is the low availability of the feedstock to produce the pellets[13]. At the same time, despite the production capacity of pellet plants, the level of production is not adequate to satisfy the domestic demand[14]. According to [15], Italy, for example, with pellet production capacity of about 0.8 Mt in 2010 would not meet the internal demand. At the EU level, production is not keeping up with the faster growth rate of pellet consumption in recent years. Cocchi et al. [15]reported that the gap between the production and consumption of pellets (in tons) had an 8-fold increase in the period 2008-2010.

The growing demand for woody biomass to produce pellets[16] and on the other hand their significant influence on environmental policies as renewable energy leads to a critical need to measure the environmental consequences connected to pellet production from woody biomass residues in orchards[17].

There is a scientific literature regarding environmental impacts from the use of woody residues from orchards to produce bioenergy. Boschiero et al. [18,19] investigated the use of woody residues from apple orchards to generate heat and power in a gasification unit using the life cycle assessment methodology. Picchi et al. [20] compared the combustion of vineyard pruning residues and wood chips in a domestic boiler to assess flue gases and heavy metal emissions. Torquati et al. [21] estimated energy balance and

CO_2 emissions derived from energy production chain from pruning residues of vineyards and olive groves in the Umbria Region [22] evaluated environmental profile of hydrogen production from almond shell via life cycle assessment method.

Several studies have also assessed environmental impact of pellet production from different feedstocks, mostly from short rotation forestry[23–25], forestry residues [26,27] and olive pomace [28].

Regarding pellet production from orchard residues, some studies considered the potential of these residues for pellet production [10]and their use in domestic boilers [29]. However, there is a lack of study on the environmental impact of pellet production from orchard residues. In addition, management of woody biomass supply chain to produce pellet has not been considered in previous studies.

The target of this study is to appraise the environmental footprints associated with all steps throughout the pellet production system. Special attention is given to orchard biomass collection activities to evaluate the real contribution of biomass provision to the global environmental burdens.

2. Material and methods

2.1. LCA methodology

LCA generally consists of four phases including goal and scope definition, life cycle inventory (LCI**),** life cycle impact assessment and interpretation of results[30]. The objective of this LCA study is to create a comparative assertion through quantifying and comparingthe environmental impacts of pellet production from orchard woody biomass namely, olive and vine biomass followinga cradle-to-gate perspective with a functional unit of 1 MJ of pelletproduced. Low calorific value of olive and vine pellet were considered 16740 MJ t_{pellet}^{-1} and 16272 MJ t_{pellet}-1, respectively.

2.1.1. System boundary description

The bioenergy production chain under assessment was divided in three principal subsystemsFigure 1:

- SS1 (subsystem 1) involving all farming operations carried out for orchards biomass production,
- SS2 (subsystem 2) including all the activities involved in woodchips production and,
- SS3 (subsystem 3) covering all activities in the factory under assessment

Waste and disposal protocols are excluded from the boundary. In addition, the use phase (i.e. combustion of pellets produced) is not included as the system boundary ends at the point of leaving the factory.

