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Abstract: Considering that peach is a significant fruit in the Mediterranean countries, and most publications on environmental impacts of fruit productions are based on one single productive year, this study attempts to perform an environmental analysis of peach production using Life Cycle Assessment, in order to provide new information on peaches, and also introduce a multiyear perspective analysis to identify the variability of the environmental impacts related to annual orchard yield and weather variations. The system studied is a peach orchard (Prunus persica L.) with integrated agricultural practices. The study analyses the cultivation period, as well as the impact of the initial orchard establishment tasks (soil preparation and planting). Data used have been collected directly from an orchard located in the North East of Spain, and covers 15 years of real production. The functional unit adopted was the cultivation of 1kg of peach. Four scenarios have been considered according to the different yield periods of the peach fruit tree: Growth, Low, High and Multiyear. The results of the study reveals that, depending on production scenario considered, the results per kg of peach can vary between 7% and 69% depending on the environmental indicator. If the impact of initial orchard establishment tasks (soil preparation and planting) is not included in the quantification, then 5% of total emissions may be overlooked, but sometimes a lack of data makes it difficult to include these stages. Caution should be taken when the functional unit is related to mass and only when a single year of production is studied, because unproductive years increase impacts on value per functional unit, whereas over-productive years decrease them. According to variability of the results obtained, multiyear approach should be considered in crops with an average life time of twenty years or higher. The present study can be considered a useful methodological framework for providing a deeper understanding of the key environmental impact issues related to fruit production based on peach case study, and how to avoid multiple interpretation of results associated to reporting annual environmental impact variations.

Highlights

- This work is based on multiyear perspective analysis.
- It includes the impact of the initial orchard establishment tasks.
- It analyses the variability of the environmental impacts related to annual orchard yield.
- Data used were collected directly from a real orchard.

Life Cycle Assessment of multiyear peach production

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Key words: LCA, environmental impacts, integrated fruit production, sustainable farming,

ABSTRACT.

Considering that peach is a significant fruit in the Mediterranean countries, and most publications on environmental impacts of fruit productions are based on one single productive year, this study attempts to perform an environmental analysis of peach production using Life Cycle Assessment, in order to provide new information on peaches, and also introduce a multiyear perspective analysis to identify the variability of the environmental impacts related to annual orchard yield and weather variations. The system studied is a peach orchard (*Prunus persica L.)* with integrated agricultural practices. The study analyses the cultivation period, as well as the impact of the initial orchard establishment tasks (soil preparation and planting). Data used have been collected directly from an orchard located in the North East of Spain, and covers 15 years of real production. The functional unit adopted was the cultivation of 1kg of peach. Four scenarios have been considered according to the different yield periods of the peach fruit tree: *Growth, Low, High and Multiyear*. The results of the study reveals that, depending on production scenario considered, the results per kg of peach can vary between 7% and 69% depending on the environmental indicator. If the impact of initial orchard establishment tasks (soil preparation and planting) is not included in the quantification, then 5% of total emissions may be overlooked, but sometimes a lack of data makes it difficult to include these stages. Caution should be taken when the functional unit is related to mass and only when a single year of production is studied, because unproductive years increase impacts on value per functional unit, whereas over-productive years decrease them. According to variability of the results obtained, multiyear approach should be considered in crops with an average life time of twenty years or higher. The present study can be considered a useful methodological framework for providing a deeper understanding of the key environmental impact issues related to fruit production based on peach case study, and how to avoid multiple interpretation of results associated to reporting annual environmental impact variations.

1. INTRODUCTION

The agricultural sector has changed in Europe over the last ten years, from traditional practices to more intensive methods, in order to increase the productivity of the plantations, and as a response to the growing demand of an increasing population. As a consequence of the increase of intensive methods, food production has become an important contribution to the depletion of natural resources and climate change (Martínez-Blanco et al., 2011[a]). The IPCC Climate Change Synthesis Report 2007 estimates that the direct impacts of agriculture contribute about 13.5% of global anthropogenic GHG emissions. Europe is currently encouraging farmers to practice more sustainable agriculture in order to meet all the needs of society: environmental, social and economic (European Commission 2012). Even so, to promote environmental friendly agricultural production it is essential for farmers to identify the causes of environmental impacts of their production systems.

A few years ago, the main concern in the food industry was safety, but recently it is becoming conscious of the environmental repercussions of their products, and is attempting to open new horizons towards sustainable production. Consumers are also increasingly aware of the environmental performance of the food products they buy, and this is reflected in their purchasing decisions. To develop a proper environmental management for industries and farmers, it is essential to know the main environmental indicators of their products: emissions, energy and water consumption, waste generation, efficiency, etc. It can also give an environmental added value to their product, at the same time that it provides valuable information for consumers (Environdec, 2012).

Table 1 shows a review of some publications about environmental impacts of fruit production. The literature review was carried out from papers in international journals and conference proceedings. The review covered all main aspects for conducting environmental analyses of fruit production systems, giving preference to the agricultural stage. The information was collected from two main approaches: LCA and agricultural aspects. For LCA approach the following items were considered: functional unit (FU), system boundaries, environmental impact assessment method, initial stages consideration, and cultivation period considered. For the agricultural approach, the country of the study, and fruit variety were taken into account.

Most of reviewed studies only consider one productive year, and initial stages of orchard establishment (soil preparation and planting) are not included. The application of environmental assessment methods in the fruit sector is conventionally divided into a field phase and a retail phase (considering a spatial time of one productive year). Although there are important differences in the environmental impacts in the field phase, a major part of the impacts is related to the distribution chain in the retail phase, mainly due to the cooling (Cerutti et al., 2013[a]). Another important aspect to be considered is that some resources are used annually, whilst others are present during the whole lifetime of the orchard (Mila i Canals and Polo, 2003).

<<***Table 1.*** *Environmental fruit studies published in last 10 years.*>>

According Table 1, Life Cycle Assessment (LCA) is one of the most used standardized methodologies (ISO14040) for estimating the environmental burdens linked to fruit production, and it has shown to be an effective mechanism to report environmental performance in the food and beverage sector in general (Vazquez-Rowe et al., 2012). However there are a limited number of fruit crop LCA studies, and they still do not present enough environmental information, the impacts are partially analysed, and the existing studies mainly focus on one productive year, when the life span of fruit crop plantations range from 20 to 60 years. Quantitative environmental assessment methodologies such as LCA require significant time and resource inputs during the data acquisition and life cycle inventory (LCI) phase. Approaches to streamlining the LCI data collection process without degrading data quality are therefore required, and is especially true for agricultural products (Bellon-Maurel et al., 2014).The main reason that may explain this is due to environmental and energy aspects for the development of fruit crops were not taken in account by farmers during the last decades, so there is no available data and the existing information that can be found are not reliable data. In recent times, after the emergence of new private sustainability standards such as: Global Gap, SAGP Guidelines, SAI initiative, etc.) and the growing competitiveness in the private markets, all the actors involved in fruit production showed much interest in environmental impacts that their products generate, and became aware of the need to collect much more reliable data to improve the quality, the availability and the temporality of these, in order to develop environmental studies with a high quality and rigorousness. Nonetheless, in the European context, the EU Framework Programme for Research and Innovation has been developed: Horizon 2020, which encourages companies to develop more sustainable strategies in order to reduce the environmental impact of their companies and the use of resources. For the fruit sector in Mediterranean countries, the peach is an important product. The main producers of peaches in Europe are: Italy, Spain, Greece and France, all together produce 42% of the world production. According to FAO statistics (2011) the largest peach and nectarine producer is Italy with 1,474,337 tonnes, followed by Spain 1,129,300 tonnes, Greece 810,000 and France 313,300. While Italy stands out as the largest producer, Spain is the major exporter, due to its early season harvest, lower production costs, and varietal renewal using higher quality varieties. Greece is the major EU peach processor. Spain is the second peach and nectarine producer in the European Union, and ranks third in the world after China and Italy (European Commission 2012). This study will analyse the region of Catalonia, located in the North East of Spain, and is the region with the second highest peach production in Spain, with a production of 367,887 tonnes/year (t y^{-1}) and a cultivated area of 11,299 ha, which is 35% of the total Spanish peach production, and 26.4% of the total fruit cultivated area (MAGRAMA 2012).

