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Abstract: Sustainable agriculture aims to reduce its environmental impact. The adoption of organic farming is becoming increasingly widespread for field and horticultural crops as one of the leading sustainable farming systems. In this research, a Life Cycle Assessment (LCA) analysis was applied to investigate the actual environmental impact of processing tomato production, in the organic (OS) vs the conventional cropping systems (CS), in a specialized Mediterranean area in Southern Italy for three consecutive years. The study compared the global warming potential (GWP; in term of kg CO_2-eq) and primary energy demand (PED; in term of MJ) of processing tomato produced in the two systems. Our results indicate that GWP recorded in OS was on average -40% compared to CS when 1 hectare was adopted as a functional unit (FU). On the other hand, GWP was on average +22% in the OS than in CS if using 1 ton of marketable fruits as FU. A similar impact, highly depending on the choice of the FU, was registered for PED as average of three years. OS showed -38% vs +28% PED than CS, using 1 ha vs. 1 t of marketable fruit. Pesticide and fungicide applications, and soil tillage had the highest impacts among management inputs on GWP and PED, in both farming systems. Hence, the environmental efficiency of these practices should be largely improved in the production of processing tomato if aiming to sustainable farming. In conclusion, the differences of sustainability observed between the two farming systems were mainly due to the far lower marketable yield recorded in the OS vs the CS. Therefore, the priority future challenge of organic tomato farming should be the reduction of the yield gap between the OS and the CS, through the development of both new genotypes and of innovative management methods, designed to reduce the gap, but not increasing the environmental impacts on the agro-ecosystem.

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Title

LCA analysis of processing tomato in the organic *vs* the conventional cropping systems in Southern Italy

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Abstract

Sustainable agriculture aims to reduce its environmental impact. In this research, a Life Cycle Assessment (LCA) analysis was applied to investigate the actual environmental impact of processing tomato production, in the organic (OS) *vs* the conventional cropping systems (CS), in a specialized Mediterranean area in Southern Italy for three consecutive years. The study compared the global warming potential (GWP; in term of kg CO2-eq) and primary energy demand (PED; in term of MJ) of processing tomato produced in the two systems. Our results indicate that GWP recorded in OS was on average -40% compared to CS when 1 hectare was adopted as a functional unit (FU). On the other hand, GWP was on average +22% in the OS than in CS if using 1 ton of marketable fruits as FU. A similar impact, highly depending on the choice of the FU, was registered for PED as average of three years. OS showed -38% *vs* +28% PED than CS, using 1 ha *vs.* 1 t of marketable fruit. Pesticide and fungicide applications, and soil tillage had the highest impacts among management inputs on GWP and PED, in both farming systems. Hence, the environmental efficiency of these practices should be largely improved in the production of processing tomato if aiming to sustainable farming. In conclusion, the differences of sustainability observed between the two farming systems were mainly due to the far lower marketable yield recorded in the OS *vs* the CS. Therefore, the priority future challenge of organic tomato farming should be the reduction of the yield gap between the OS and the CS, through the development of both new genotypes and of innovative management methods, designed to reduce the gap, but not increasing the environmental impacts on the agro-ecosystem.

Keywords: LCA, organic cropping system, conventional cropping system, processing tomato, global warming potential, primary energy demand

Abbreviations: OS = organic cropping system; CS = conventional cropping system

1. Introduction

The search for food security, after the growing concerns about the increase of world population and its impact on climate change, in most cases is not considering the problem of greenhouse gases (GHGs) emissions. In fact, one of the most impelling challenges for agriculture is how to improve the food yield without increasing the GHGs. Agriculture is one of the economic sectors contributing to the production of GHGs emissions (IPCC, 2014): hence, one of the priorities in the international agricultural policy agenda is to guarantee the growth of crop yield while limiting its carbon footprint (Alexandratos and Bruinsma, 2012). Since chemical products are not allowed in the organic cropping system (OS), this could be an alternative and more sustainable method for the production of the crops (Bender and van der Heijden, 2015), contributing to the reduction of GHGs (Scialabba and Hattam, 2002).

In the last years, the request of organic foods increased around the world (Dias et al., 2015). The consumers are attracted by its promise of healthier as of more sustainable foods. An interesting study based on a meta-analysis of 343 peer-reviewed publications showed that the organic crops, compared to the non-organic ones have on average higher concentrations of antioxidant compounds, lower concentrations of cadmium and lower incidence of pesticide residues in their edible organs (Barański et al., 2014).

Nevertheless, consumers may not have access to credible information about the real environmental impacts of the organic as of other cropping systems (Meisterling et al., 2009 and Nilsson et al., 2004), and large studies for the different crops are required to verify if that promise of higher sustainability and lower GHGs impacts are really met or not. A possible way to investigate the environmental impact of agricultural processes is Life Cycle Assessment (LCA). The LCA methodology is worldwide accepted and appreciated because it allows an objective measurement of environmental performances of products and processes (Badino and Baldo, 1998; Guinée, 2002). In fact, according to the ISO 14040 standards (ISO, 2006), LCA is defined as an objective technique to assess the potential environmental impacts.

In the last years, many studies compared the OS and the CS, showing a wide variation for their environmental impacts (Tuomisto et al., 2012a; Tuomisto et al., 2012b; Williams et al., 2010). In general, across crops, OS minimizes the pollution effects on the agro-environment, it maintains healthier and fertile soils (Mehdizadeh et al., 2013), where it increases the soil carbon stocks (Jastrow et al., 2007; Tuomisto et al. 2012a). Moreover, the OS was shown to improve other soil characteristics through the higher organic matter contents, such as soil biodiversity (Mader et al., 2002); OS also helps to reduce erosion and nutrient leaching (Hansen et al., 2001). On the other hand, OS generally showed lower yields due to lesser use of external inputs, with a higher presence of pests and weeds (Köpke et al., 2008). An interesting meta-analysis study that compared the environmental impacts of the OS and the CS in Europe, showed that OS reduces environmental impact *per* unit of area but, due to lower yield, more land use is required; moreover, contrasting results were shown *per* product unit (Tuomisto et al. 2012a).