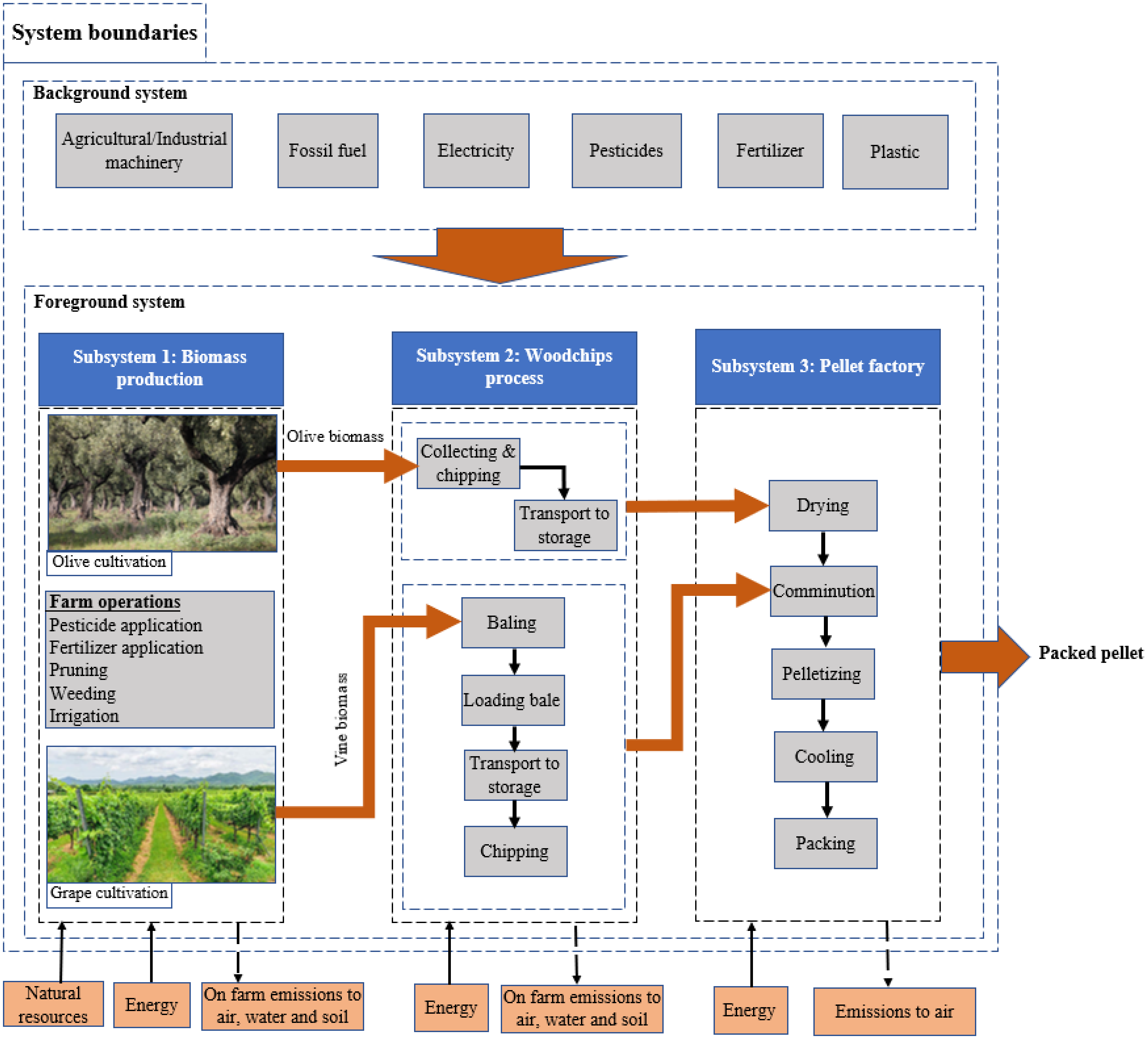

Figure 1. The diagram of the system boundary of pellet production

2.1.2. Inventory data collection

Subsystem ‘Biomass production’—SS1

In this study, the data for foreground system related to biomass production were collected by visiting and interviewingwith the growers in 21orchards, consisting of 12vineyards in provinces of Treviso, Pordenone and Udine and 9olive groves in province of Viterbo. These farms were randomly selected from the provinces of Treviso, Pordenone and Udine. The data included all annual use of physical inputsand outputs. In addition, on-farm emissions to the water, soil and air caused by application of inputs, i.e. fertilizer, pesticide and diesel fuel consumption for farm operations during the cultivation of grape and olive were estimated using IPCC guidelines [31].

To estimate biomass production, pruning material was weighted by setting upa data acquisition form according to UNI EN 14778/2011 guideline, which governs the methods for taking samples of solid biofuels[32]. The data required includes cultivation areas of the raw material and relevant features like inter-row line of vineyard, distance on the row between screw and screw, number of homogeneous rows in the sampled length, the length of the rows as well as year of planting, variety of vines, vine nursery, manual or mechanical pruning, the ratio between the number of rows and the number of swaths where the prepared branches are stacked.

The average vine biomass yield per hectare was determined as dry weight via the following formulas (Formulas 1, 2)[32]:

$$\mathrm{Rtq} = \mathrm{Mtq} * ((1000/\mathrm{L}/\mathrm{I})/2)/1000 \qquad \textbf{(1)}$$

Where Rtq: production of shoots (t/ha); Mtq: the average weight of samples collected in vineyard (kg); L: the length of the inter-row segment (m); I: the width of the inter-row in the sampled section (m); 2: the ratio of the number of rows to the number of swaths.

$$\mathrm{Rss} = (\mathrm{Mss} * ((10000/\mathrm{L}\ /\mathrm{I})/2)/1000) \qquad \textbf{(2)}$$

Where Rss: production of shoots in dry matter (t/ha); Mss: the average weight of the dried samples collected in the vineyard (kg); L: the length of the inter-row segment (m); I: the width of the inter-row in the sampled section (m); 2: the ratio of the number of rows to the number of swaths.

In the case of olive groves, biomass produced by pruning of olive trees varies depending on age of plant and the number of plants per hectare. The average pruning material from vineyard and olive groves were estimated as 2.9 and 4.5 t/ha, respectively.

Table 1 presents the inventory of inputs and on-farm emissions from biomass production.

Table 1. Inventory data for subsystem 1 per functional unit (1 MJ energy of pellet).

Items	Unit	Quantity (Unit MJ^{-1})	
		Vine biomass	Olive grove biomass
A. Output	kg	0.064	0.062
B. Input from technosphere			
1- Pesticides	g		
Insecticide			
Organophosphorus-compound		0.054	0.026
Fungicide			
Captan		0.09	
Copper oxide			0.077
Herbicide			
Glyphosate			0.009
2- Fertilizers	g		
Compost		6.8	
Nitrogen fertilizer, as N		0.57	0.63
Urea		1.33	
Potassium fertilizer, as K_2O		2	0.58
Phosphate fertilizer, as P_2O_5		1.33	0.3
Sulfur		0.86	
3- Diesel	g	2.52	0.2
4- Electricity	kWh	0.0008	
C. On-farm emissions			
1- Emissions to air	g		
Ammonia (NH_3)		0.057	0.06
Dinitrogen monoxide (N_2O)		0.02	0.007
Nitrogen oxides (NO_x)		0.0044	0.0014
Carbon dioxide (CO_2)		10.6	0.88
Methane (CH_4)		0.0013	0.00007
2- Emissions to water	kg		
Nitrate (NO_3^-)		0.16	0.2
Phosphorus		0.066	0.014
3- Emissions to soil	g		
Pesticides		0.13	0.11

Subsystem ‘Woodchips production’—SS2

Biomass collection and truning into woodchips were managed by two different approches. In one approach, olive pruning biomass previously raked and accumulated into rows was shreded into fragments in various sizes by a tractor equipped with rotary cutter and simultaneously carried on an storage then unloaded on an agricultural trailer. In second approach, vine branches previously placed in rows were packed, by a towed round baler.It took material from ground and packed it into cylinders of 1.2 meters wide and 1.5 meters in diameter. Once formed, balewas expelled in the row and subsequently collected by a tractor with loader and transported out of the vineyard.

In both approaches, storage phase lasted 7 months and took place during the spring-summer period to take advantage of environmental temperatures and solar radiation. Bales were stored in an open shed while woodchips were held in an indoor silo.

