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Research article

Evaluation of comparative scenarios from different sites of chestnut production using life cycle assessment (LCA): Case study in the Beira Interior region of Portugal

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ABSTRACT

The evaluation of the environmental impacts of chestnut production in the Beira Interior region (Portugal) is accessed. The comparative life cycle assessment (LCA) was performed with the use of openLCA software with 16 Environmental Footprint (EF) impact categories retrieved from the AGRIBALYSE database. The system boundary was from "cradle-to-farm gate" and the functional unit was 1 ton of chestnut delivered to consumers (only wholesale buyers). The processes model for the production of agricultural machinery, pesticides, fertilizers, and materials was modeled based on surveys and existing literature. The data was gathered from four different production areas: Serra da Estrela, Malcata, Gardunha, and Plateau area. Each site has two selected representative producers inner 250 km^2 square radius environment. The results showed that the average GHG emissions in the low-input group (Estrela and Gardunha) were 1.83 kg CO_2-eq/ton with the energy burden (80–89%) as main contribution emissions and in the intensive-input group (Malcata and Plateau) were 2.61 kg CO_2-eq/ton with the main contribution source of emissions are fertilizer (76–83%). Sensitivity analysis results indicate shift input material and cultivation activities in chestnut production systems can be possible for all study areas without reducing yield production. The suggestions in this article can be used by farmers, policymakers, and other stakeholders to adopt new alternative production scenarios.

1. Introductions

In Europe, Portugal is the third major producer of chestnut (*Castanea sativa* Mill), during centuries chestnut still provides important nutritional, cultural value, and conservation. In 2020, Portugal became the sixth chestnut producer worldwide with 27.1 thousand tons

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[1]. In specific, the Beira Interior area is one of the major chestnut production areas in Portugal [2]. Orchards area is increasing during the past ten years by 0.3 times/year since 2015 [3]. The terms of the production system, the increasing production, and orchards tend to require more input material (fertilizer, pesticide) and energy (non- or renewable). Which, both aspects are considered to be the main drivers of environmental greenhouse gas (GHG) emissions [4]. Concerning current conditions, it is necessary to anticipate the future of chestnut industrialization in Portugal by analyzing chestnut production scenarios and providing alternative low-carbon scenarios for improving the sustainability of chestnut production.