The aim of this work is to calculate the environmental impact of a multiyear peach production system in the North East of Spain, using LCA methodology. Data used in the study have been directly collected from an experimental orchard, and fifteen years of production have been considered. This study is a peach analysis based on a multiyear system experiment, which allows working with a reliable and high-quality experimental dataset and supports to highlight the importance of the multiyear approach in order to reduce variability and underestimated environmental impacts. The results also may be useful to identify the hot spots of peach production in its agriculture stage, and provide new inventory data and results of Mediterranean peach fruit.

2. MATERIALS AND METHODS.

The environmental analysis of multiyear peach production will be performed using LCA methodology according to Standard ISO 14040:2006.

2.1. Life Cycle Assessment

LCA is defined by ISO 14040 as the compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle. The end results are dependent on the systems boundaries and the functional unit (FU), which is the unit to which the results of the LCA are related, and used further for the communication of the LCA results.

The impact categories considered in this study on the performance of LCA are mid-point characterization factors, and the calculation method used is Recipe Midpoint H. In this method, the environmental flows were assigned by multiplying them by the corresponding characterization factor for different impact categories. Calculations were performed using Simapro 7.3.3 software, together with ecoinvent database 3.0.

In order to obtain scientific, verified, and comparable information about the environmental performance of the products, the results will be reported according to product category rules (PCR) procedures that have been developed in accordance with ISO 14025. Given that the scope of the study is fruit, the PCR model chosen will be: Fruits and nuts.

According to Recipe Midpoint (H) characterization method, the following environmental impact indicators were considered in the study:

- Climate Change (CCH) expressed in kg CO2 eq
- Ozone Depletion (ODP) expressed in kg CFC-11eq
- Photochemical oxidant formation(PHO) expressed in kg NMVOC
- Terrestrial Acidification (TAC) expressed in kg SO2 eq
- Freshwater Eutrophication (FEU) expressed in kg P eq
- Marine eutrophication (MEU) expressed in kg N eq
- Agricultural land occupation (ALO) expressed in m2a
- Urban land occupation (ULO) expressed in m2a
- Natural land transformation (NLT) expressed in m2
- Water depletion (WDP) expressed in m3
- Metal depletion (MDP) expressed in kg Feeq
- Fossil depletion (FDP)expressed in kg oil eq
- Ecotoxicity (Etox) expressed in CTUe
- Demand for non-renewable energy resources (NRE) expressed in MJ-eq

The indicators chosen are midpoint indicators. The classification and characterization stages were carried out excluding normalization, in order to avoid subjectivity in the analysis. The quantification of the ecotoxicity (Etox) indicator has been done according the USEtox model using Simapro software. USEtox is a model based on scientific consensus, providing midpoint characterization factors for human and freshwater eco-toxicological impacts of chemicals in life cycle impact assessment, developed under the United Nations Environment Program (UNEP) and the Society for Environmental Toxicology and Chemistry, (SETAC) Life Cycle Initiative (UNEP-SETAC toxicity model, 2008).

2.2 Functional unit.

The choice of system boundaries, the definition of functional unit (FU), and allocation procedures plays an important role in the LCA of food products. The most commonly used functional unit is based on mass, but recently there are more ways of expressing the functional unit for food products, such as energy balance or protein content (Schau et al., 2008), and nutritional value (Martínez Blanco et al., 2011[b]). A mass based functional unit is adequate when only analysing the agricultural stages of the life cycle of fruit for descriptive purposes (Milà i Canals et al., 2006). According to fruit and nuts PCR, and in order to compare the results according to yield variations over the years, a mass based functional unit has been chosen, so the FU was defined as a "cultivation of 1kg of peach. Considering that the function of the orchard is to produce, the fact of using an FU based on a mass unit also allows reflecting seasonal variability. A functional unit based on hectares could hide the variability of results.

2.3 Experimental orchard design.

The demonstrative plantation studied is a peach orchard of *Prunus persica L.* It has an area of 1 hectare and is located in Gimenells (Lleida) in the North East of Spain. According to a USDA soil Survey (1999), the soil texture is loamy, and its physical proprieties are favourable for the root development, with fruit cultivation being possible. The orchard has a planting frame of 4x5m, the plot is designed with 15 rows of 20 trees (300trees/ha). Peach cultivation is done using integrated fruit production according to the European Integrated Farming Framework 2010. Integrated Production is defined as a system of agricultural production of quality food, using methods that respect the environment and human health in order to obtain high quality products, minimize the use of agrochemicals, optimize production methods and reduce waste. The average yield of the orchard is 36,148 kg· ha^{-1} ±10%. Maximum production was achieved in year eight, with 48,350 kg· ha^{-1}, and the minimum was achieved in the second year, with a production of 18,745 kg· ha^{-1}

2.4 System description.

The study only focuses on the cultivation period, but it also includes the initial establishment tasks: soil preparation and plantation. The nursery stage has been excluded, mainly due to the lack of reliable data regarding this phase of peach-growing. According to Vazquez-Rowe et al. 2012, given the longevity of the crops, and the small percentage of annual tree replacement, its exclusion should not significantly affect the final results. The agricultural stages considered in this study are: soil preparation and plantation, fertilization, irrigation, pest management, weeds mowing, pruning, and harvest. Post-harvest operations (storage, processing, packaging, and commercialization) are not included. Figure 1 shows the boundaries of the system studied. Different management tasks are involved depending on the agricultural stage. Soil preparation and plantation tasks were performed mechanically with tractors (these tasks are only done once, at the beginning of the orchard when trees are planted). Agrochemicals were applied using a tractor and a sprayer. Fertilizers were applied through the irrigation system with electric pumps (fertigation). Pruning was done manually, and the wood was crushed with a tractor implement and incorporated into the soil (it is considered as a soil structuring effect). The emissions related to pruning waste degradation have not been considered. It has been assumed that biogenic carbon emitted, as well as the biogenic carbon fixed from the biomass of the tree or the peach, was not taken into account as a potential global warming indicator according to the ISO14067/ PAS2050-1. For this case study, the information about the effect of the pruning waste has on the soil was not available, however it is an interesting effect that will be considered for further research. Weed mowing was done with a tractor implement. Harvesting was done manually, but required a self-driven platform and a tractor to transport the fruit to the storehouse. Considering the characteristics of the system studied and all the tasks involved, the following inputs have been taken into account to make the inventory: production of fertilizers and their application to the field, pest management substances manufacture and their application (fungicides and insecticides), machinery manufacture and implements used with their transport to the orchard, water use, energy use (from irrigation pumps and inputs manufacturing).

*<<**Figure 1.** System boundaries. >>*

2.5 Inventory.

Experimental data have been directly obtained from the Catalan Research Institute of Food and Agriculture Technology (IRTA) orchards. The data used to make the inventory cover 15 years of real production. Table 2 shows the inventory considered in the study, according to the FU described in Section 2.2 and also in Figure 1. As the FU chosen is related to the kg of fruit produced, four different production scenarios have been considered related to the different production periods of the fruit tree: *Growth, Low, High and Multiyear*, in order to analyse the variation of environmental results according to the orchard yield, all four scenarios are based on real data. The *Growth* scenario covers between years 1 and 3, when the orchard starts to produce fruit but has not yet reached full production. *Low* scenario covers when the fruit tree starts to go into full production between years 4 and 5. *High* scenario is when the orchard reaches the maximum fruit yield, around year 7. *Multiyear* scenario is the average of 15 years production.