Some studies performed in the CS, compared the agronomical (Elherradi et al., 2005; Hargreaves et al., 2008; Odlare et al., 2008; Poudel et al., 2001) and the environmental (Blengini, 2008; Hansen et al., 2006; Lundie and Peters, 2005; Martínez-Blanco et al., 2009; Ruggieri et al., 2009; Tidåker et al., 2007) performances of organic and mineral fertilizers. Other studies compared the OS and the CS (Dalgaard et al., 2001; Haas et al., 2001; Meisterling et al., 2009; Refsgaard et al., 1998), studying the related environmental impacts in different crops.

As regards wheat, Tuomisto et al. (2012b) reported that the CS had the higher PED and GWP, both *per* unit of area and *per* product unit, than the OS; nevertheless, combining the best practices from the OS and the CS, the authors conclude being possible to maintain a satisfactory yield level reducing the environmental impacts.

Unfortunately, the comparison studies between the two farming systems (OS *vs* CS) that could quantify their difference in environmental impacts rarely dealt with tomato for fresh market and industry, and in particular not with processing tomato cropped in the same area, using the same soil type, the same weather conditions and genotypes.

However, if analyzing the importance of horticultural crops, tomato is the second crop in term of economic value and the first processed vegetable in the World (Gould, 2013), thus playing a key role in the human diet (Brandt et al., 2006). In addition, Southern Europe is the second producer of processing tomato worldwide (Miltenburg, 2015) and Italy is the main producer in Europe with almost 4.5 million tons per year (Bacenetti et al., 2015).

Therefore, we aimed to study the LCA of processing tomato cropped in the OS *vs* the CS in very similar soil type and climatic conditions. The study was performed in a highly specialized Mediterranean environment, through three years of field trials, to identify the steps that might reduce the energy use and GHGs emissions for improving sustainability of processing tomato management in Southern Europe.

2. Materials and methods

The LCA analysis was used, considering the entire life cycle “at farm gate”, providing a method to evaluate yield obtained with two different cropping systems (OS *vs* CS), without considering the following steps of the supply chain of the different tomato-based foods (concentrated, peeled, dried, etc.). LCA calculates the environmental impact at each stage in the life cycle taking into account upstream environmental flows.

2.1 Functional unit and system boundary

One hectare (1 ha) of the crop was used as a functional unit (FU) to study the potential environmental impacts of processing tomato production. Furthermore, we also report the results of the environmental impact of the organic and the conventional processing tomato based on 1 ton (1 t) of marketable fruit, in term of fresh weight. In the present study, both FUs were used as a reference for input and output flows normalization (ISO, 2006). The use of both functional units could improve the assessment of environmental results (Abeliotis et al., 2013; Khoshnevisan et al., 2014). Figure 1 shows the stages considered for LCA in the two investigated cropping systems. The broad system object of study required a detailed data collection recorded for each operation done on both cropping systems. Most of these data were obtained experimentally in the open field. When experimental and local information was not available, bibliographical sources were used to complete the life cycle inventory.

2.2 Categories of impact and LCA methodology

A life cycle analysis approach at the farm gate was performed. Global warming potential (GWP) was adopted as the impact category for this study. Functional units expressed in kg CO_2-equivalents (CO_2-eq), were obtained using Tier 2 methodologies recommended by the IPPC (2006). Moreover, the primary energy demand (PED), expressed in MJ, was investigated *per* functional unit as well.

2.3 Life cycle inventory

In our study, real experimental data, collected in open field during three years (2010-2012) in Southern Europe, were used.

The present study took into account all the supply-chain stages of processing tomato production, both in the OS and in the CS. The study considered the process from the soil tillage of transplanting bed preparation to the harvest of the fruits at 85% of maturity and all the inputs related to each agricultural operation.

The amounts of fuel as well as the types of farm equipments (such as the power of the agricultural machinery) used during the cultivation, were recorded in both cropping systems and then used for the analysis.

Most data related to energy consumption were recorded during the crop growth cycles, in addition, data from available, published studies were used, in particular those regarding electrical energy (EPA, 2014; Pehnt, 2006), gasoline and lubricant (Furuholt, 1995; Cuevas, 2005), and fertilizer production (Skowroñska and Filipek, 2013; Hesq and Jenssen 2010). For the assessment of electrical Italian energy, data published by IEA (2012) were considered for the 3-year period (2010-2012). Finally, emissions from diesel combustion were referred to EEA (2013) emission guidebook for off-road machineries.

2.3.1 Data of mineral fertilizers production and transport

Inputs in terms of the unit of fertilizers (N–P–K) were based on soil analysis (Ronga et al. 2017) and crop nutrient requirements. The present study compared the OS *vs* the CS; therefore, the doses of fertilizers were calculated by taking into account the real crop request, considering the nutrient concentration already present in the soils and the nitrogen content in the water well administrated, reaching the same quantity of total nitrogen (150 N kg ha^{-1}) in both cropping systems. In the OS, potassium and other micronutrient content in the soil were sufficient for the crop development; thus, no other doses were applied. Organic and mineral nitrogen fertilizers were used in the OS and the CS, respectively. For all transports, the distances were considered twice to take into account the return trip, except for the case of mineral fertilizers transport due to the efficiency of international transport platforms.

2.3.2 Data of the agricultural practices

Data on agricultural management were recorded in two experimental fields located in the Sele Valley, in Battipaglia (Salerno District, Italy), one of the major areas for the production of processing tomato and its transformation in the Country.

The production was done following the best available techniques for the organic and the conventional management. Six modern cultivars of processing tomato commonly used in Southern Italy were cultivated during Spring and Summer 2010-2012 in the OS (40°36’ N; 14°56’ E) and in the CS (40°35’ N; 14° 58’ E).

Both cropping systems had very similar soil types, classified as Typic Haplox-erepts (Staff, 1996). Each replicate was 4.0 x 5.0 m and contained 60 plants. Planting was done using seedlings at the fourth true leaf stage at a plant density of 3 plants m^{-2} using a randomized complete block design with three replicates in both cropping systems.