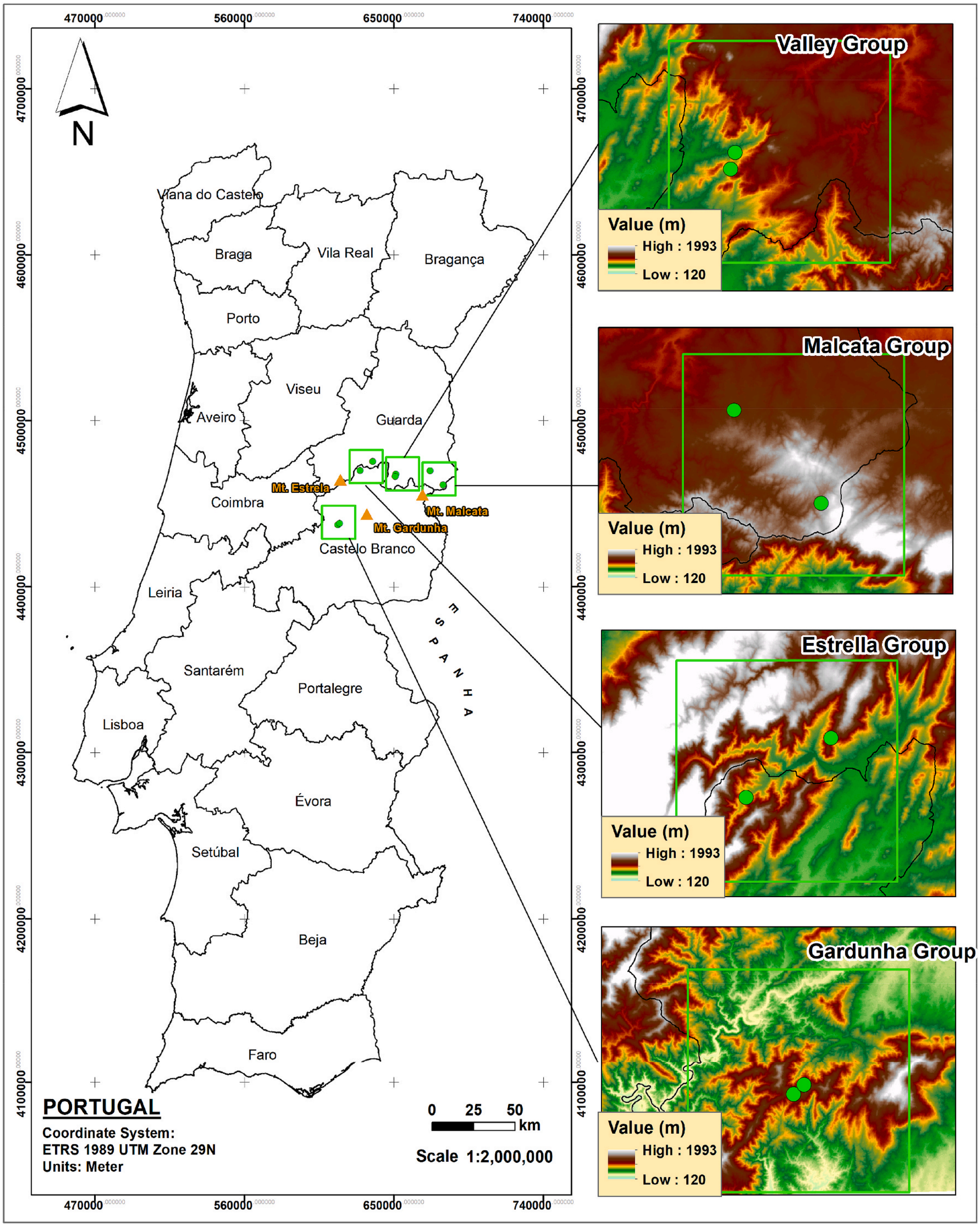

Fig. 1. Production study site location and topography.

In terms of sustainability, there are three dimensions/pillars (social, economic, and environmental), however, Life Cycle Assessment (LCA) is an appropriate method to assess and highlight the environmental sustainability of the production activities system. The method provides a solution for holistic analysis systems based on real field activities (resource input) and the identification of environmental impacts (emission). Furthermore, a wide range of research has used the LCA approach to assist and evaluate environment effect activities in different fields of agriculture. On the main agricultural stage and product [5,6], agricultural by-products [7,8], agricultural food processing [9,10], and agricultural systems [11,12].

The Environment Footprint (EF) is a recent LCA method which is a high relevant analysis tool to provide a set of environmental impact analyses for use of water, land, and resources. Particularly, in agriculture sector as well-known massively relies on natural resources (agroclimatic, water, land), energy, also contributes to various pesticide residue contamination. This method was proposed by European Commission (EC) in 2013 through official communication 'Single Market for Green Products' (COM/2013/196)[13]. In parallel, the publication also included with EF beta version involved a number of stakeholders for testing LCA studies with two specific set, in product and in organizational. Afterward since 2018 Environmental Footprint Category Rules (EFCRs) were approved and published method with dataset as guideline for determining the EF [14]. The indicators are multi-criteria covering water, energy consumption, metals, chemicals, use of land and other materials [15]. The evaluation result of EF can provide environment impacts viewpoint on the global warming, carbon footprint, eutrophication, acidification, ecotoxicity, and ozone depletion [16]. Two studies highlighted as benchmark applied the EF method to evaluate environmental impacts in cultivation systems. These studies have been conducted by [17] on different open field strawberry production systems in Germany and Estonia, and [18] on viticulture organic grape production in Cyprus.

In LCA of chestnut production, to date literature review reveals there are only two studies available. First, Ref. [19] presented an environmental impact analysis with the ReCiPe method on fresh and frozen chestnut from two producers with a specific on environmental improvement in post-harvest and distribution stages. Second,[20] study in Italy only focuses on the ecological footprint of the chestnut nursery production stage. However, both of study is used a small sample scope and none of them consider environmental characteristics as main aspect to compose a chestnut production scenario. In order to fill this research gap, the present LCA study will evaluate the EF of chestnut scenarios applied by producers at the different characteristic orchard sites. To design a sustainable production scenario through an efficient carbon model, it is necessary to evaluate producing activities. With scope attempt to (i) evaluate and compare the carbon footprint from chestnut cultivation with various scenarios applied by producers, (ii) identify critical activities or processes that are produced more impacts on the environment and inefficiency carbon production, and (iii) provide an alternative model for reducing the cultivations environmental impact.