The production considered for the Growth scenario is 18,745 kg ha-1, for Low it is 31,625 kg ha^{-1}, for High is 48,350 kg ha^{-1}, and the production considered for Multiyear is 36,280 kg ha^{-1}. The production ranges chosen are in line with the fruit growing study reported by Iglesias (2013). These scenarios are proposed to quantify the variability of LCA indicators depending on the consideration of a single year (productive or not) or a multiyear approach.

*<< **Table 2.** Inventory for FU and selected production scenarios (FU=1kg of peach). >>*

2.5.1. Data assumptions.

Some assumptions have been made in order to optimize the calculation and the application of the methodologies:

- Change Land Use: It was assumed that the land occupied is arable and that it had been used for agriculture for a long time. Therefore, no impacts caused by land transformation were taken into account as the plot has been an orchard for more than 25 years (ISO14067).

- Agrochemicals substances (insecticides and fungicides). The active ingredients of the pesticides used have been taken into account. Individual pesticide production data were not available, thus the generic pesticide process from ecoinvent database v3.0 has been chosen (ecoinvent Centre).

- Machinery: Experimental data of the number of machinery operations and the working hours for running the machines and their implements have been used to quantify the amount of machinery input per kg of fruit. Emissions of machinery production and diesel consumed for machinery operations have also been taken from ecoinvent database v.3.0 (Ecoinvent Centre).

- Electricity:

The electricity consumed for irrigation pumps was known, and the impact of generation and distribution of electricity demand was estimated using information from ecoinvent database v3.0, according to the Spanish electricity mix of low voltage (ecoinvent Centre).

- Irrigation water: The orchard studied was irrigated with electric pumps, and the water came from a Catalan public irrigation canal (Catalonia-Aragon).

- Fertilizer emissions: It has been considered the emissions of fertilizer production and the emissions of fertilizers used have been taken into account. Nitrogen (N_2O), phosphorus (P_2O_5) and potassium (K_2O) emissions were modelled according to the literature (Bentrup 2001; Audsley 1997). As regards diffuse emissions, according Audsley (1997), it was assumed as 2% of NH_3 volatilization for simple nutrient fertilizer (ammonium nitrate), and 4% for multinutrient fertilizer (NPK). NO_x emissions were assumed as 10% of the N_2O emissions. The N_2O emission factor assumed for all fertilizers is 1.25% of N addition (Bentrup, 2001).

- Transport of input materials and substances to the orchard: It was assumed that the vehicle used to transport the materials and substances from the production plant to the local point of sale was a 7.5 t lorry, and the distance covered was 150km. The vehicle considered to deliver the materials from the regional cooperative to the plantation was a small van<3.5t and the distance, 15km.

- Carbon sequestration: there is a lack of knowledge on specific topics, and in particular a lack of inventories to estimate carbon sequestration (Alaphilipe et al., 2012)**.** No specific land and biomass carbon sequestrations were taken into account in this work, as the soil carbon content remained constant during the years of the study, and there was no change in the use of the land. Biogenic carbon has not been considered as either kidnapped or as issued, because is for temporary short chain.

3. RESULTS AND DISCUSSION.

The results obtained are based on the FU (production of 1kilogram of peach) and according to the impact indicators defined in Section 2.1. Results and discussion are organized into three sections: 3.1 LCA results, 3.2 Agricultural stages impact contribution, 3.3 Annual evolution of impacts

3.1 LCA results

Figure 2 shows relative percentage values of all impact categories analysed according to scenarios considered. Large differences between 30-50% were identified in the environmental impact values depending on the production scenario (Growth, Low, High and Multiyear). *High* scenario presents the lowest impact in relative percentage in all impact categories, because the maximum yield is achieved in this scenario, thus the amount kg of peach produced is higher than other scenarios (48,350 $kg.ha^{-1}$), so the impact associated per kg of fruit becomes lower. *Growth* scenario has the highest relative percentage in all impact categories, as the kg of fruit produced is very low (18,745 $kg.ha^{-1}$), thus the impact associated per kg of fruit produced becomes the highest.

<< ***Figure 2.*** *Relative impact values per FU depending on the production scenarios considered.* >>

3.2 Agricultural stages impact contribution

Table 3 shows the results of total impact values and agricultural stages contribution expressed in % for each impact category studied, and according to the production scenario (*Growth, Low, High and Multiyear*). Depending on the scenario considered, the percentage contribution of each impact category can vary between 7%-69%. Impact values per FU for all agricultural stages studied become higher if they are calculated according to *Growth* and *Low* scenarios because the kg of peach produced in this scenario are lower. In the impact categories required in Fruit and nuts PCR a range of variance can be observed in the results: NRE 8-52%, GWP 11-50%, WDP 14-52% and Etox 12-69%.

Of the all agricultural stages considered in the study, fertigation is the stage that presents the highest contribution percentage in 10 of the 14 impact categories studied for all scenarios, with a maximum contribution of 99.93% in WDP category (Growth scenario) and a minimum contribution of 45.66% in FDP category (Multiyear scenario). Pest management presents the highest contribution in the 4 remaining impact categories, with a maximum of 64.50% in Etox (Growth scenario) and a minimum of 47.22% in ODP. Fertilizer dosages are calculated according to the requirements of the fruit tree, and the maximum potential yield expected for each year according to the variation in annual conditions (age of the orchard, soil analysis results and climatic conditions); thus, every year a maxim value of fertilizers dosage is defined for the orchard, because once the maximum dose is exceeded it does not guarantee higher yield.

If the soil preparation and planting stages are not included in the calculation, then the 5% of total emissions can be overlooked, considering that the life span of peach plantation of 15 years. However they are distributed over the fifteen years of production (these tasks are only done once, at the beginning of the orchard when trees are planted). Cerutti (2013[a]) reported that orchards are perennial and biological systems, and these two characteristics add complexity to the modelling of fruit systems. But if the productive period alone is considered, the environmental impacts of the final product are underestimated considerably. The longer the life span of the peach crop plantation, the lower is the contribution of initial agricultural stages such as soil preparation and planting. Milà I Canals (2006) stress that it is important to consider the nursery in environmental impact assessments, but a lack of data makes this difficult. According to Cerutti (2013[a]), the nursery where orchard seedlings are produced should be considered an upstream process delivering grafted plants to the orchards, and the impact during this stage should be included in assessments of fruit production systems, even if impacts are spread over the lifetime of the orchard. This has not been included in this study due to the lack of available experimental information.

Results obtained were compared with other publications of fruit production with similar agricultural stages and life span such as: apple, orange and peach production. The impact percentage contribution of the agricultural stages considered in the study are consistent with the results described for other fruit studies described I Table 1 such as Sanjuán (2005), Coltro (2009), Clasadonte (2010[a,b]) and Alaphilipe (2012). It should be mentioned that the aforementioned publications only considered productive periods for one year. The existing studies for peach fruit are related to Eco indicators, so it has not been possible to validate and compare the total impact values obtained in this study because there are no existing peach studies focused on mid-point characterization factors.

Once the environmental impact of the different agricultural stages is evaluated, and taking into consideration that fertigation is the stage that presents the highest contribution percentage in 10 of the 14 impact categories studied for all scenarios (this is because manufacturing of fertilizers have a significant impact), it would be interesting for farmers to try and choose another kind of fertilizer with low environmental impact and encourage them to try to adjust the application dose, with better the monitoring of nutrients contents in soil and crop. Other important recommendations for farmers, in order to promote orchard better environmental performance are: the orchard design (trees orientation, planting frame, irrigation system) and geographic location, in order to reduce water consumption and pesticides use.

*<<**Table 3.** Total and relative percentage impact values per FU depending on the production scenarios considered in this study.>>*

3.3 Annual evolution of impacts

This section describes the annual evolution of the impact categories recommended for Fruit and Nuts PCR: a) Non-renewable resources, b) Global warming potential, c) Water depletion, and d) Ecotoxicity during the 15 years of life span of peach orchard.