The water content of vine biomass and olive grove biomass was measured around 40-50% and 35-45%, respectively.On the other hand, the humidity content of woodchips must be lower than 14% prior to comminution (grinding) process for pelletizing. Therefore, this can be achieved either through collecting biomass into round bales and natural drying or by drying process in factory.

In the area studied, the vine biomasswas baled and dried in open air. Through this process the water content of bales dropped to 12-14% and therefore,it could directlyenter thegrinding phase without further drying requirements. However, olive woodchips were required to be dried in the factory. After the natural drying, round bales were chipped by a mobile chipper. In both approaches, around 2% of the total woody biomasschipped was directly emitted to the atmosphere as wood dust [33].

In woodchips production process, the foreground data collected were related to fuel consumptions for all of the machines (chipper, tractor equipped with rotary cutter, trailer, baler and loader). Background data related to emissions from production of fossil fuel consumed in the agricultural machinery[34]as well as the production and use of machinery [35] were extracted from Ecoinvent database® [36,37].

Table 2 reports the chief data regarding the machines used in the different operationsincluded in this subsystem.

Table 2. Characteristics of machines involved in collecting, transport and chipping activities.

Operation	Machinery	Power (kW)	Weight (t)	Capacity	Diesel consumption[a]	Operation hours	Lifespan	Average distance (km)

Collecting	Tractor	80	2.4	-	20 kg/ha	1.17 h/ha	10,000 h[b]	
	Rotary cutter	50	1.65	3.2 t/h	-	1.1 h/ha	1000 h[b]	
Transport to storage	Tractor	100	4.7	-	20.8 kg/h	0.25 h	10,000 h[b]	10
	Trailer	-	3.5	18 m3	-	-		
Baling	Tractor	48.7	4.48	-	12 kg/ha	1.5 h/ha	10,000 h[b]	
	Baler	33	2.25	1.76 t/ha	-	1.45 h/ha	1000 hb	
Bale loading	Tractor	50	2.5	-	13 kg/ha	1 h/ha	10,000 h[b]	
	Loader	31	0.5	-	-	-		
Transport to storage	Tractor	82	4.5	-	20 kg/h	0.25 h	10,000 h[b]	10
	Trailer	-	1.2	6 m3	-	-	-	
Chipping	Chipper	397	4	18 t/ha	8.6 kg/ha	0.16 h/ha	10,000 h[c]	

[a] Referred to productive machine hours without delays.
[b] [38].
[c] [39].

Subsystem ‘Pellet factory’—SS3

Data regarding construction and operation of pelleting plant was estimated from literature[25]. Therefore, the productivity of plant was assumed as 2 t/h with 2000 h working hours per year.

Table 3summarizes the most relevant inventory data managed in SS3. Secondary data were considered for the production of fuels, electricity, plastics and machines, and they were also taken from the Ecoinvent database® [35,40].Table 4shows the infra-structures considered, the materials and their lifetimes.

Table 3 Inventory table for pellet production factory per functional unit (1 MJ energy of pellet).

Items	Unit	Quantity (Unit MJ^{-1})	
		Vine woodchips	Olive woodchips
A. Output	MJ	1	
B. Input from technosphere			
1- Woodchips	g	62	60
2- Electricity	kWh		
Drying		-	1.25E-3
Comminution		2.3E-3	2.25E-3
Pelletizing		1.4E-3	1.36E-3
Cooling		8.23E-5	8E-5
3- Natural gas	MJ	-	0.016
4- Diesel	g	0.6	0.59

5- Plastics	g	5.4E-5	5.2E-5
C. Output to environment Emissions to air			
1- Carbon dioxide (CO_2)	g	2.5	2.4
2- Wood dust	g	1.24	1.2
3- Methane (CH_4)	g	3.3E-4	3.2E-4
4- Dinitrogen monoxide (N_2O)	g	2.08E-5	2.03E-5

Table 4. Characteristics and lifetimes of the pellet plant infrastructures [25].

Sections	Infrastructure type	Materials	Lifetime (y)
Drying	Cup elevator, magnetic separator	Steel low-alloyed: 700 kg	50
	Rotary drum	Aluminum wrought alloyed: 640 kg Aluminum sheet rolling: 640 kg	10
	Exhaust fan	Aluminum: 1000kg Steel low-alloyed: 1000 kg	50
	Natural gas boiler	Refractory: 70 kg Cast iron: 4200 kg Chromium steel: 230 kg Steel low-alloyed: 190 kg Rock wool: 40 kg	20
Comminution	Cup elevator, screw conveyor	Steel low-alloyed: 700 kg	50
	2 hammermills	Reinforces steel: 2500 kg Steel sheet rolling: 2500 kg	10
Pelleting	2 feed screw, 2 screw extractors	Steel low-alloyed: 700 kg	50
	2 presses	Steel low-alloyed: 4000 kg Steel rolling: 4000 kg	10
Cooling	2 feed hoppers, 2 screw conveyors	Steel low-alloyed: 700 kg	50
	Cooler	Steel low-alloyed:200 kg	15
	Screw extractor	Steel low-alloyed: 210 kg	50

2.1.3Impact assessment

In this study, environmental results are characterized and normalized using Recipe midpoint (H) v1.13[41], in the line with the same approach used in other LCA studies[26,42]. In this approach, normalized results are assessed to identify potential impacts. Afterwards, these impact categories selected are characterized for further assessment. Among a total of eighteen impact categories assessed, those categories with negligible effects have been omitted from displayed results. Subsequently, six categories were assessed, namely, marine ecotoxicity, freshwater ecotoxicity, human toxicity, freshwater eutrophication, marine eutrophication and natural land transformation. The impacts were calculated in SimaPro software (version 8.3.0).

2.1.4 Uncertainty and sensitivity analysis

Uncertainty issues are always relevant in LCA studies. However, they deem to be more critical when developing comparative models. Therefore, uncertainty analysis is necessary to support results of comparative studies [43].