2. Study site and methods

2.1. Study site

The site area in the present study is located in the Beira Interior region of Portugal. As [21] claimed, chestnut cultivation environments require low temperatures in winter and altitudes over 500 m. There are four study sites selected with reference to environmental characteristics for optimal chestnut cultivation detail (Fig. 1). Each site has two selected representative producers inner 250 km^2 square radius environment. In this study, eight chestnut producers were selected with purposive criteria (have production records, regular harvesting, and main income). In Figure (1), shown (i) Plateau site, located at 40°20′51.500″ N – 7°36′8.906″ W, (ii) Malcata site, located at 40°14′0.000″ N – 7° 2′0.000″ W, (iii) Estrela site, located at 40°19′18.800″ N – 7°36′46.501″ W, and (iv) Gardunha site, located at 40°7′ 59.722″ N – 7° 25′49.978″ W.

2.1.1. Plateau site characteristics

The location of Plateau study site is located between Mt. Malcata and Mt. Estrela. The site has an altitude of range 700 m–900 m which is a relatively middle-mountain environment compared to the Estrela site and Malcata site. Topography is characterized by granite and shale stone [22]. On this site, most chestnut orchards are aged between 10 and 15 years, it requires more frequent pruning, and approximately 70% with watering needs during summer.

2.1.2. Malcata site characteristics

Malcata site is located between Castelo Branco and Guarda sharing the natural geographical zone with Spain, the site is about 10–20 km away from Spain [22]. The average chestnut orchard is located at an altitude of range 1500 m–1900 m with the majority age being 11–12 years old. This site has adopted intensively cultivated practices to increase productivity through the application of natural and chemical fertilizer, maintenance with suitable machinery, and irrigation equipment.

2.1.3. Estrela site characteristics

It is located about 60 km north of the Castelo Branco and has an altitude of range 1200 m–1400 m [22]. On this site, the chestnut orchard has average early age (<10 years), a non-intensive farming system with minimum use of chemical herbs and fertilizers, without an irrigation system, and manual maintenance.

2.1.4. Gardunha site characteristics

The location of Gardunha study site is located 17 km west of Castelo Branco, the morphology in the area is shallow while the soil texture is from granular soil to silt loam, during summer this area is approximately 65% deficient in water resources [22]. On this site chestnut orchards, range from age over 25 years with minimum maintenance altitude located at 1400 m–1600 m.

2.2. Methods

The consequential modeling approach was performed in the present case study to investigate the environmental impact of chestnut fruit production in the Beira Interior region (Portugal). In order to better investigate, it is important to note the data used to build the life cycle inventory (LCI) in the present study has two group aspects of data. First, the upstream process (fuel, fertilizers, pesticides, machinery), and second, the downstream process (harvesting, postharvest, distribution) has been collected using questionnaires following the system boundaries (Fig. 2). The emission factors for all the operations in the background and foreground system were extracted from AGRIBALYSE v3.0 database perform with openLCA Software [23]. With all origin material were refer to domestic production in Portugal and consumption of resources are allocated to the system outputs. More detail in Table 1 provide a description origin source used on the process of systematic modeling EF with 16 indicators.

2.2.1. System boundaries

The LCA attribute was extracted from real activities chestnut producer based on the "cradle-to-farm gate" approach (orchard to domestic wholesale buyers). The specified functional unit uses 1 ton (1.000 kg) to reflect how much resource consumptions require of production chestnut cycle at different site production. The process systematic point has a flow consisting of input and output, however, in some flow was not available in AGRIBALYSE. In the present study, the process systematically has 7 stages consisting of crop production, cultivation operations, fertilizers, pesticides, machinery, irrigation system, and distribution market.