From year 1 to year 4 orchard is not very productive because the fruit tree is getting stabilized, from year 5 it starts to come into full production. Between years 6 to 12 it reaches the stable production. From year 13 to 15 the orchard begins to lose efficiency until year15 when it ceases to be productive and acquires the finest of its useful life. Note that in the first year (year 1) there is no fruit production, so results are discussed from second year; maximum production was achieved in the year 8 with 48,350 kg· ha^{-1} and the minimum was achieved in the year 2, with 18,745 kg· ha^{-1}. Note that annual yield variability not only depends on the orchard age, it also depends on the meteorological conditions, so the fact of considering a range of years allows these variables to be reflected on the yield. The climatic conditions are an important fact to be considered in agricultural practices when annual variation is studied, because weather has an effect on many aspects of fruit production such as: yield, water requirements, pest management and weed mowing. Thus, it is important to have meteorological inventory with local data evolution, in order to evaluate the multiyear approach. The fact of studying 15 years of real production, means that the variability of the climatic conditions are more reflected in the results than if we only had studied a single year of production. Note that the yield variations not only depend on the orchard age, it also strongly depends on other variables, such as fruit variety, geographic location, planting frame, climatic conditions, irrigation system, fertilizer supply and pest control optimization. Therefore, it is important to have data related to these other variables and for as long a period of time as possible to as to reflect them in the results.

a) Non-renewable energy resources (NRE)

Figure 3a represents the $MJ.ha^{-1}$ consumed for the inputs considered during 15 years. It can also can be observed The evolution of MJ per kg of peach per year (dashed line) can also be observed in the Graph. As regards the MJ required to produce 1 kg of peach, it can be observed that during the second year the value is very high around 4 $MJ\cdot kg^{-1}$, but from the second year onwards fruit yield per hectare begins to increase, then the MJ. kg^{-1} decreases, reaching a minimum value in year 8 of around 1.8 $MJ\cdot kg^{-1}$ (in this year the maximum yield is achieved). Concerning the values of the $MJ.ha^{-1}$ for inputs considered, it can be observed that they are inversely proportional to the kg produced. Fertilizers are the input with the highest contribution in this category during the fifteen years considered, due to the energy needed for their manufacturing. In the second year the $MJ.ha^{-1}$ has a minimum of 3.8 E+04 $MJ.ha^{-1}$, as fruit trees are not very productive low fertilization is needed, just the dose to promote the correct development of the crop but no the fruit. On the other hand during years 8-10 the maximum yield is achieved, so more fertilization is needed to promote fruit development, in consequence the $MJ.ha^{-1}$ consumed has a maximum value 6.5 E+04 $MJ.ha^{-1}$. Between years 10 to 12 the $MJ.ha^{-1}$ tends to stabilize because as the kg produced becomes stable so fertilizers dose also becomes stable. In years 14 and 15 the $MJ.ha^{-1}$ consumed decreases, because the orchard starts to become unproductive, so less agricultural tasks are invested due to fruit yield decrease.

b) Climate change (CCH)

Figure 3b quantifies the emissions in terms of kg $CO_{2eq.}ha^{-1}$ for the inputs considered during 15 years, and also illustrates the evolution of the kg CO_{2eq} per kg of peach and year. Regarding to the kg CO_{2eq} emitted to produce 1 kg of peach it can be observed that during the second year the maximum value is achieved 0.37 kg $CO_{2eq}\cdot kg^{-1}$, but from the second year onwards fruit yield begins to increase, then the $kgCO_{2eq}\cdot kg^{-1}$ decreases getting the minimum value in year 8 around 0.16 $kgCO_{2eq}\cdot kg^{-1}$. When fruit yield begins to be constant then kg CO_{2eq} per kg of peach value decreases and then tends to stabilize (0.15-0.20 $kgCO_{2eq}\cdot kg^{-1}$). About the values of kg $CO_{2eq.}ha^{-1}$, once more fertilizers are the input with the highest contribution for the fifteen years considered, due mainly to the high emissions related to their manufacturing process. The maxim value is achieved in year 8 with 6E+03 kg $CO_{2eq.}ha^{-1}$. This year is when more fertilization is needed to promote fruit development, and more machinery hours and more diesel consumption is required to collect the kg of fruit produced; and on the contrary the minimum is in year 2 with 3.5E+03 kg CO_{2eq}.ha^{-1} when less fertilization, machinery and diesel are involved.

c) Water Depletion (WDP)

Figure 3c represents the $m^3.ha^{-1}$ consumed for the inputs considered during 15 years, and the m^3 per kg of peach and year. It can be observed that the maximum m^3consumed to produce 1 kg of peach is in the second year, 0.5 kg CO_{2eq} ·kg^{-1}, then as fruit yield begins to increase, the $m^3.kg^1$ decreases, reaching the minimum value in year 8 of around 0.2 kgCO_{2eq}·kg^{-1}. As regards the inputs considered, in this category, water has the highest contribution during the fifteen years, due to the amount of water needed for the irrigation. The minimum value of $m^3.ha^{-1}$ is achieved in the second year with 1.6E+03 $m^3.ha^{-1}$ and this is also the year when low irrigation is required because tree requirements are lower due to it not being a full productive year. The maximum value is achieved in year 8 with 1.8E+04 $m^3.ha^{-1}$, as this is the year when high irrigation is needed to help to promote fruit progress. Between years 6-13 the quantification of $m^3.ha^{-1}$ tends to be stable because the yield is stable, and as agricultural management tasks are constant, it starts to decrease at years 14-15, when the yield and water requirements become lower.

d) Ecotoxicity (Ecotox)

Figure 3d represents ecotoxicity impact in $CTUe.ha^{-1}$ for the inputs considered for 15 years, and also $CTUe.kg^{-1}$ per kg of peach and year. In this category, once more, the maximum impact to produce 1 kg of peach is in achieved in the second year, $1.E^{+04}$ CTUe ·kg^{-1}, and reaches a minimum value in year 8, $4.E^{+03}$ CTUe ·kg^{-1}. As regards the inputs considered in the values of $CTUe.ha^{-1}$, diesel consumption has the highest contribution during the fifteen years, due mainly to the high ecotoxicity of some of its chemical components. The maxim value of $CTUe.ha^{-1}$ is achieved in year 8 with 1.2E+08 $CTUe.ha^{-1}$. In this year more machinery hours and more diesel consumption are required to collect the kg of fruit produced, and on the contrary the minimum is in year 2 with 1E+08 $CTUe.ha^{-1}$ when less machinery and diesel are required because fruit yield is very low. During the intermediate years the quantification of $CTUe.ha^{-1}$ tends to be stable, and it starts to decrease at years 14-15 when the yield decreases.

*<<**Figure 3.** Evolution PCR impact values per FU over the years.>*

4. CONCLUSIONS

The results of the study reveal that when the FU is related to mass units, using different production scenarios can generate a variation in the environmental impact results of between 7% and 69%, depending on the impact indicator. Therefore, caution should be taken when the FU is related to mass and only a single year is studied, because in the years that the yield is low the impact values per FU increase. On the contrary, in the years that the yield is high, the impact values per FU decrease; thus, depending on the year chosen for the fruit studies, the results can be biased. Geographic location of fruit orchards is also an important aspect to be considered in the data collection phase, because in temperate areas orchards reach maturity as early as two years after the plantation, and reach full production from the fifth year, which can significantly affect yield average, depending on the amount of years taken into account. Yield variability not only depends on the orchard age, it also strongly depends on other variables such as fruit variety, geographic location, planting frame, climatic conditions, irrigation system, fertilizers supply and pest control optimization. So it is important, when the UF is related to yield, to have data related to other variables and for many periods of time as possible, to reflect these variables in the results. According to the results obtained in this study in crops with an average life time of twenty years or longer, a multiyear approach is strongly recommended when the functional unit is related to kg produced.