The agronomical management was the same reported by Ronga et al. (2015). In addition, the amount of water supply for irrigation was based on crop evapotranspiration for both environments. A total of 370, 400 and 400 mm of irrigation water was applied in 2010, 2011 and 2012 respectively, by drip irrigation. Weeds and pests were controlled according to the production rules of Campania Region, Italy. Weather parameters (minimum and maximum temperature and rainfall) were recorded at both locations and were very similar during the crop cycle (T min 16.1 °C, T max 29.3 °C, rainfall 6.4 mm, in the OS; T min 17.6 °C, T max, 28.5 °C, rainfall 6.5 mm, in the CS).

The parameters recorded in each cropping system were analyzed by ANOVA using GenStat 17th edition software. The analysis of variance reports the average genotypic values recorded. Differences between the means were analyzed using the Duncan test at $P < 0.05$.

2.3.3 Irrigation and Fertigation

Water, fertilizers and phytosanitary agrochemicals were supplied using a standard infrastructure in each cropping system. Tanks, centrifugal pumps and pipes for dissolving fertilizers and channeling the water and nutrients, electro-valves for controlling dosage and a network of integrated drip pipes constituted the fertigation system.

The electricity required by pump of 2.7 kW, to pump water and nutrient in the fertigation system, was considered in the analysis. For irrigation scheduling in quantity and times, evapotranspiration of the crop (ETc) was calculated as ETc = ETo × Kc, where ETo (reference evapotranspiration) was considered according to Hargreaves and Samani (1985), and Kc was the crop coefficient of tomato, as reported by Allen et al. (1998), adjusted for the environmental conditions. In each plot, 100% of ETc was restored when 40% of total available water was depleted, according to the evapotranspiration method of Doorenbos and Pruitt (1977).

2.3.4 Phytosanitary treatments

The type and the amount of agrochemicals were applied following the European and Regional regulations for the organic and the conventional crop managements, respectively. Each cropping system required foliar spry applications for the control of biotic stresses. As regards the pathogen and pest control, only fungicides (sulphur and copper oxy-chloride) and pesticides (azadirachtin A, spinosad and pyrethrins) admitted in organic agriculture were used in the OS, while common and additional fungicides (sulphur, copper oxychloride, difenoconazole and aluminum-fosetil) and pesticides (azadirachtin A, imidacloprid, spinosad, abamectin and emamectin benzoate), admitted in conventional agriculture, were used in the CS. The main pests and pathogens observed in both cropping systems were: aphids, tomato leaf miner, common red spider, tomato leaf spot fungus and tomato early blight.

2.3.5 Post-application emissions

Direct emissions from fertilizer administration and soil management were calculated according to the method described in the 2006 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories applying Tier 1 method (IPCC, 2006). An emission of 0.01 kg of N_2O for each kg of N applied to the field was considered. Using this approach, 0.85 kg of direct emission of N_2O ha^{-1} for the organic cultivation (85 kg N ha^{-1} in the OS) and 1.5 kg of direct emission of N_2O ha^{-1} for the conventional cropping systems (150 kg N ha^{-1} in the CS) for each year were considered.

In this research, crop residues emissions were considered according to equation 11.6 (IPCC, 2006). Data on crop residues were reported in Table 1. The indirect N_2O emissions were considered according to the Tier 1 method (IPPC, 2006) taking into account also the atmospheric deposition of N volatilized from soil management, soil leaching and runoff.

2.3.6 Management of waste generated in the production stage

As previously mentioned, only the waste generated by production, such as non-yield biomass (leaves, stems and roots) and non-commercial tomatoes (unripe fruits), were considered in the inventory.

2.3.7 Omitted process

Our goal, as said before, was to uncover differences between the OS and the CS. In the OS and the CS some agricultural operations were the same for both cropping systems. Therefore, omitting them did not affect the GWP and PED differences between the two cropping systems, as reported by Meisterling et al. (2009). Impact of seed, seedling and pipeline production on the production of processing tomato, was similar in both cropping systems and was omitted from this analysis. In addition, in the present study, the contributions of the manufacture and maintenance of farm equipment, the production of pesticides and fertigation systems, their transport and their waste management were not considered. Moreover, as both the OS and the CS produced tomatoes are putatively allocated to the same local transformation industry and market, commercialization and processing of tomato were excluded from the analysis.

3. Results and Discussion

Agriculture adopts huge amount of energy for agricultural operations contributing to global warming with the emission of carbon dioxide, methane and nitrous oxide. Hence, it is necessary to identify key strategies to mitigate the production of GHGs (Ntinas et al., 2016). Nowadays, in agriculture, the most important challenge is to increase the crop yield to supply food to a growing population, while reducing the carbon footprint. Organic agriculture is often represented as an environmentally sustainable agricultural system; it was therefore our aim to investigate how much it can really decrease, or *vice versa* increase, the carbon footprint of an important horticultural crop for the Mediterranean diet, such as processing tomato, in a suited area of production. Other authors showed the capability of the OS to reduce the carbon footprint of the agroecosystem (Dalgaard et al., 2001; Haas et al. 2001; Meisterling et al, 2009; Refsgaard et al., 1998; Tuomisto et al., 2012a; Tuomisto et al., 2012b), however, our study is the first performed on processing tomato collecting real data in the open field, through three years of field experiment, in two farms located in the same geographic area, with similar soil characteristics, weather conditions and cropping the same cultivars.

The agronomical data and impact of each stage of production were analyzed, to compare the total environmental impact observed in the OS *vs* the CS, averaged trough three years of field trials. Hence, inputs and their variability were discussed to give useful information to farmers, consumers and policymakers following the concept of GWP and PED.

3.1 Yield

Differences for both marketable and total yield were observed in the two cropping systems (Table 1): the OS recorded lower value than the CS (on average across years and cultivars -54% and -55%, respectively). The yields obtained under the organic management, in the present study, were in accordance to the average yields recorded in the similar area (Farneselli et al., 2013 and Ronga et al., 2015). The same observation can be made for the conventional production; similar values were reported, also in other environments, by Martínez-Blanco et al. (2011), Muñoz et al. (2008) and Elia and Conversa (2012).