2.2.2. Inventory analysis

The inventory data was collected from 2019 to 2021, and all relevant production data (inputs raw materials, detailed operational activities, and output) and other factors (age, plant population) involved are identified and calculated. The summarized data present in Table 2 is the mean of values input and output, extracted from surveys and interviews with detail of each operation or sub-operation that followed system boundaries. The output was chestnut fruit and GHG emissions, other environmental impact along the production system to soil and water is also calculated with detail in Table 3. The fuel consumption well be converted as energy and all emissions well be converted to carbon (CO2) following the Intergovernmental Panel on Climate Change (IPCC) guideline [24].

2.2.3. Life cycle impact assessment

All input and activities that could possibly produce emissions on nature must be evaluated from upstream to downstream. Table 3 shows the list and units of impact indicators applied followed by the EF 3.0 method with 16 environment indicators for calculation of potential impacts caused by chestnut producers from cradle to grave.

These 16 indicators are usually used in LCA agriculture system studies with the main focus on climate conditions and toxicity (ecologic). Consist with, Acidification potential as an indicator of acidifying substances deposition on terrestrial and freshwater. Climate change (fossil, biogenic, land use, and transformation) is the value of estimated Global warming potential (GWP) [25]. Ecotoxicity freshwater is the accumulation of potentially toxic emitted from species. Eutrophication freshwater is the phosphorus value that indicates restrained nutrients dissolved in freshwater, while terrestrial is the N index emitted to the terrestrial environment [26]. The human non-cancer effect is measuring the morbidity potential emitted in the human population. Ionising radiation in agriculture is considered as an electricity mix production. Land use is dealing with the effect on ecosystems to support life system functions of biodiversity (biotic production, groundwater, mechanical filtration) [27]. Ozone depletion and photochemical ozone formation are expressing potential destructive gases emitted from orchards. Particular matter and Resource use (fossils, minerals, and metals) is a

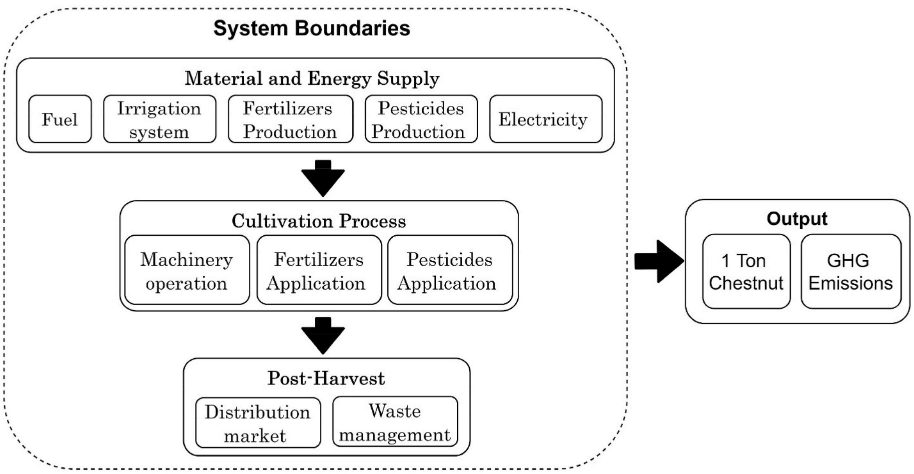

Fig. 2. System boundaries for the life cycle assessment of chestnut production.

Table 1
Detail source process systematic modeling.

Process	Flow input	Type	Source of data
Crop production	Nursery production, Replanting, Landfill emissions, Waste management Transportation	SD	AGRIBALYSE 3.0, 2021
Cultivation operations	Machinery operation (Land used, tillage, pruning, harvest)	SD	AGRIBALYSE 3.0, 2021
	energy (diesel –electricity) consumption on orchards, Waste management, Transportation	SD, LD	AGRIBALYSE 3.0, IPCC Guidelines 2006
Fertilizers	Type of fertilizers used	SD, RD	AGRIBALYSE 3.0, Survey
	Production of fertilizers	SD	AGRIBALYSE 3.0, 2021
	Doses of application	RD	Survey
	Waste management, Transportation	SD	AGRIBALYSE 3.0, 2021
Pesticides	Type of pesticides used	SD	AGRIBALYSE 3.0, 2021
	Production of pesticides doses	RD	Survey
	Waste management, Transportation	SD	AGRIBALYSE 3.0, 2021
Machinery	Production of Machinery	SD	AGRIBALYSE 3.0, 2021
	Waste management	RD, LD	Survey, IPCC Guidelines 2006
	Type of Machinery	SD	AGRIBALYSE 3.0, 2021
	Waste management, Transportation	SD	AGRIBALYSE 3.0, 2021
Irrigation system	Type of irrigation System used (canal, pumping, electricity)	RD	Survey
	Waste management, Transportation	SD	AGRIBALYSE 3.0, 2021
Distribution market	Type of transport	SD, RD	AGRIBALYSE 3.0, Survey
	Waste management	SD, LD	AGRIBALYSE 3.0, 2021 IPCC Guidelines 2006
	Market Distance	RD	Survey
	Waste management, Transportation	SD	AGRIBALYSE 3.0, 2021