In agricultural stages contribution, fertigation has the highest contribution in all impact categories studied, followed by pest management. This is because manufacturing of fertilizers and pesticides have a significant impact. Weed mowing, pruning and harvest impacts are mainly due to the use of machinery, and their involvement in the cultivation process is more sporadic than fertigation. As regards initial orchard establishment tasks (soil preparation and planting), if they are not included in the impacts quantification, 5% of total emissions may be overlooked. Sometimes a lack of data makes it difficult to inventory and include these stages. On the other hand, it is essential to encourage the farmers to try to choose another kind of fertilizer with low environmental impact, and encourage them to try to regulate the application dose, and improve the monitoring of nutrients contents in soil and crop. They should also consider the orchard design and its geographic location to promote a better orchard environmental performance.

This study contributes to complete the fruit LCA literature and provides new information for peach analysis, as well as introducing a multiyear perspective analysis to identify the variability of results related to annual yield conditionings and climatic conditions. The results may be useful to identify the hot spots of peach production, in order to identify the stages with higher impact and obtaining more environmentally friendly fruit practices. The study also provides new inventory data and results on the Mediterranean peach fruit. This work also provides an additional methodological perspective. Although LCA is a useful tool for estimating the impact associated with a product or process, there are still some issues to be resolved regarding to the quality of environmental impact databases and data available because sometimes, due the need to work with generic data, as in the case of pesticides or fertilizers, it may vary the results.

To complete this study, systems boundaries will be further extended to embrace the whole life of peach production, from plant production and plantation to final consumer disposal, in order to estimate the overall impact.

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Table

Table 1. *Environmental fruit studies published in last 10 years.*

Fruit	Country	Tool	Method	Boundaries	FU	Cultivation Period	Initial stages	References.
				EUROPE				
Apple	Switzerland	LCA	SALCA v.31	Production	ha, $	4 years	No	Mouron et al. 2006
Apple	France	LCA	CML EDIP97 IPCC 2007	Production	ha	1 year	No	Alaphilipe et al. 2012
Apple	Italy	LCA	EDIP	Production	kg	1 year	yes	Cerutti et al. 2013[b]
Apple	Italy	LCA	CML01	Production & supply chain	kg	1 year	yes	Assomela 2012
Kiwi	Greece	LCA	CML01	Production & supply chain	kg	1 year	yes	Zeus 2012
Citrus (products)	Italy	LCA	IPCC GWP100 CML01	Production & processing	kg	1 year	No	Beccali et al. 2010
Orange	Spain	LCA	CML	Production	t	1 year	No	Sanjuán et al. 2005
Orange	Italy	LCA	Impact 2002+	Production & processing	kg	1 year	No	Clasadonte et al. 2010[b]
Peach	Italy	LCA	Impact 2002+	Production & processing	kg	1 year	No	Clasadonte et al. 2010[a]
Nectarine	Italy	EF	Eco indicator 99	Production	gha t^{-1}	1 year	No	Cerutti et al. 2010
Strawberry	Uk, Spain	Literature	IPCC 2007	Production & processing	kg	1 year	No	Williams et al. 2008
				OTHER COUNTRIES				
Apple	New Zeeland	LCA	EDIP97	Production & processing	t	2 years	yes	Milà Canals et al. 2006
Apple	Brazil, Uk	LCA	CML01 Baseline 2000	supply chain	t	1 year	yes	Sim et al. 2007
Cacao	Ghana	LCA	CML01	Production & processing	kg	1 year	No	Ntiamoah et al. 2008
Pear	China	LCA	IPCC 2007	Production & processing	t	1 year	No	Liu et al. 2010
Orange	Brazil	LCA	EMS4 PIRA	Production & processing	kg	1 year	No	Coltro et al. 2009
Pineapple	Costa-Rica	LCA	PAS,2050 USEtox TRACI	Production & processing	kg	1 year	No	Ingwersen 2012
kiwi	New Zeland	CF	PAS 2050	Production & supply chain	kg	6 years	yes	Mc. Laren el al 2010

Table 2. Inventory for FU and selected production scenarios (FU=1kg of peach).

Production scenarios		**Growth**	**Low prod**	**High prod**	**Multiyear***
INPUTS					
From the technosphere					
Energy inputs	Units				
Diesel	g	8.49	6.11	4.48	6.04
Electricity	kwh	0.06	0.04	0.03	0.04
Transport	tkm	1.2	1.24	1.31	1.28
Materials inputs					
Fertilizers:					
K_2O	g	4.91	3.64	2.38	3.10
N_2O	g	4.96	3.68	2.40	3.14
P_2O5	g	0.67	0.51	0.33	0.43
Agrochemicals:					
fungicides (generic)	g	2.25	1.33	0.87	1.18
insecticides (generic)	g	0.56	0.33	0.22	0.30
Machinery:					0
Use	g	0.76	0.55	0.40	0.54
Accessories	g	0.05	0.04	0.04	0.05
Water	l	347.43	253.36	165.72	216.93
OUTPUTS					
To the technosphere					
Peach	kg	18,745	31,625	48,350	36,280
Emissions to the atmosphere					
Diesel:					
CO_2	g	25.95	18.67	13.71	18.47
SO_2	mg	4.98	6.04	4.44	5.98
VOC	mg	18.46	28.72	21.08	28.41
NOX	mg	169.28	268.67	197.23	265.79
NH_3	mg	0.07	0.12	0.09	0.12
CH_4	mg	0.42	0.77	0.57	0.76
N_2O	mg	0.41	0.72	0.53	0.71
Fertilizers:					
N_2O	mg	6.04E-03	4.48E-03	1.32E-04	5.20E-03
NH_3	mg	1.27E-02	9.41E-03	9.41E-03	1.09E-02

*Average production

Table 3. Total and relative percentage impact values per FU depending on the production scenarios considered in this study.