The lower total and leaf biomass (on average -23% and -29%, respectively; Table 1) reached by tomato plants could be among the most important drivers for the reduced yields in the OS. Considering that the total soil nitrogen (expressed as sum of soil content and external input) and volume of water irrigation were the same for both cropping systems in each year, the lower leaf and plant biomass showed by the OS could have been due to the higher incidence of biotic and abiotic stresses such as a lower availability of (organic) nitrogen, higher presence of weeds and diseases (data not shown), as reported by Clark et al. (1999), de Ponti et al. (2012) and Ronga et al. (2017). In addition, current organic farming uses cultivars developed for high input cropping systems, (Lammerts et al, 2011), that could have a different physiological behavior, nutrient use efficiency and yield performance when cultivated in the OS and not in the CS (Ronga et al., 2017). The use of processing tomato cultivars specifically bred for higher adaptation to low input cropping systems could hopefully result in higher yields, and consequently also the GWP and PED might be improved. From an economic point of view, the higher price that is paid by Italian industry for processing tomato cultivated in the OS (on average 135 euro ton^{-1}; +56% in comparison with the conventional product) is helping to reduce the distances; however it is considered not enough to balance the revenue between the two cropping systems (C. Piazza, personal communication).

Finally, the yield gap between the OS *vs* the CS exists, and it will be shown how this influences the overall environmental sustainability of organic processing tomato, at least in the environment object of this study. Therefore, one of the first challenges for organic processing tomato production is the identification of both appropriate crop rotation and innovative organic fertilizers that timely satisfy the plant nutrient need and take to increase uptakes. A second important goal for the expansion of organic horticulture is the breeding of cultivars specifically suited for the organic systems, *i.e.* more resilient to pests, diseases and weed competition (Dorais and Alsaniuns, 2015).

3.2 Environmental impact assessment and its interpretation

The influence of each stage of the production on the total impact of the cropping systems (OS *vs* CS), were assessed. The different stages of agricultural production included all management operations, from soil tillage for preparing the transplanting bed, to the harvest of fruits at 85% of maturity.

The results of GWP of this agricultural process based both on 1 ha and on 1 t of marketable fruit, are reported in Figure 2, while Figure 3 shows the percentage contribution of each stage. Table 2 reports the differences (named delta) of the LCA parameters between the two systems expressed as the percent difference between the OS and the CS. A significant difference between the two cropping systems was observed. However, it has been fundamentally shown that such a difference in environmental impact largely depends on the functional unit considered.

Regards the GWP using 1 ha as FU (Figure 2a and Table 2), the OS showed a far lower impact, on average -40% than the CS (3154.03 kg CO_2-eq ha^{-1} in the OS *vs* 5290.74 kg CO_2-eq ha^{-1} in the CS). On the other hand, taking into account 1 t of marketable fruit as FU (Figure 2b and Table 2), the OS displayed, on average, 67.49 kg CO_2-eq t^{-1} *vs* 55.16 kg CO_2-eq t^{-1} in the CS; thus, the cultivation of 1 t of processing tomato in the OS recorded higher emissions than the CS (on average +22%). As far as the contribution of single stages of the management process, in term of kg CO_2-eq ha^{-1}, the application of fungicides and pesticides, which accounted for approximately 28% of the total, reported the highest impact in the OS. This stage was followed by soil tillage, field emission, irrigation and diesel production, set at 24%, 18%, 13% and 7%, respectively; finally, fertilizer production showed the lowest impact (6%; Figure 3). In the CS, a similar partition was observed. However, in the conventional farming soil tillage had the highest impact (31%), followed by pesticide and fungicide applications with 27%, field emission that contributed, on average, 19%, irrigation with an impact of 8%, diesel production 8% and fertilizer application that reported the lowest impact (3%).

Agriculture is facing challenges of sustainability both in the OS that in theCS, such as improving soil quality, recycling nutrients, enhancing biodiversity and crop yields. Farmers and policy makers should understand where GHGs emissions come from and how to reduce them with the final aim of improving the sustainability of the whole agro-ecosystem (Gunady et al., 2012). Thus, as already reported by Tuomisto et al., (2012b), an improvement in sustainability of soil tillage (such as minimum or strip tillage), fertilization (such as different rotation, use of compost, nitrogen-fixing crops, green manure, etc.) and irrigation management (such as different technique, e.g. partial or deficit irrigation) should be considered with the final objective of decreasing the environmental impacts of processing tomato cultivated in both systems. Moreover, efforts should focus on improving organic yield to reduce the carbon footprint of processing tomato cultivated in the OS (Köpke et al., 2008).

Results regarding primary energy demand based both on 1 hectare and on 1 ton of marketable fruit, the contributions of each stage and the delta results were reported (Figure 4, 5 and Table 2, respectively).

Using 1 ha as FU, the OS reported a far lower impact than the CS, on average -38% (Figure 4a). On the other hand, the average total PED was ca. 793.27 MJ t^{-1} of marketable fruit obtained in the OS and 617.91 MJ t^{-1} of marketable fruit obtained in the CS (Figure 4b and Table 2). Analyzing the percentage contributions in term of MJ ha^{-1} (Figure 5), in the OS the application of fungicides and pesticides stage had the biggest impact on primary energy demand and represented ca. 30% of the total impact. This stage was followed by: soil tillage (27%), irrigation (20%), fertilizer production that contributed, on average, *per* 12%; fertilizer application, whit impact of 8% and diesel production (3%).

In the CS, a similar behavior was observed, although with some notable differences in PED partitioning. Soil tillage was the operation with the biggest impact, responsible for 35% of the total, followed by pesticide and fungicide applications that contributed to 31%, fertilizer production was higher than irrigation, the two accounts for approximately 14% and 12%, respectively. As in the OS, fertilizer application and diesel production were minor contributors, respectively, with 4% and 3% of the total PED impact.

In addition, as reported in Table 2, the OS performed better in term of reduction of the GWP (kg CO_2-eq ha^{-1}, -40%) compared to the reduction of the PED (MJ ha^{-1}, -38%) than the CS. Moreover, pesticide and fungicide applications had the highest impact both on GWP and PED in the OS and the same was for soil tillage in the CS.

Results reported by Brodt et al. (2013) indicate that California-produced conventional and organic tomato paste, and canned diced tomatoes are almost equivalent in term of energy use and GHGs emissions, recording yield of 90 t ha^{-1} and 85 t ha^{-1} in the CS and OS, respectively. These yields were obtained using 197 and 224 units of N in the CS and in the OS, respectively. Moreover, as far as input of irrigation water ca. 800 mm was used. The main difference respects the results reported in the present work was due to the different yield recorded in the OS, -41% in our study compared to the Californian yield obtained in the OS, considering that in the present study 150 units of N and 400 mm of irrigation water *per* hectare were used.