Note: (RD: Raw data, SD: specified database, LD: literature data).

Table 2
Inventory of chestnut production per ton.

Descriptions Input	Study area production				Unit
	Estrela	Gardunha	Plateau	Malcata	
Area	2	3	2	1.4	ha
Average Age	7 to 8	over 25	13 to 15	11 to 12	year
populations of tree	312	135	200	193	pcs
Plant Distance	8 × 8	15 × 15	10 × 10	8 × 8	meters
Fertilizer	N (25%) (13.6) Manure (mix) stocked in pit (134)	–	$CaCO_3$ (124) N (17%) (11) P (14%) (30) K (14%) (20) Manure (mix) (36)	$CaCO_3$ (30) N (25%) (15) Organic Compost (189)	kg
Pesticides	Weeding using animals	Glyphosate (5)	–	Copper sulfate (14.3)	
Maintenance	Pruning with the chainsaw (gasoline) (14.3)	Pruning with the chainsaw (gasoline) (13.6) Weeding with Brush cutter (Gasoline) (12.8)	Weeding with Blower and Brush cutter (Gasoline) (9.3)	Pruning with the chainsaw (gasoline) (14.6) Machinery weeding with Tractor with a chisel (Diesel) (16.7)	Liter
Irrigation System	–	–	Water hose's only trees below 10 years (77)	Irrigation system with Diesel motor (187)	
Harvesting	Manual collecting with tractor Diesel transport to warehouse (6.6)	Manual collecting with tractor Diesel transport to warehouse (5.8)	Manual collecting with Van Diesel transport to warehouse (7.3)	Collecting with Tractor and trailer Diesel (7.8)	
Post-Harvest	–				kWh
Average delivery	van diesel (142)	van diesel (96.6)	van diesel (189.8)	van diesel (248)	Km
Output					
Emission CO_2					kg
Fertilizer and pesticides	157.32	6.67	102.5	320.62	
Fuel	40.12	35.96	47.62	66.61	

calculation to estimate abiotic depletion for all non-organic sources [28]. Irrigation water has two directions water scarcity or pollution, in this present LCA study, water use is intended to evaluate quantitative available water remaining (AWARE) by adjusting the system used in orchards.

Table 3
Impact indicators for the evaluation of chestnut production.

Impact	Acronym	Unit
Acidification	AC	g mol H+ eq
Climate change	CC	kg CO_2 eq
Climate change – Biogenic	CH–B	kg CO_2 eq
Climate change – Fossil	CH–F	kg CO_2 eq
Climate change – Land use and LU change	CH-LL	kg CO_2 eq
Ecotoxicity, freshwater	ECF	CTUe
Eutrophication, freshwater	EUF	kg P eq
Eutrophication, terrestrial	EUT	mol N eq
Human toxicity, non-cancer	HNC	CTUh
Ionising radiation	IR	kBq U-235 eq
Land use	LU	Pt/m^2a
Ozone depletion	OD	kg CFC11 eq
Particulate matter	PM	disease inc
Photochemical ozone formation	POF	kg NMVOC eq
Resource use, fossils	RUF	MJ
Resource use, minerals and metals	RUM	kg Sb eq
Water use	WU	m^3 depriv

3. Result and discussion

3.1. Amount of impact categories

From inventory activities present in Table 2, the chestnut production type can be divided into two groups. First, the intensive input is located on Plateau and Malcata. Second, low-input is located on Estrela and Gardunha. Afterward, all production data were analysed on EF indicators. The result presented in Table 4 is the estimated total amount of environmental impact produced. For 1-ton chestnut fruit, in the intensive input group, the Plateau site has produced more amount than the Malcata site over most indicators, while, for the low-input group, the Gardunha site has more amount than the Estrela site. Overall, intensive input emits twice the amount of impact on all aspects, however, in comparison within the group, the different amount of impact is not really significantly produced. This is due to most producers using a similar composition of input material, even with different concentrations it only influences slightly the environmental impact.