Impact category		Soil prep	Planting	Fertigation	Pest m.	Pruning	Moving	Harvest	TOTAL
Units		% total	% total	% total	% total	% total	% total	% total	
Growth									
kg CO2 eq	CCH	0.42	0.58	70.22	21.66	0.86	1.71	4.54	2.50E-01
kg CFC-11 eq	ODP	0.46	0.57	43.89	47.22	0.95	1.89	5.02	2.81E-08
kg NMVOC	PHO	1.91	2.27	0.00	64.47	3.78	7.55	20.02	3.44E+04
kg SO2 eq	TAC	0.52	0.65	67.14	23.10	1.04	2.07	5.49	1.64E-03
kg P eq	FEU	0.15	0.23	66.06	30.48	0.37	0.74	1.97	5.65E-05
kg N eq	MEU	0.44	0.53	40.33	51.45	0.87	1.75	4.63	1.12E-04
m2a	ALO	0.12	0.20	79.31	17.71	0.32	0.64	1.70	2.33E-03
m2a	ULO	0.04	0.05	96.12	3.05	0.09	0.18	0.47	5.45E-03
m2	NLT	0.73	0.89	56.47	29.68	1.47	2.95	7.81	6.87E-05
m3	WDP	0.00	0.00	99.93	0.06	0.00	0.00	0.01	3.21E-01
kg Fe eq	MDP	0.34	0.60	61.84	29.30	0.96	1.90	5.06	1.52E-02
kg oil eq	FDP	0.71	1.16	48.64	37.39	1.46	2.92	7.73	5.21E-02
CTUe	Etox	2.42	0.94	0.00	64.50	3.77	7.55	20.00	5.98E+03
MJ	NRE	0.86	1.76	55.94	30.58	1.41	2.81	7.46	2.38E+00
Low									
kg CO2 eq	CCH	0.34	0.47	70.74	20.23	0.70	1.39	6.15	1.83E-01
kg CFC-11 eq	ODP	0.37	0.46	39.81	50.39	0.76	1.48	6.73	2.08E-08
kg NMVOC	PHO	1.68	2.00	0.00	56.75	3.33	6.65	29.60	2.31E+04
kg SO2 eq	TAC	0.42	0.53	68.16	20.85	0.85	1.68	7.51	1.19E-03
kg P eq	FEU	0.11	0.18	64.37	31.97	0.29	0.58	2.49	4.28E-05
kg N eq	MEU	0.33	0.41	38.20	53.17	0.66	1.33	5.90	8.75E-05
m2a	ALO	0.10	0.16	77.97	18.80	0.26	0.51	2.20	1.72E-03
m2a	ULO	0.03	0.04	96.03	3.06	0.07	0.14	0.62	3.98E-03
m2	NLT	0.61	0.73	57.81	26.39	1.22	2.39	10.85	4.91E-05
m3	WDP	0.00	0.00	99.93	0.06	0.00	0.00	0.01	2.34E-01
kg Fe eq	MDP	0.27	0.48	61.48	29.16	0.77	1.52	6.31	1.12E-02
kg oil eq	FDP	0.58	0.95	49.11	35.29	1.19	2.33	10.54	3.78E-02
CTUe	Etox	1.96	1.43	0.00	52.44	3.07	6.13	34.97	4.36E+03
MJ	NRE	0.69	0.75	55.48	29.75	1.13	2.21	9.98	1.76E+00
High									
kg CO2 eq	CCH	0.32	0.45	67.87	21.60	0.75	1.41	7.60	1.25E-01
kg CFC-11 eq	ODP	0.33	0.40	35.19	54.42	0.67	1.34	7.65	1.42E-08
kg NMVOC	PHO	1.56	1.84	0.00	52.39	3.07	6.14	35.00	1.07E+04
kg SO2 eq	TAC	0.41	0.51	65.64	21.70	0.82	1.63	9.29	7.32E-04
kg P eq	FEU	0.11	0.17	59.83	36.01	0.27	0.54	3.08	2.92E-05
kg N eq	MEU	0.29	0.36	33.44	57.53	0.58	1.16	6.63	6.11E-05
m2a	ALO	0.09	0.15	74.47	21.74	0.25	0.49	2.80	1.14E-03
m2a	ULO	0.03	0.04	95.37	3.54	0.07	0.14	0.81	2.60E-03
m2	NLT	0.58	0.70	55.23	26.67	1.17	2.34	13.32	2.91E-05
m3	WDP	0.00	0.00	99.91	0.07	0.00	0.00	0.01	1.53E-01
kg Fe eq	MDP	0.25	0.45	57.22	31.81	0.72	1.42	8.13	7.24E-03
kg oil eq	FDP	0.54	0.89	45.82	36.74	1.11	2.22	12.68	2.31E-02

CTUe	Etox	1.96	1.43	0.00	52.45	3.07	6.13	34.96	1.86E+03
MJ	NRE	0.65	0.70	51.64	31.84	1.06	2.12	11.99	1.09E+00
Multiyear									
kg CO2 eq	CCH	0.36	0.50	68.09	21.73	0.80	1.53	6.98	1.62E-01
kg CFC-11 eq	ODP	0.36	0.36	36.38	53.57	0.74	1.48	7.02	2.00E-08
kg NMVOC	PHO	1.69	1.69	0.00	54.60	3.34	6.68	31.69	2.16E+04
kg SO2 eq	TAC	0.45	0.45	65.48	22.30	0.90	1.79	8.51	1.05E-03
kg P eq	FEU	0.12	0.12	60.58	35.39	0.30	0.60	2.83	3.90E-05
kg N eq	MEU	0.33	0.33	34.17	56.91	0.66	1.31	6.22	8.32E-05
m2a	ALO	0.10	0.10	75.08	21.28	0.27	0.54	2.56	1.54E-03
m2a	ULO	0.04	0.04	95.42	3.53	0.08	0.15	0.73	3.44E-03
m2	NLT	0.63	0.63	54.68	28.16	1.26	2.52	11.99	4.46E-05
m3	WDP	0.00	0.00	99.92	0.07	0.00	0.00	0.01	2.01E-01
kg Fe eq	MDP	0.28	0.28	57.69	31.75	0.79	1.57	7.42	1.03E-02
kg oil eq	FDP	0.59	0.59	45.66	37.67	1.21	2.42	11.49	3.49E-02
CTUe	Etox	2.09	1.52	0.00	55.09	3.26	6.52	31.51	3.85E+03
MJ	NRE	0.71	0.71	51.44	32.49	1.23	2.48	10.90	1.62E+00