In this study, two types of uncertainty, data and method uncertainties are assessed. Data uncertainty is quantified through a defined range as ±10%. Sensitivity analysis is also performed to estimate the effect of impact assessment method choice on the outcome of the study and compare results of vine and olive pellet by using ReCipe midpoint (H) and CML-IA methods.

2.2. Net energy analysis

Net energy analysis is a methodology to quantify the energy demand to manufacture a product or create a service [44,45]. It computes the gross energy requirement considering both direct and indirect energy consumption [46]. To determine primary energy required, it is necessary to track life cycle of energy through the relevant industrial system[47]. Net energy analysis is based on the same system boundary used in the LCA[48]. The cumulative energy demand (CED) [49] was applied to calculate gross energy requirement.

3 Results and discussions

3.1. Energy perspective

Figure 2shows the comparative shares of different activities for vine and olive pellet. For vine pellet production, the primary energy use was found to be 0.6 $\mathrm{MJMJ}_{\mathrm{pellet}}^{-1}$, from which biomass cultivation, pelletizing and baling were the main contributors and they were consumed as 0.48 $\mathrm{MJMJ}_{\mathrm{pellet}}^{-1}$, 0.06 $\mathrm{MJMJ}_{\mathrm{pellet}}^{-1}$ and 0.027 $\mathrm{MJMJ}_{\mathrm{pellet}}^{-1}$. This results also revealed that chipping phase and transportation were the least demanding energy activities. Life cycle primary energy requirement for olive pellet production was 0.19 $\mathrm{MJMJ}_{\mathrm{pellet}}^{-1}$, which was less than that of vine pellet. Biomass cultivation (0.09 $\mathrm{MJMJ}_{\mathrm{pellet}}^{-1}$) and pelletizing (0.06 $\mathrm{MJMJ}_{\mathrm{pellet}}^{-1}$) were the main contributors to the total energy inputs in olive pellet production. Furthermore, energy needs from chipping (0.02 $\mathrm{MJMJ}_{\mathrm{pellet}}^{-1}$) was relatively high. These results are in the line with those previously reported by Fantozzi and Buratti [25] investigated energy consumption and environmental footprints of pellet production from poplar, a Short Rotation Coppice (SRC) in Italy. They reported poplar cultivation (42.1%) and wood pelleting (37.9%) were main processes which contribute to energy consumption.

Table 5 summarizes the results of energy analysis of vine, olive and poplar wood pellet productions for cumulative energy demand (CED) and energy return ratio (ERR) which are metrics used to assess energy technologies [48]. Cumulative energy demand signifies how much primary energy input is demanded to deliver 1 MJ of pellet. The ERR is the inverse of CED and defined as the ratio of total usable energy produced from the process analyzed to the life cycle primary energy input (measured as CED). A positive (>1) value for ERR is a favorable for renewable energy sources. Higher ratios represent improved processing energy efficiency. Results indicated that the ERR of olive pellet was three times of that of vine pellet due to lower energy requirements in biomass cultivation (5.22 vs. 1.7). Higher ERR of olive pellet production can be interpreted by higher energy delivered from olive pellet and less life cycle primary energy demand. ERR of wood pellet was estimated as 3.25 [25]. CED of vine pellet was more than that of olive pellet (0.6 vs. 0.19). The differences are interpreted by different primary energy use and different energy content of theses pellets.

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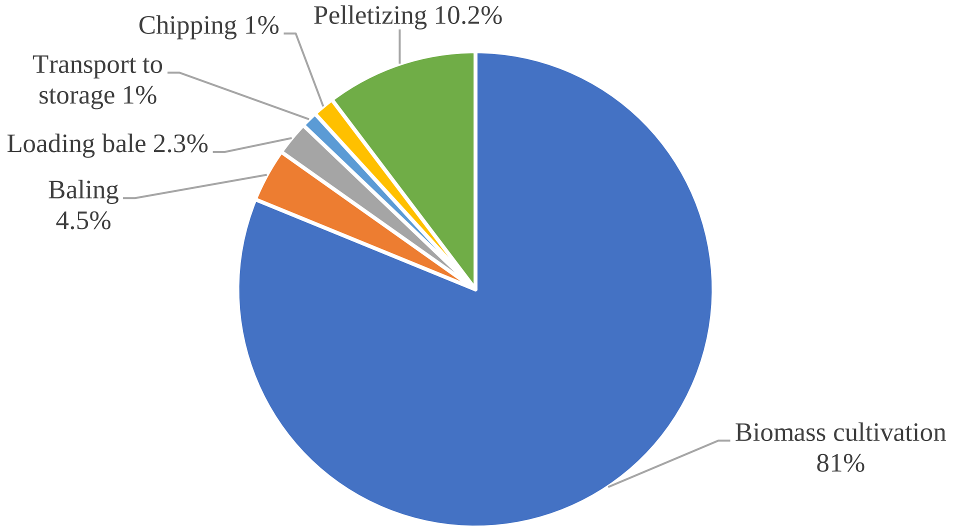
a. Vine pruning pellet