In Table 4 two results are highlighted, first impact is climate change indicators were observed to identify field emissions produced that contribute to global warming potential (GWP). In detail, on climate change impact, Estrela site has 1.26 kg CO_2 eq, Gardunha site has 1.35 kg CO_2 eq, Malcata site has 3.81 kg CO_2 eq, and Plateau site has 5.05 kg CO_2 eq. And the second impact is acidification of land and the freshwater impact which is associated with soil nutrient solubility, and plant damage on physiology and vegetation. The present data shows that the Estrela site has 1.21 g mol H^+ eq, Gardunha site has 1.23 g mol H^+ eq, Malcata site has 3.52 g mol H^+ eq, and Plateau site has 4.76 g mol H^+ eq. These impacts could drive to a serious failure since the chestnuts fruit development phase occurs during the summer period (August to September), thus, during this period Mediterranean areas are often with high temperatures and low water availability [29,30].

Furthermore, the results in Table 4, could not justify or describe the process or activities that have critical damage to environmental

Table 4
Environmental impact amount of chestnuts production in different scenarios.

Symbol	Unit	Low-input		Intensive-input	
		Estrela	Gardunha	Malcata	Plateau
AC	g mol H+ eq	1.215	1.237	3.526	4.762
CC	kg CO_2 eq	1.267	1.352	3.817	5.059
CH–B	kg CO_2 eq	6.877	7.162	4.653	7.438
CH–F	kg CO_2 eq	1.266	1.351	3.811	5.050
CH-LL	kg CO_2 eq	5.403	5.637	1.595	2.133
ECF	CTUe	1.920	1.929	5.453	7.383
EUF	kg P eq	3.755	3.824	1.084	1.462
EUT	mol N eq	4.821	4.870	1.389	1.884
HNC	CTUh	2.428	2.522	7.156	9.588
IR	kBq U-235 eq	1.597	1.724	5.405	7.392
LU	Pt/m^2a	3.095	3.103	8.755	1.185
OD	kg CFC11 eq	2.008×10^{-5}	2.193×10^{-5}	6.233×10^{-5}	8.215×10^{-5}
PM	disease inc	6.264	6.744	1.924	2.553
POF	kg NMVOC eq	6.800	6.983	1.991	2.684
RUF	MJ	1.577	1.718	4.951	6.563
RUM	kg Sb eq	7.681	7.913	2.233	2.996
WU	m^3 depriv	2.155	2.156	6.085	8.247

impacts. In regard to cultivation, each producer has a unique scenario such as the type of input material, maintenance activities and machinery tools used. Normally, producers set production scenarios based on farming experience with consideration for environmental characteristics such as topography, soil, and water resources. Hence, in order to elucidate the origin of environmental impact and identify specific production processes, the identified "hotspots" have been changed to provide alternative scenarios. The comparative contribution analysis was performed to understand a more detailed impact contribution aspect analysis in the next chapter.

3.2. Contribution of stage to each impact category

The detail shown in Fig. 3 presents a comparative contribution analysis performed to identify the percentage contribution of each stage onto the impacts amount produced. For the low-input practices group Fig. 3(A), high emissions share produced in the cultivation operational and distribution market ranging from 22.67% to 28.36%, while the intensive input Fig. 3(B) group in fertilizer and machinery ranged from 24.67% to 29.14%.