Figure 1. System boundaries for the production of 1 kg of peach

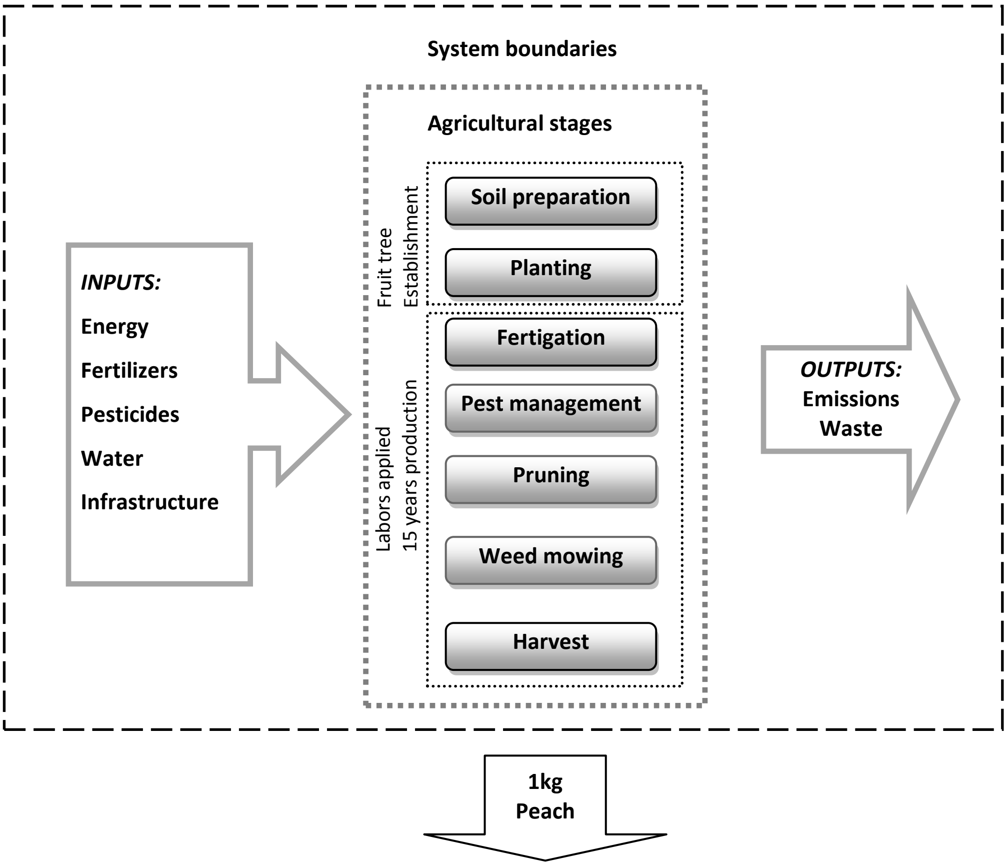
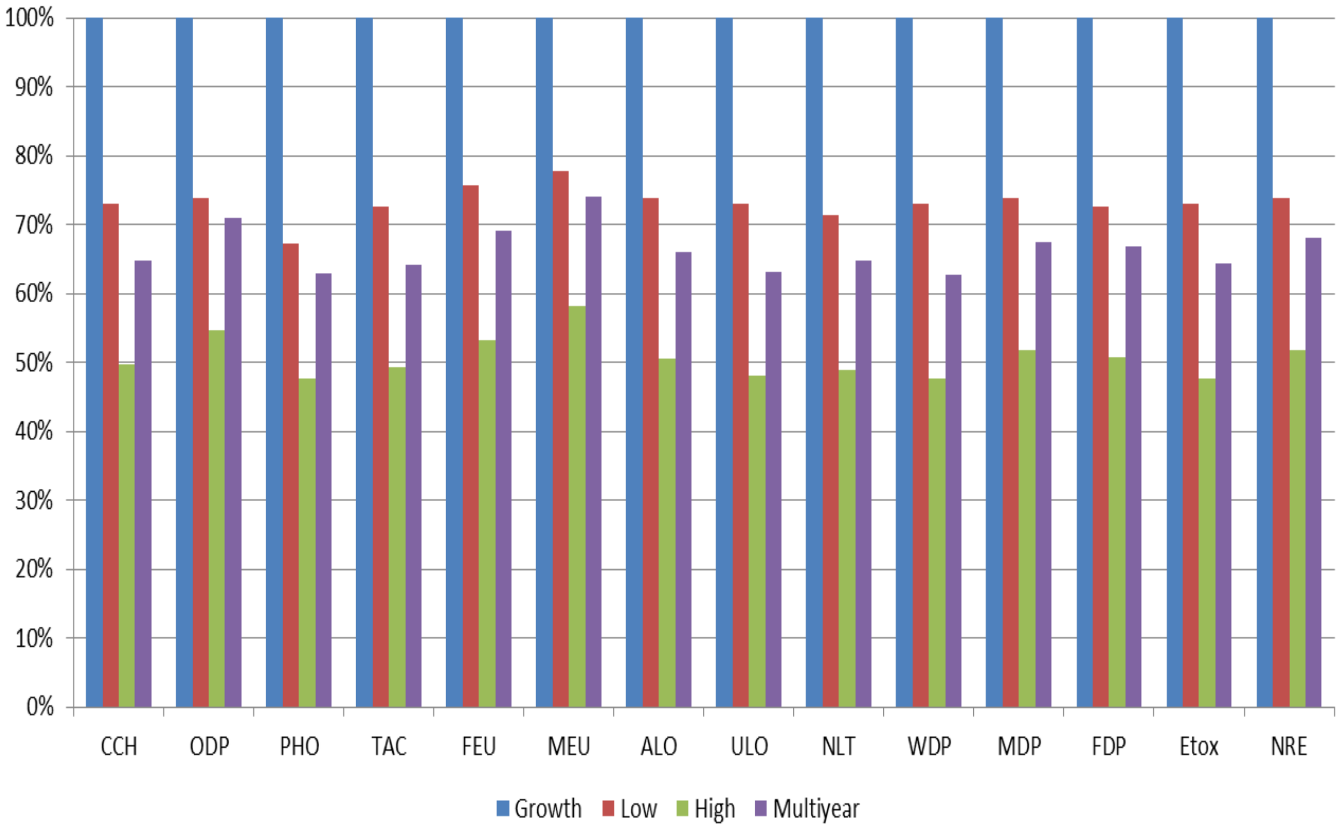


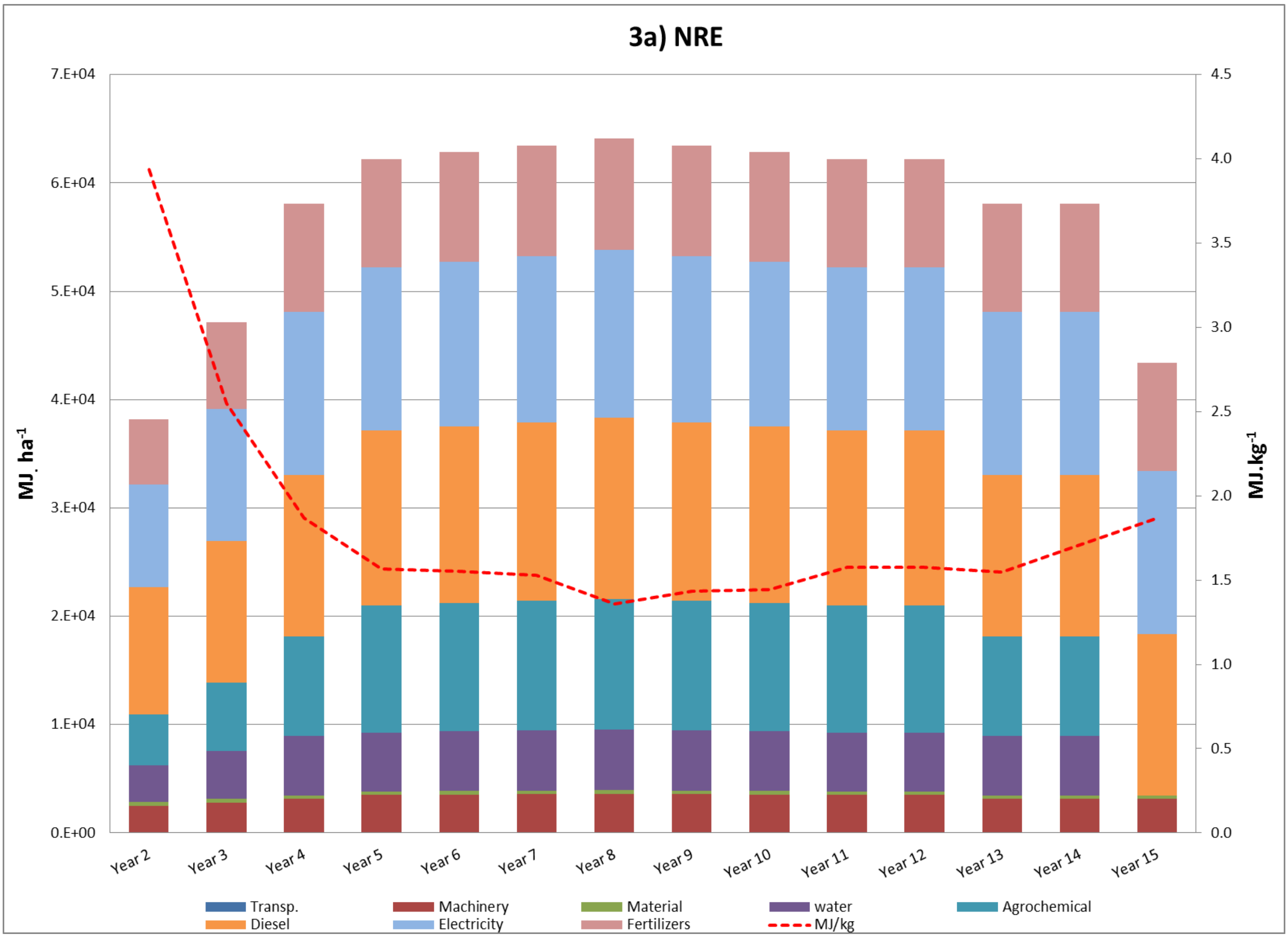
Figure 2. Relative impact values per FU depending on the production scenarios considered