On the other hand, our results regarding total agriculture carbon footprint obtained both in the OS and in the CS are quite in agreement with those reported by Ntinas et al. (2016), even if slight differences as regards pesticides and field N_2O emissions, higher and lower respectively, in our work. These differences were probably due to the different number of foliar spry applications and different management of nitrogen, moreover, both influenced by the different environments investigated (Greece *vs* Italy). Furthermore, the results of the present study of the contribution of each stage regarding the GWP obtained in the CS are in agreement with Martínez-Blanco et al. (2011), apart from mineral fertilizer stage that contributed less in our study. In fact, in our work, less than one third of nitrogen applied in the field was used to reach similar marketable yield.

Focusing the attention on another important crop such as wheat, Tuomisto et al. (2012b) reported lower GWP and PED in the OS both *per* hectare and *per* grain yield and the stage that recorded the highest contribution was field emission. Similar results were highlighted by Meisterling et al. (2009) as regards GWP of 1 kg of bread loaf. The main difference in field emission between processing tomato and wheat was probably due to the different methods of application of the fertilizers. In fact, on processing tomato at top dressing applications the fertilizers are incorporated into the soil or distributed by fertirrigation, reducing the nitrogen volatilization and hence the field emission, while these two practices are not used in wheat production at top dressing fertilization.

The present work offers an important observation on each stage of production, which might help farmers in taking decisions on how to reduce the carbon footprint of processing tomato. In general, pesticide and fungicide applications, soil tillage and field emission were three stages with the highest impact in the contribution of the GWP in both the OS and the CS. Similar behavior was reported also for the impact on PED, except for field emission that was replaced by irrigation. An interesting point emerging from this study relates to the pesticide and fungicide applications that had the highest impact in the OS due to the few fungicides (as foliar sprays) allowed in the OS. In fact, such pathogens as *Septoria lycopersici* Speg. and *Alternariwere alternata* f. sp. *lycopersici* (recorded in the present study), were both difficult to control without the use of systemic products, hence more foliar spry applications were required using only copper. The second interesting point was that CS might reduce the impact of soil tillage, using alternative tillage to plow such as disc harrow.

As regards field emission the OS performed almost as well as the CS (18% *vs* 19%). In fact, the same units of total N were considered for the production in both the cropping systems investigated. The irrigation was another stage with high influence on PED, (Figure 4). Thus, these stages that had a high impact could be improved in future researches.

Other interesting issues are represented by the percentage contributions of fertilizer application and irrigation stages that impacted more in the OS than in the CS both in term of GWP and PED due to the fertilizers allowed in the OS that have a lower content of nutrient compared to the fertilizer allowed in the CS (eg. manure *vs* urea) requiring more quantitative and hence more time to spread the same unit *per* hectare. In addition, as regards irrigation, in the present work some pesticides, allowed in the OS, were injected by fertirrigation increasing the impact. The use of innovative fertility building crop might be a possible strategy to reduce the percentage of impact of both stages, increasing the soil organic carbon and water holding capacity.

The production of the processing tomato in the OS showed more sustainable agricultural practices than the CS *per* ha, at least in Southern Italy. However, nowadays is not sustainable to cultivate new areas, even though the production of the processing tomato shows a reduction of the carbon footprint *per* hectare cultivated. Hence the breeding of cultivars suitable for the OS, should be a fundamental point to be persuaded to obtain more rustic genotype, which might tolerate the different biotic and abiotic stresses allowing a reduction of external inputs and an increase of yield minimizing the environmental impact due to the production.

As regards the best practices, the intensive use of fertility building crops (Thorup-Kristensen et al., 2012), the application of natural biostimulants such as compost tea (Pane et al., 2012), or plant growth promoting bacteria (Zaccardelli et al., 2010) could be able to improve the nutrient management increasing the plant tolerance to abiotic and biotic stresses in the OS.

Moreover, the use of systems of precision agriculture and decision support could help to improve the crop yield in the OS, investigating the spatial and temporal variability and helping farmers and consultants to apply the best available techniques (Basso et al. 2011; Basso et al., 2013).

The information reported in the present study is notable because it was obtained within the same territory for both cropping systems, enabling the evaluation of variables that have a fundamental role for the production such as weather conditions, soil type and biological resources. Our results could be useful to evaluate the impact of different strategies used in the OS and might be exported to other Mediterranean areas with similar conditions. In addition, these results could help stakeholders to understand better the suitability of LCA tool to develop cropping system strategies, addressing the norms and incentives for farmers that adopt sustainable practices (Tuomisto et al., 2012a). However, as reported by Martínez-Blanco et al. (2011), other indicators such as soil erosion or economic value or quality aspect, should be taken into account in further researches.

Finally, CO_2 labeling is recognizable by the consumers and might represent an important instrument to influence consumer choices, even if consumers alone are not able to drive choices towards products with a low carbon footprint (Theurl et al., 2014). Hence, future researches should improve the carbon footprint of the crops, spreading more and more of these studies, to be able to give scientific support to these labels.

4. Conclusions

In the present study, a comparative LCA of processing tomato cropped in the OS *vs* the CS in Southern Italy was performed evaluating the differences both in term of GWP (kg CO2-eq) and PED (MJ). Our results showed that GWP and PED were lower in the OS than the CS when 1 ha of production was used as FU. On the other hand, using 1 ton of marketable fruit as FU, the results changed drastically reporting higher carbon footprint in the OS than in the CS. These differences were due to the fact that the hectare yields obtained in organic system were on average nearly the half of the conventional one, especially for cash crops that were produced in a short crop rotation and in a country where the weather conditions allow the growth of biotic stress throughout the year. Moreover, our results indicate that pesticide and fungicide applications in the OS and soil tillage in the CS are the stages with the major impact, due to the high level of diseases in the former and a high number of soil operation in the latter. Therefore, efforts to improve the environmental impact of processing tomato cropped in the OS should focus primarily on the reduction of the yield gap, by adopting innovative management strategies and new specifically suitable cultivars. Then, efforts should be made to increase the use of precision agriculture and the development of product allowed in the OS, such as the use of biofertilizers and biostimulants in order to alleviate the biotic and abiotic stresses and improving the carbon footprint.