b. Olive pruning pellet

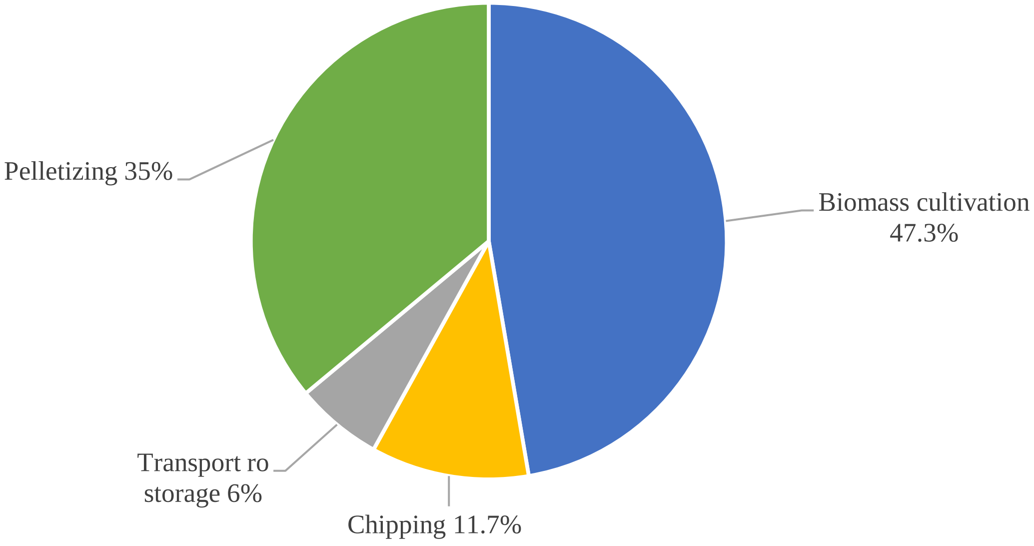


Figure 2. Comparison of CED in Vine and Olive pruning pellet production.

Table 5. Energy analysis result (CED, ERR) for Orchard pruning pellet and wood pellet

	Vine pruning pellet	Olive pruning pellet	Poplar wood pellet [25]
Cumulative energy demand (CED) ($MJ_{primary}/MJ_{delivered}$)	0.6	0.19	0.3
Energy return ratio (ERR) ($MJ_{delivered}/MJ_{primary}$)	1.7	5.22	3.25

3.2. Environmental perspective

3.2.1 Comparative life cycle impact assessment and interpretation

Table 6presents the distribution of the characterization results among the different subsystems. The results show that the environmental impact is mainly due to biomass cultivation (90-99% of the total impact) and pelletizing (0.5-7%). [25]reported the similar result for pellet production from poplar.

As it isseenin Table 6, aquatic ecotoxicity (MEc, FEc) of olive cultivation was higher than that of vine production (5E-4 vs. 3.7E-4 kg 1,4-DB_{eq} t^{-1}). It refers to impacts oftoxic substances on freshwater and marine ecosystems. Similarly, HT of olive cultivation was higher than that of vine cultivation (1.7E-2 vs. 8E-3 kg 1,4-DB_{eq} t^{-1}).The slight contribution of pelletizing process to these impact categories is owing to the production of electricity requirements in this activity.

Table 6.Characterization results associated with the packed pellet production (ReCipe, FU: 1 MJenergy of pellet).
Freshwater eutrophication (FEu), Marine ecotoxicity (ME), Freshwater ecotoxicity (FEc), Human toxicity (HT), Natural land transformation (NLT), Marine eutrophication (ME).

Impact category	Unit	Vine pellet (Unit MJ^{-1})			Olive pellet (Unit MJ^{-1})		
		SS1 (%)	SS2 (%)	SS3 (%)	SS1 (%)	SS2 (%)	SS3 (%)
FEu	kg P_{eq}	1E-4 (99)	2.4E-7 (0.43)	6E-7(0.57)	2.8E-5 (97)	2.9E-7 (1)	5.9E-7(2)
MEc	kg 1,4-DB_{eq}	1.8E-4 (89)	8.6E-6 (4.5)	1.4E-5 (6.5)	3E-4 (91)	9.8E-6 (4)	1.6E-5 (5)
FEc	kg 1,4-DB_{eq}	1.9E-4 (89)	9.2E-6 (4.3)	1.5E-5 (6.7)	2E-4 (90)	1E-5 (4.1)	1.8E-5 (5.9)
HT	kg 1,4-DB_{eq}	8E-3 (90)	3E-4 (4.8)	4E-4 (5.2)	1.7E-2 (94)	4E-4 (2.8)	5E-4 (3.2)
NLT	m^2	8.6E-6 (78)	1.2E-6 (12)	1.1E-6 (10)	1E-6 (34)	7.7E-7 (28)	1.1E-6 (38)
MEu	kg N_{eq}	6.4E-5 (99)	3E-7 (0.5)	3.5E-7 (0.5)	6.2E-5 (99)	1.8E-7 (0.4)	4.2E-7 (0.6)

A comparative overview of characterization results for vine and olive pellet are presented in Figure 3. Evaluation of environmental indicators indicated that impact categories of HT, FE and MEc for olive pellet production were higher than those of vine pellet production, and therefore, vine pellet was more environmentally compatible than olive pellet for most of impact categories. Nevertheless, production of vine pellet generates higher environmental loads in the forms of FEu and NLT. The difference in MEu of vine and olive pellet production was negligible. Higher MEc, FEc and HT of olive pellet production were caused by emissions in production phase of copper oxide applied as pesticide in olive growing. The optimum application of this pesticide or replacement with alternative pesticide are possible pathways to reduce associated environmental emissions. FEu of olive pellet production was 28% of that of vine pellet (Figure 3). This means that 1 MJ energy from olive pellet causes 72% less eutrophication than 1 MJ energy from vine pellet. FEu expressed as kg P_{eq} per kg emission and encompasses all impacts owing to immoderate levels of macro-nutrients in the environment caused by emissions of nutrients to water. It is principally dependent on the production and application of fertilizers, chiefly ureaand phosphate. Nitrogen emissions (especially due to NO_3^{-1}) and phosphate emissions owing to fertilizer consumption are mainly contributed to FEu[50].