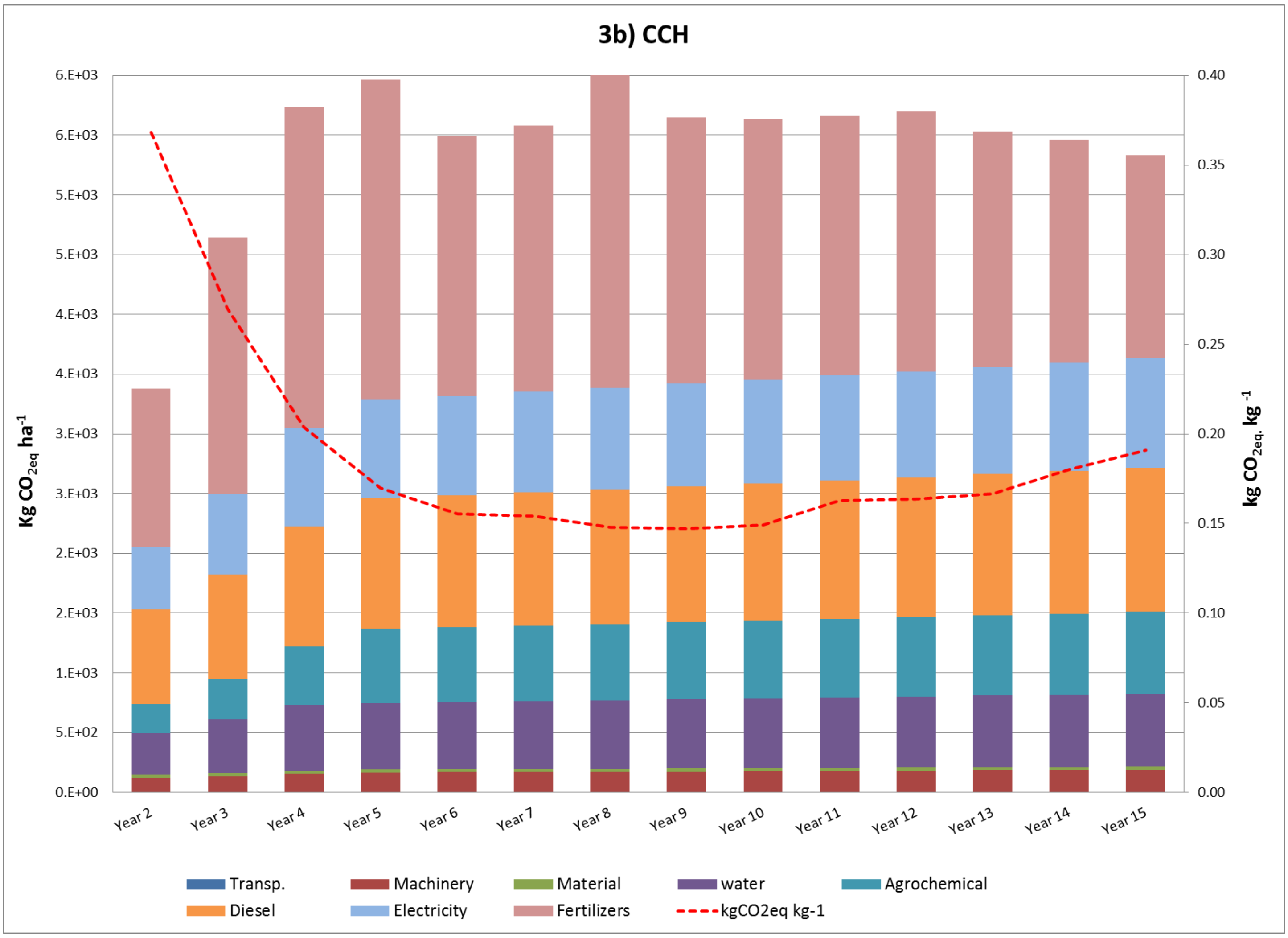
CCH = climate change; ODP = ozone depletion; PHO = photochemical oxidant formation; TAC = terrestrial acidification; FEU = freshwater eutrophication; MEU = marine eutrophication; ALO = agricultural land occupation; ULO = urban land occupation; NLT = natural land transformation; WDP = water depletion; MDP = metal depletion; FDP= fossil depletion; Etox = Ecotoxcity; NRE demand for non-renewable energy resources.

Figure 3. Evolution PCR impact values per FU over the years

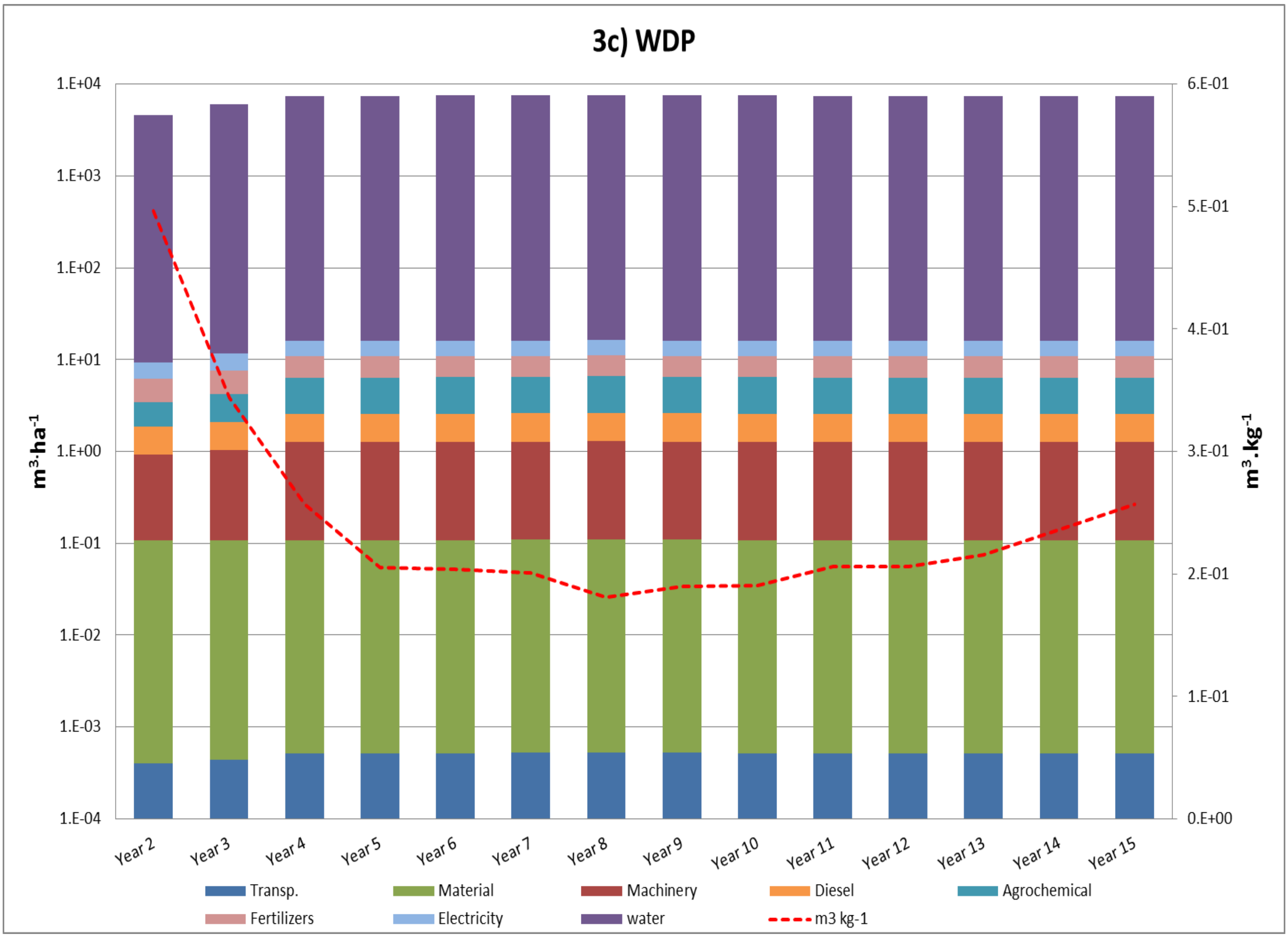
3a) NRE= non renewable energy



3b)CCH= climate change



3c) WDP= water depletion



3d) Ecotox= ecotoxicity