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5. References

Abeliotis, K., Detsis, V., Pappia, C., 2013. Life cycle assessment of bean production in the Prespa National Park, Greece. J. Clean. Prod. 41, 89-96.

Alexandratos, N., Bruinsma, J., 2012. World Agriculture towards 2030/2050: the 2012 Revision. ESA Working Paper No. 12-03. FAO, Rome, Italy.

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper No. 56. FAO, Rome, Italy.

Bacenetti, J., Duca, D., Negri, M., Fusi, A., Fiala, M., 2015. Mitigation strategies in the agro-food sector: The anaerobic digestion of tomato purée by-products. An Italian case study. Sci. Total. Environ. 526, 88-97.

Badino, V., Baldo, G., 1998. LCA Istruzioni per l'Uso. Esculapio, Bologna, Italy.

Barański, M., Średnicka-Tober, D., Volakakis, N., Seal, C., Sanderson, R., Stewart, G.B., Benbrook, C., Biavati, B., Markellou, E., Giotis, C., Gromadzka-Ostrowska, J., Rembiałkowska, E., Skwarło-Sońta, K., Tahvonen, R., Janovská, D., Niggli, U., Nicot, P., Leifert, C., Gromadzka-Ostrowska, J., 2014. Higher antioxidant and lower cadmium concentrations and lower incidence of pesticide residues in organically grown crops: a systematic literature review and meta-analyses. Br . J. Nutr. 112, 794-811.

Basso, B., Cammarano, D., Fiorentino, C., Ritchie, J.T., 2013. Wheat yield response to spatially variable nitrogen fertilizer in Mediterranean environment. Eur. J. Agron. 51, 65-70.

Basso, B., Sartori, L., Bertocco, M., Cammarano, D., Martin, E.C., Grace, P.R., 2011. Economic and environmental evaluation of site-specific tillage in a maize crop in NE Italy. Eur. J. Agron. 35, 83-92.

Bender, S.F., Heijden, M.G.A., 2015. Soil biota enhance agricultural sustainability by improving crop yield, nutrient uptake and reducing nitrogen leaching losses. J. Appl. Ecol. 52, 228-239.

Blengini, G.A., 2008. Using LCA to evaluate impacts and resources conservation potential of composting: a case study of the Asti District in Italy. Resour. Conserv. Recy. 52, 1373-1381.

Brandt, S., Pék, Z., Barna, É., Lugasi, A., Helyes, L., 2006. Lycopene content and colour of ripening tomatoes as affected by environmental conditions. J. Sci. Food. Agric. 86, 568-572.

Brodt, S., Kramer, K.J., Kendall, A., Feenstra, G., 2013. Comparing environmental impacts of regional and national-scale food supply chains: A case study of processed tomatoes. Food Policy 42, 106–114.

Clark, M.S., Horwath, W.R., Shennan, C., Scow, K.M., Lantni, W.T., Ferris, H., 1999. Nitrogen, weeds and water as yield-limiting factors in conventional, low-input, and organic tomato systems. Agric. Ecosyst. Environ. 73, 257-270.

Cuevas, P., 2005. Comparative life cycle assessment of biolubricants and mineral based lubricants. Dissertation, University of Pittsburgh.

Dalgaard, T., Halberg, N., Porter, J.R., 2001. A model for fossil energy use in Danish agriculture used to compare organic and conventional farming. Agric. Ecosyst. Environ. 87, 51-65.

de Ponti, T., Rijk, B., van Ittersum, M.K., 2012. The crop yield gap between organic and conventional agriculture. Agric. Syst. 108, 1-9.

Dias, V.D.V., Schultz, G., Schuster, M.D.S., Talamini, E., Révillion, J.P., 2015. The organic food market: a quantitative and qualitative overview of international publications. Ambient. Soc. 18, 155-174.

Doorenbos, J., Pruitt, W.O., 1977. Crop water requirement. FAO Irrigation and Drainage Paper No. 24. FAO, Rome, Italy.

Dorais, M., Alsanius, B., 2015. Advances and Trends in Organic Fruit and Vegetable Farming Research, in: Janick, J. (Eds.), Horticulture Reviews, 1st edn. John Wiley & Sons, Hoboken, New Jersey, USA, pp 185.

EEA, 2013. EMEP/EEA emission inventory guidebook, Copenhagen, Denmark.

Elherradi, E., Soudi, B., Chiang, C., Elkacemi, K., 2005. Evaluation of nitrogen fertilizing value of composted household solid waste under greenhouse conditions. Agron. Sustain. Dev. 25, 169-175.

Elia, A., Conversa, G., 2012. Agronomic and physiological responses of a tomato crop to nitrogen input. Eur. J. Agron. 40, 64-74.

EPA, 2014. United States Environmental Protection Agency. Emission factors for greenhouse gas inventories available at:http://www.epa.gov/climateleadership/documents/emission-factors.pdf

Farneselli, M., Benincasa, P., Tosti, G., Pace, R., Tei, F., Guiducci, M., 2013. Nine-year results on maize and processing tomato cultivation in an organic and in a conventional low input cropping system. Ital. J. Agron. 8:2.

Furuholt, E., 1995. Life cycle assessment of gasoline and diesel. Resour. Conserv. Recycl. 14, 251-263.

Gould, W.A., 2013. Tomato production, processing and technology. Elsevier, Amsterdam.

Guinée, J.B., 2002. Life cycle assessment: an operational guide to the ISO standards Part 1 and 2. Ministry of Housing. The Netherlands: Spatial Planning and Environment (VROM) AND Centre of Environmental Science (CML) available on line at http://www.leidenuniv.nl/cml/ssp/projects/lca2/lca2.html

Gunady, M.G., Biswas, W., Solah, V.A., James, A.P., 2012. Evaluating the global warming potential of the fresh produce supply chain for strawberries, romaine/cos lettuces (Lactuca sativa), and button mushrooms (Agaricus bisporus) in Western Australia using life cycle assessment (LCA). J. Clean. Prod. 28, 81-87.