Noteworthy all emissions produced are strongly associated with chemical compounds release and energy burdens. In more detail, analysis results showed that Fertilizers are the highest contribution responsible for approximately 26% of all scenarios. For chemical fertilizer, this was associated with release (N, NO_x, P) during the mineral manufacturing process [31]. And, manure fertilizer has slower nutrition absorption in soil induces inefficient during application [32,33]. Therefore, an increasing number of manure applications is still possibly slightly availability of soil nutrients, while the energy burden derived from transportation for application fertilizers increases SO_2 emissions. Since, during this present study, manure fertilizer chemical composition was not available in the database comparison with chemical fertilizers was not possible.

Furthermore, the energy burden interpretation of fuel combustion consists of three different phases (cultivation operations, machinery, and distribution market) is the second-highest contributor, in cumulative analysis having a share range of 21%–32% for all impact indicators. In this attribute, the Plateau scenario, result on Fig. 3(B) is indicated as efficient energy utilization showing emissions impact produced relatively lower on all indicators. This advantage is mainly due to the Plateau site scenario topography characteristics allowing optimal orchard management such as plant distance.

3.3. Sensitivity analysis

In order to evaluate and find alternative scenarios with low emission impact output without reducing productivity, a sensitivity analysis was carried out to identify different scenarios for determining the optimal scenario. For this purpose, two different scenarios were taken to be assessed, then the results will be compared with the median scenario in terms of reducing 16 environment impact indicators during the production life-cycle. First is the conservation, in this scenario zero input on fertilizer and pesticides, with minimum cultivation operations similar to [34] study in Italy. And, the second is the renewable energy scenario, in this scenario, energy burden resources are modified into biofuels replacing fossil fuels as proposed by [35].

The sensitivity analysis results in Fig. 4, show that the conservation scenario has the lowest impact on climate change and ozone indicators, however, for applying this scenario producers depended on huge cultivated scale orchards and requires intense watering as nutrient input. This is an extremely adaptive and feasible option in Portugal for typical producers with minimum cost, small-sized orchards <3 ha or 2 ton/year fruit production, and will enable low (79%) photochemical ozone formation impact. Furthermore, the renewable energy scenario shows an average on all EF impact indicators. Thus, in comparison to climate aspect indicators, the renewable energy scenario has a higher impact than both scenarios. Due to the biofuel production system in renewable energy scenario use at a global level production system (e.g., biofuel imported from Germany while processing factory in Asia), this factor significantly increases carbon.

Overall, the optimal mixture of fertilizer manure and chemical applications is the most significant influential scenario for the chestnut production system. The results of the sensitivity analysis showed a mixture of fertilizer application considerably to environmental improvements in 20%–30% of all climate impact categories. Then, the energy resource replacement of fossil fuel with biofuel can mitigate 5%–12% of all ozone impact categories. Also, optimal management is important such as the duration of pruning, and control the amount of fertilizer could obtain high productivity with less environmental impact. These results indicate that a shift in proper material and adjusted production activities in systems can lead to the development of chestnut production sustainability.

3.4. "Hot spots" and suggestions

Based on all results analysis, there are certain alternative scenario suggestions for cutting the environmental impact of the chestnut production system drawn from four site case studies. In the present study, the main hot spots identified were the fertilizers stage index (type, production, doses), and the second is the cultivation operations stage index (land used, tillage, pruning, harvest). Regarding, impacts from fertilizers stage were significantly associated with ineffective mineral consumption, the cutting emission of this stage can be suggested that is (i) performing nutrient plan management by combined application of organic and chemical through adjusting dose follow with morphological stages, (ii) frequently nutrient monitoring (e.g. soil analysis), for the determination of agronomic nutrient necessary, and (iii) reuse all crop residues from orchard activities such as pruning, weeding, and shells for composing fertilizers. Meanwhile, the energy burden as a second hot spot was mostly originated in the cultivation operations stage. Fuel combustion is a more significant influence on ozone indicators. At this stage, it is noteworthy to mention that all sites have different topography characteristics, planting distance, and load weight transported. These are dependent factors to assign a total fuel consumption during