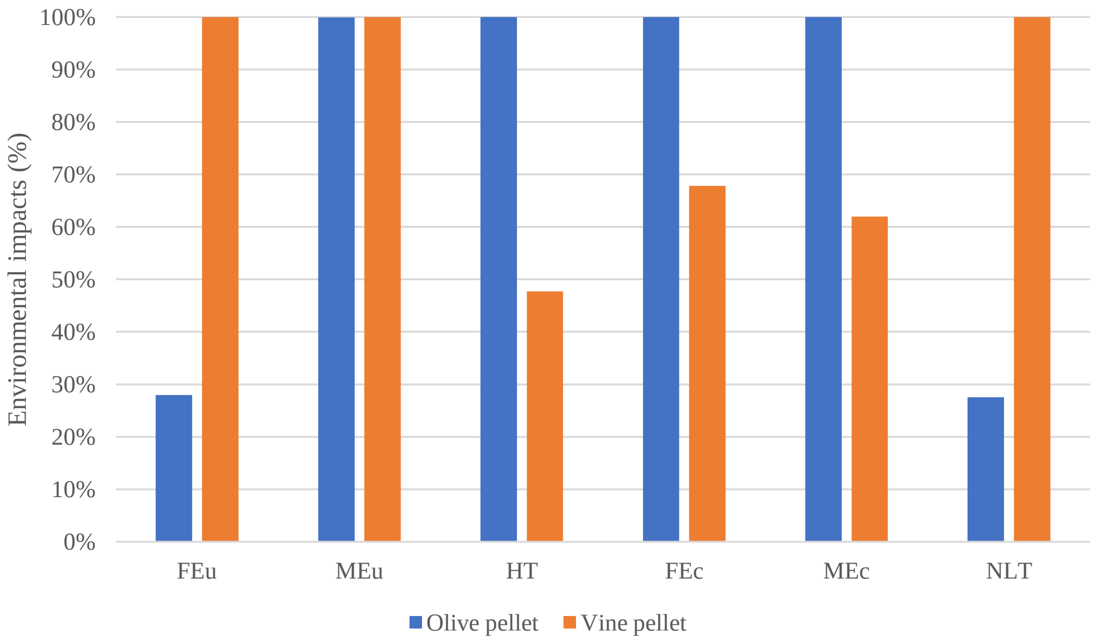


Figure 3. Comparative characterization results of Olive and Vine pruning pelletizing (ReCipe, FU: 1 MJ energy of pellet)

To sum it up, comparative LCA of vine and olive pellet showed that for most of the impact categories, the environmental loads of olive pellet were more than those of vine pellet, and this was greatly owing to higher consumption of pesticides, especially copper oxide, for olive cultivation, which entails mainly toxic substances such as copper and zinc emitted to water during manufacturing process. In fact, environmental impacts of products connected to agricultural systems depend on a large extent on farmer production practices.

Figure 4 illustrates the percent contribution of normalized impact categories from olive cultivation in the region. The greatest effects on most of the impact categories were derived from production of inputs such as pesticides, fertilizer and diesel, followed by emissions from application of fertilizers such as nitrate, phosphorus, CO_2, NH_3, N_2O and NO_x. Normalized impact categories for vine biomass production are presented in Figure 5. Among vine biomass production inputs, the main contributors to total emissions were fertilizers particularly potassium sulfate and urea, followed by emissions from their applications. Application of nitrogen fertilizer contributes to MEu impact; therefore, replacing nitrogen fertilizer by manure will reduce MEu in vine biomass production in the region. Moderate application of nitrogen fertilizer depend on crop demand is advocated for decrease in nutrient leaching, aquatic eutrophication and NO_x emissions.

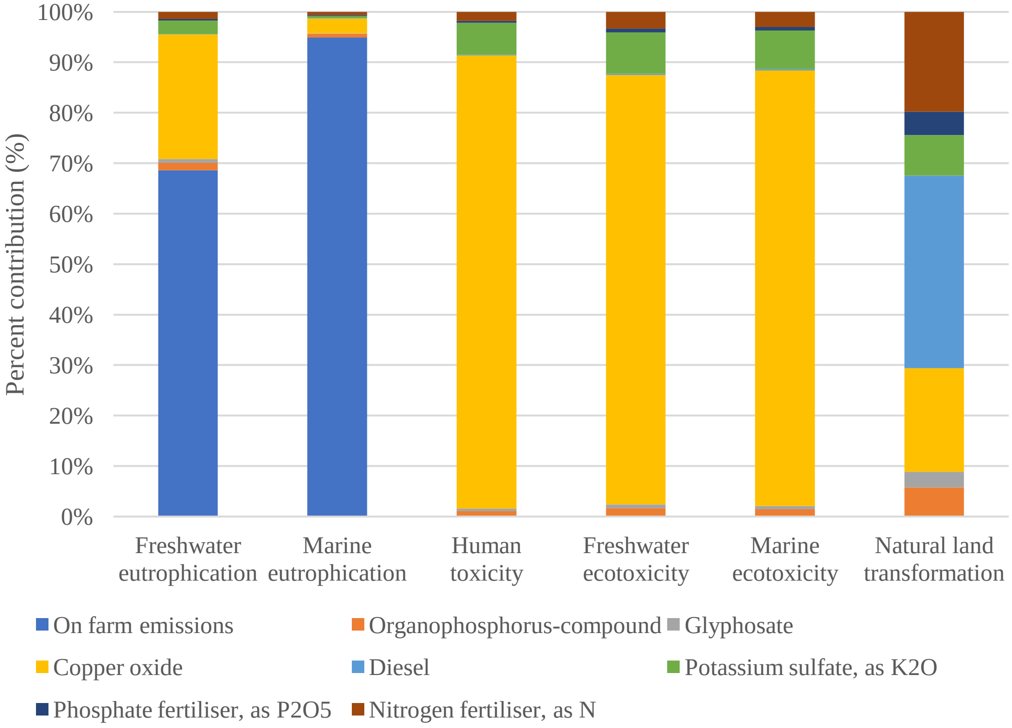


Figure 4. Percent contribution of normalized impact categories in Olive biomass cultivation (FU: 1 MJ energy of pellet)