Haas, G., Wetterich, F., Geier, U., 2000. Life cycle assessment framework in agriculture on the farm level. Int. J. Life Cycle Assess. 5, 345-348.

Haas, G., Wetterich, F., Köpke, U., 2001. Comparing intensive, extensified and organic grassland farming in southern Germany by process life cycle assessment. Agric. Ecosyst. Environ. 83, 43-53.

Hansen, B., Alroe, H.F., Kristensen, E.S., 2001. Approaches to assess the environmental impact of organic farming with particular regard to Denmark. Agric. Ecosys. Environ. 83, 11–26.

Hansen, J., Sato, M., Ruedy, R., Lo, K., Lea, D.W., Medina-Elizade, M., 2006. Global temperature change. Proc. Natl. Acad. Sci. USA 103, 14288-14293.

Hargreaves, G.H., Samani, Z.A., 1985. Reference crop evapotranspiration from tem-perature. Appl. Eng. Agric. 1, 96-99.

Hargreaves, J.C., Adl, M.S., Warman, P.R., 2008. A review of the use of composted municipal solid waste in agriculture. Agric. Ecosyst. Environ. 123, 1-14.

Hesq, Y., Jenssen, T., 2010. Calculation of Carbon Footprint of Fertilizer Production available at: http://www.yara.com/doc/29293_2010_Carbon%20footprint%20of%20AN%20-%20Method%20of%20calculation.pdf

IEA, 2012. Statistic Report. Italy: electricity and heat for 2012. International Energy Agency available at: http://www.iea.org/statistics/statisticssearch/report/?country=ITALY=&product=electricityandheat

IPCC, 2006. IPCC Guidelines for National Greenhouse Gas Inventories. Institute for Global Environmental Strategies (IGES) for the IPCC, Kanagawa, Japan

IPCC, 2014. Climate Change 2014–Impacts, Adaptation and Vulnerability: Regional Aspects. Cambridge University, New York.

ISO, 2006. ISO 14040: Environmental Management – Life Cycle Assessment – Requirements and Guidelines. Geneva, Switzerland

Jastrow, J.D., Amonette, J.E., Bailey, V.L., 2007. Mechanisms controlling soil carbon turnover and their potential application for enhancing carbon sequestration. Clim. Change. 80, 5-23.

Khoshnevisan, B., Rafiee, S., Omid, M., Mousazadeh, H., Clark, S., 2014. Environmental impact assessment of tomato and cucumber cultivation in greenhouses using life cycle assessment and adaptive neuro-fuzzy inference system. J. Clean. Prod. 73, 183-192.

Köpke, U., Cooper, J., Petersen, H.L., van der Burgt, G.J., Tamm, L., 2008. QLIF workshop 3: performance of organic and low input crop production systems. In 16th IFOAM Organic World Congress, Modena, Italy.

Lammerts van Bueren, E.T., Jones, S.S., Tamm, L., Murphy, K.M., Myers, J.R., Leifert, C., Messmer, M.M., 2011. The need to breed crop varieties suitable for organic farming, using wheat, tomato and broccoli as examples: A review. NJAS - Wageningen J. Life Sci. 58, 193-205.

Lundie, S., Peters, G.M., 2005. Life cycle assessment of food waste management options. J. Clean. Prod. 13, 275-286.

Mader, P., Fliessbach, A., Dubois, D., Gunst, L., Fried, P., Niggli, U., 2002. Soil fertility and biodiversity in organic farming. Science 296, 1694-7.

Martínez-Blanco, J., Muñoz, P., Antón, A., Rieradevall, J., 2009. Life cycle assessment of the use of compost from municipal organic waste for fertilization of tomato crops. Resour. Conserv. Recycl. 53, 340-351.

Martínez-Blanco, J., Muñoz, P., Antón, A., Rieradevall, J., 2011. Assessment of tomato Mediterranean production in open-field and standard multi-tunnel greenhouse, with compost or mineral fertilizers, from an agricultural and environmental standpoint. J. Clean. Prod. 19, 985-997.

Mehdizadeh, M., Darbandi, E.I., Naseri-Rad, H., Tobeh, A., 2013. Growth and yield oftomato (Lycopersicon esculentum Mill.) as influenced by different organic fertil-izers. Int. J. Agron. Plant. Prod. 4, 734-738.

Meisterling, K., Samaras, C., Schweizer, V., 2009. Decision to reduce greenhouse gases from agriculture and product transport: LCA case study of organic and conventional wheat. J. Clean. Prod. 17, 222-230.

Miltenburg, J., 2015. Changing a multidomestic production network to a global function network: North America Heinz ketchup from 1960 to 2015. Int. J. Prod. Econ. 168, 267-278.

Muñoz, P., Antón, A., Nuñez, M., Paranjpe, A., Ariño, J., Castells, X., Montero, J., Rieradevall, J., 2008. Comparing the environmental impacts of greenhouse versus open-field tomato production in the Mediterranean region. Acta Hort. 801, 1591-1596.

Nilsson, H., Tuncer, B., Thidell, A., 2004. The use of eco-labeling like initiatives on food products to promote quality assurance - is there enough credibility? J. Clean. Prod. 12, 517-26.

Ntinas, G.K., Neumair, M., Tsadilas, C.D., Meyer, J., 2016. Carbon footprint and cumulative energy demand of greenhouse and open-field tomato cultivation systems under Southern and Central European climatic conditions. J. Clean. Prod. 142, 3617-3626.

Odlare, M., Pell, M., Svensson, K., 2008. Changes in soil chemical and microbiological properties during 4 years of application of various organic residues. Waste Manage. 28, 1246-1253.

Pane, C., Celano, G., Villecco, D., Zaccardelli, M., 2012. Control of Botrytis cinerea, Alternaria alternata and Pyrenochaeta lycopersici on tomato with whey compost-tea applications. Crop. Prot. 38, 80-86.

Pehnt, M., 2006. Dynamic life cycle assessment (LCA) of renewable energy technologies. Renew. Energy 31, 55-71.

Poudel, D.D., Horwath, W.R., Mitchell, J.P., Temple, S.R., 2001. Impacts of cropping systems on soil nitrogen storage and loss. Agric. Syst. 68, 253-268.

Refsgaard, K., Halberg, N., Kristensen, E.S., 1998. Energy utilization in crop and dairy production in organic and conventional livestock production systems. Agric. Syst. 57, 599-630.