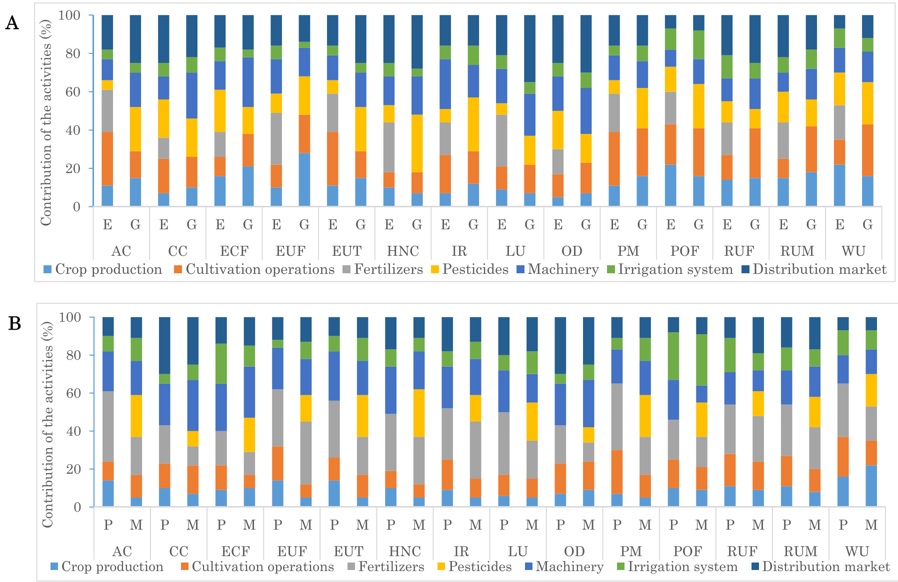

Fig. 3. Comparative contribution of each production process to each impact indicator on different scenario productions (A: Low-Input and B: Intensive-Input) (E: Estrela, G: Gardunha, M: Malcata, P: Plateau).

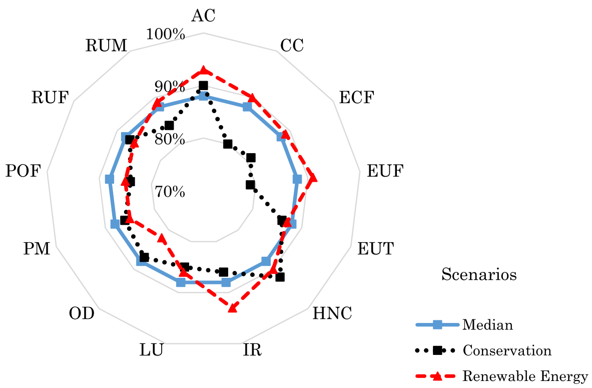

Fig. 4. Sensitivity percentage estimation for each scenario adopted in the chestnut cultivation systems.

the cultivation process. Therefore, to achieve emission reduction we suggest: (i) efficient application scheduling with other maintenance activities, and (ii) regenerate machinery tools and vehicles with high-end technology compatible with biofuel. However, due to the limitation of literature on LCA on chestnut production systems, the comparison present study result with other studies is limited.

4. Conclusion

In inventory analysis, results indicating the producers are more dependable on experience than decision-support tools to compose a production scenario. In specific, the producer still has not yet considered the environmental characteristics as an advantage aspect to compose a more sustainable production scenario. Which is with this aspect is helpful for sorting the activities or unit processes that are required a certain huge amount of resources. It can lead to reducing emissions, efficient use of resources, and minimizing costs with similar output. Through, connected EF methodological framework with AGRIBALYSE database, the present study findings are key environmental impacts of chestnut production system from the study area in the Beira Interior region of Portugal. With approach, combine a comparative contribution analysis and sensitivity analysis with 16 environmental footprint indicators to provide specific hotspot activities information detailed on the chestnut production system. In general, analysis results indicate fertilizer stage and cultivation operations stage had the highest effect on the environmental impact indicators with different exposure directions. The fertilizer stage is toward the climate change index, while cultivation operations are toward the Ozon index. Adaptive recommendations from this study may drive cutting emissions by 15%–20%, and the possibility can be cutting costs as well to improve a sustainable chestnut production system. They can also be applied in similar characteristic environments elsewhere.

Finally, we suggest further studies on perform life-cycle analysis integrating multi-criteria decision making (MCDM) and Material

Flow Analysis (MFA). This suggestion could fill limitation gap of study and may be confirm the potential on economic, social and environmental benefits of best chestnut production scenario.

Declaration of competing interest

The authors declare that we have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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