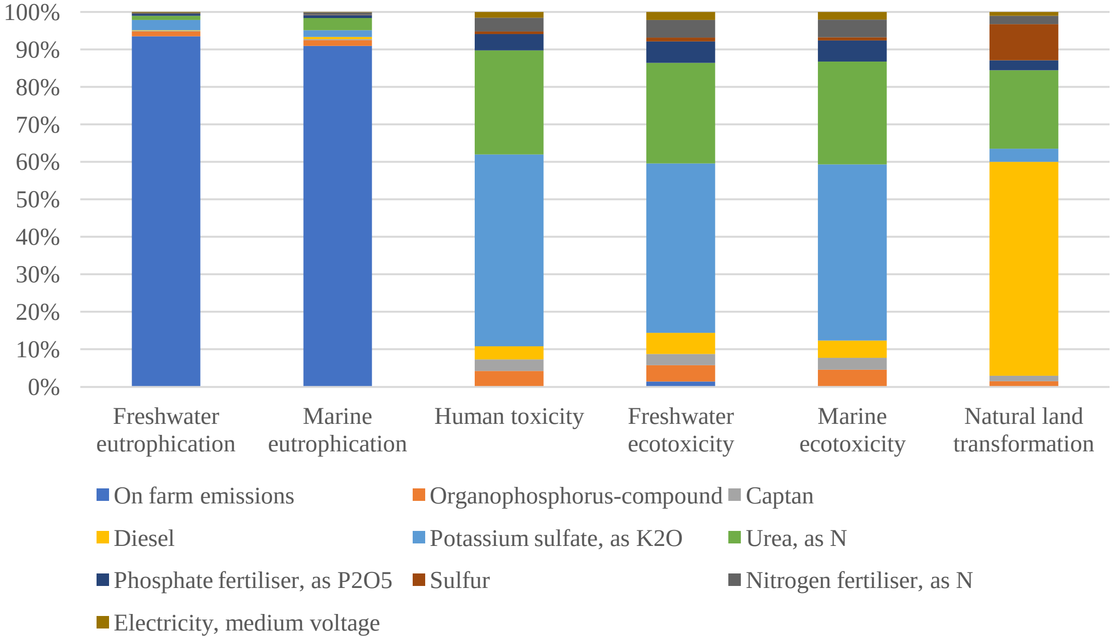


Figure 5. Percent contribution of normalized impact categories in Vine biomass cultivation (FU: 1 MJ energy of pellet)

3.2.2. Uncertainty and sensitivity analysis

In order to show the changes of comparative ecoprofiles of olive and vine pellet by application of different LCA models, the CML-IA baseline model was used and LCA results of olive and vine pellet are comparatively presented in Table 7. Impact categories of MEc, FEc, HT and EP were found to be main contributors to environmental emissions profile of both vine and olive pellet by normalizing the result in CML-IA model. Other impacts were found to be immaterial and are therefore excluded from analysis.
Using CML model, human toxicity impact for vine and olive pellet was found to be 0.01 and 0.016 kg 1,4-$DB_{eq}MJ^{-1}_{pellet}$, respectively. High value of eutrophication potential from vine pellet is considerably resulted from emissions by fertilizer use especially urea in the farm. By using CML model, HT, FEc and MEc for olive pellet were higher than those of vine pellet. The similar comparative results wereobtained in ReCipe midpoint (H) model presented in the previous section; however, the magnitude of some of the impact categories was different in two models which can be interpreted by discrepancies in approaches to characterization modeling. For example, magnitude of MEc is considerably different in CML-IA and ReCipe, but when analyzing the percent contribution of different inputs on MEc, pesticides and chemical fertilizers are main contributors in both of the models.

Sensitivity analysis of different emission sources on impact categories of vine and olive pellet are presented as tornado diagrams in

Figure 6. These diagrams show the variables which have the greatest effetcs on each of the impact categories. The results present the impact of 10% increase and 10% decrease in average values of the individual input parameters on outcome of model. As it is seen, in olive pellet production, the most sensitive variable on HT, FEc and MEc was copper oxide. However, HT, FEc and MEc in vine pellet production showed the highest sensitivity on potassium sulfate. This is interpreted by high dependency of vineyards to this fertilizer use. Phosphate fertilizer, diesel and nitrogen fertilizer contributed the most to FEu, NLT and MEu, respectively, in vine and olive pellet productions. As magnitude of MEc in CML-IA and ReCipe models was considerably different, the contribution of emission sources on MEc is analyzed further in detail. In environmental profile of vine pellet by ReCipe model, MEc was contributed by potassium sulfate (41.7%), urea (24.4%), diesel (6.8%), pesticides (5.6%), phosphate fertilizer (5%) and pelletizing (4.8%); similarly, in CML-IA model MEc of vine pellet was contributed by potassium sulfate (42%),

urea (20.7%), pesticides (6.7%), pelletizing (5.9%), phosphate fertilizer (5.4%) and diesel (5%). These results revealed that, in vine pellet production, potassium sulfate and urea are dominated by other emission sources in both of the ReCipe(

Figure 6, V_5) and CML-IA models. However, in environmental assessment of olive pellet, copper oxide, potassium sulfate, pelletizing and nitrogen fertilizer were found to be substantial contributors to MEc in the Recipe (

Figure 6, O_5) and CML-IA models. Overall, the results of uncertainty and sensitivity analysis signified that fertilizers and pesticides had high impacts on all impact categories. Efficient use of pesticides and fertilizers in olive groves and vineyards can reduce corresponding environmental emissions.

Table 7. Impact assessment results at characterization for vine and olive pellet production using (CML-IA, FU: 1 MJ energy of pellet).
Human toxicity (HT), Fresh water aquatic ecotox. (FEc), Marine aquatic ecotox. (MEc), Eutrophication (EP).

Impact category	Unit	Vine pruning pellet	Olive pruning pellet
HT	kg 1,4-DB_{eq}	0.01	0.016
FEc	kg 1,4-DB_{eq}	0.006	0.008
MEc	kg 1,4-DB_{eq}	21.2	24.9
EP	kg PO_{4eq}	3E-4	1E-4

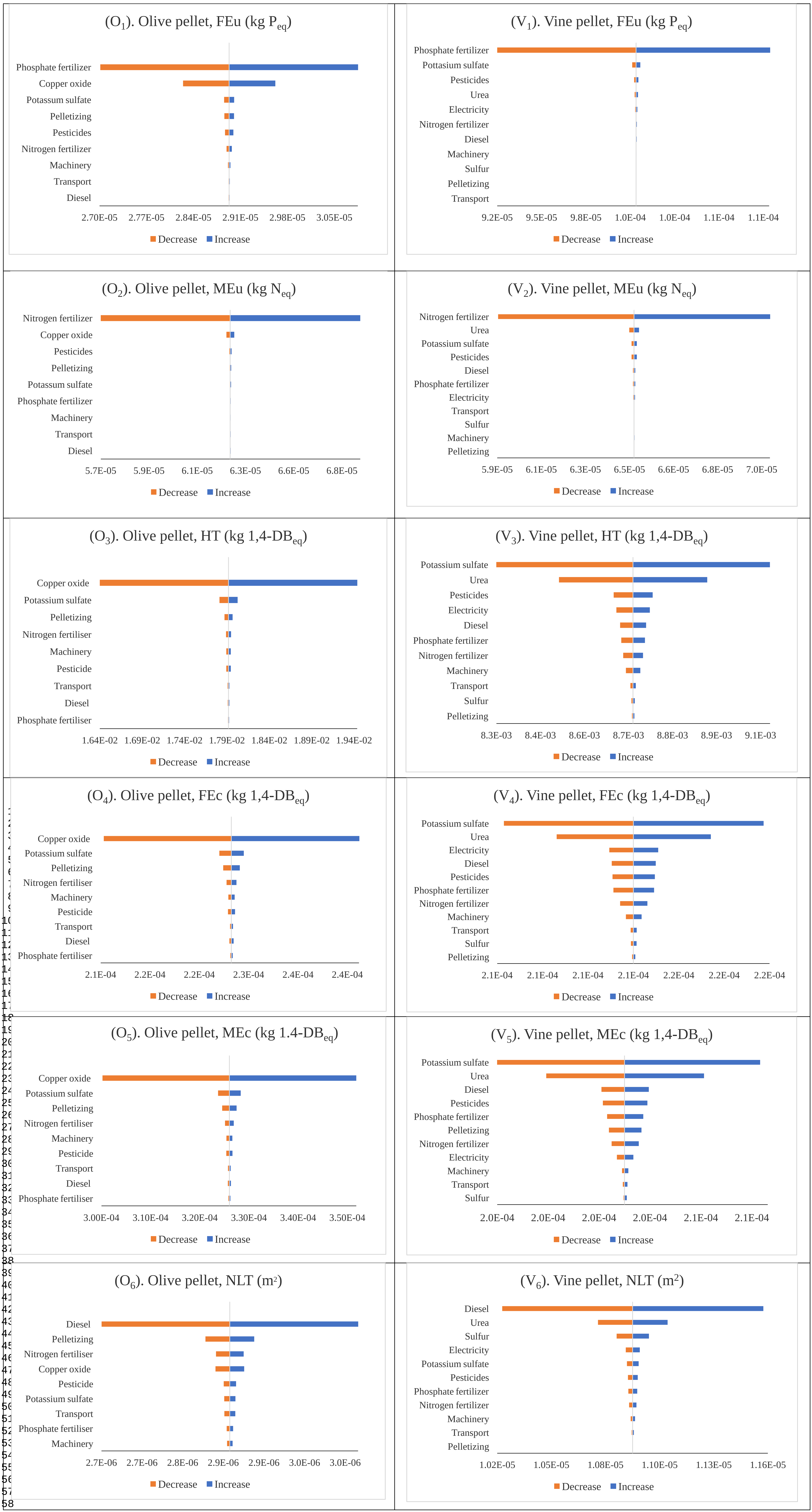


Figure 6. Sensitivity analysis of input parameters on impact categories for Vine and pellet production systems

4. Conclusion

The LCA study indicated that all environmental burdens are mostly imposed by agricultural operations. Olive pellet had higher human toxicity, marine ecotoxicity, freshwater ecotoxicity and marine eutrophication. Nonetheless, vine pellet production system was characterized by higher freshwater eutrophication and natural land transformation. Moreover, energy analysis revealed that ERR of olive pellet was higher than that of vine pellet production. Therefore, the olive pellet biomass chain has a more favorable energy balance than that of vine pellet.

Sensitivity analysis results also revealed that fertilizers and pesticides had the highest contributions to all impact categories. Hence, efforts should focus on reduction/ suitable use of nutrients and efficient management of pesticide which lead to decrease in environmental impacts and to enhance ERR of pellet production systems from orchard biomass.

Systematic application of fertilizers and pesticides are strongly encouraged within the framework of sustainable development of production systems. In this line, application of fertilizers at an appropriate rate and a decent timing through an efficient method count as possible pathways for more environmental friendly pellet production from orchard biomass.

These findings as a pattern can be applied by managers and decision makers to recognize the most energy-efficient and environmental-cleaner pellet production systems.

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