Ronga, D., Lovelli, L., Zaccardelli, M., Perrone, D., Ulrici, A., Francia, E., Milc, J., Pecchioni, N., 2015. Physiological responses of processing tomato in organic and conventional Mediterranean cropping systems. Sci. Hortic. 190, 161-172.

Ronga, D., Zaccardelli, M., Lovelli, L., Perrone, D., Francia, E., Milc, J., Ulrici, A., Pecchioni, N., 2017. Biomass production and dry matter partitioning of processing tomato under organic vs conventional cropping systems in a Mediterranean environment. Sci. Hortic. 224, 163-170.

Ruggieri, L., Cadena, E., Martínez-Blanco, J., Gasol, C.M., Rieradevall, J., Gabarrell, X., Gea, T., Sort, X., Sánchez, A., 2009. Recovery of organic wastes in the Spanish wine industry. Technical, economic and environmental analyses of the composting process. J. Clean. Prod. 17, 830-838.

Scialabba, N., Hattam, C., 2002. Organic agriculture, environment and food security. FAO, Rome, Italy.

Skowrońska, M., Filipek, T., 2013. Life cycle assessment of fertilizers: a review. Int. Agrophys. 28, 101-110.

Staff, S.S., 1996. Keys to Soil Taxonomy, United States Department of Agriculture. Natural Resources Conservation Service, 644.

Theurl, M.C., Haberl, H., Erb, K.H., Lindenthal, T., 2014. Contrasted greenhouse gas emissions from local versus long-range tomato production. Agron. Austain. Dev. 34, 593-602.

Thorup-Kristensen, K., Dresbøll, D.B., Kristensen, H.L., 2012. Crop yield, root growth, and nutrient dynamics in a conventional and three organic cropping systems with different levels of external inputs and N re-cycling through fertility building crops. Eur. J. Agron. 37, 66-82.

Tidåker, P., Mattsson, B., Jönsson, H., 2007. Environmental impact of wheat production using human urine and mineral fertilisers–a scenario study. J. Clean. Prod. 15, 52-62.

Tuomisto, H.L., Hodge, I.D., Riordan, P., Macdonald, D.W., 2012a. Does organic farming reduce environmental impacts?–A meta-analysis of European research. J. Environ. Manage. 112, 309-320.

Tuomisto, H.L., Hodge, I.D., Riordan, P., Macdonald, D.W., 2012b. Comparing global warming potential, energy use and land use of organic, conventional and integrated winter wheat production. Ann. Appl. Biol. 161, 116-126.

Williams, A.G., Audsley, E., Sandars, D.L., 2010. Environmental burdens of producing bread wheat, oilseed rape and potatoes in England and Wales using simulation and system modelling. Int. J. Life Cycle Ass. 15, 855-868.

Zaccardelli, M., Campanile, F., Del Galdo, A., Perrone, D., 2010. Control of Viral Damages on Tomato in Open Field, by Treatments with a PGPR Strain of Pseudomonas putida. Acta Hort. 914, 405-407.

		Fresh Weight / Dry Weight (t ha^{-1})	OS	CS
MY		FW	46.44	**101.90***
TY		FW	49.90	**110.10**
Crop biomass	Total	DM	3.16	**4.10***
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	Root	DM	0.27	0.26

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(OS = organic cropping system, CS = conventional cropping system, MY = marketable yield (fresh weight), TY = total yield (fresh weight). FW = fresh weight. DM = dry weight. Mean values between column followed by asterisk (*) indicate significant differences at $P<0.05$ according to Duncan's multiple range test.

Index	Units	OS	CS
Delta-MY		**-54%**	
Delta-TY		**-55%**	
GWP	kg CO_2eq ha^{-1}	3154.03	5290.74
Delta-GWP		**-40%**	
GWP	kg CO_2eq t^{-1}	67.49	55.16
Delta-GWP		**+22%**	
PED	MJ ha^{-1}	37092.22	59364.83
Delta-PED		**-38%**	
PED	MJ t^{-1}	793.27	617.91
Delta-PED		**+28%**	

Table 2. Differential (= Delta) fruit yield and LCA results of processing tomato cultivations in two different cropping systems (OS = organic cropping system, CS = conventional cropping system, MY = marketable yield, TY = total yield).

***Title Page**

The authors mutually agree that manuscript **LCA analysis of processing tomato in the organic *vs* the conventional cropping systems in Southern Italy** should be submitted to Journal of Cleaner Production.

'Declarations of interest: none'

Dear Editor,

please consider the enclosed manuscript **LCA analysis of processing tomato in the organic *vs* the conventional cropping systems in Southern Italy** for publication in Journal of Cleaner Production.

The present manuscript investigates the Life Cycle Assessment analysis of processing tomato production, in the organic *vs* the conventional cropping systems, in a specialized Mediterranean area in Southern Italy for three consecutive years. The work was performed in the same territory, hence the two cropping systems had similar soils and weather conditions. Moreover, the same genotypes were cultivated in both the cropping systems. The study compared the global warming potential and primary energy demand in the two cropping systems, focusing the attention on the stages that more affected the production and suggesting solutions to increase the processing tomato sustainability.

This is significant because tomato plays a significant role in the World production and commerce. In addition, nowadays farmers are called to increase the agricultural sustainability and few published papers reported the Life Cycle Assessment comparing processing tomato cropped in the Mediterranean basin using the same genotypes and similar soils and weather conditions. We believe that this manuscript is appropriate for publication by Journal of Cleaner Production because it might contribute to the improvement of processing tomato sustainability and productivity.

This manuscript is an unpublished work.

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It is the original work of the authors.

The manuscript was not previously submitted to Journal of Cleaner Production and is not under consideration for publication in any other journal.

'Declarations of interest: none'

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Thank you for your consideration of this manuscript.

Yours Sincerely

Domenico Ronga

Highlights:

- Pesticide and fungicide applications have the highest impact in the OS
- Soil tillage has the highest impact in the CS
- One ha of processing tomato has less impact in the OS than CS
- More hectares are needed to reach the same food production in the OCS respect the CS
- One ton of marketable tomato fruit has still a lower carbon footprint in the CS than OS

Figure
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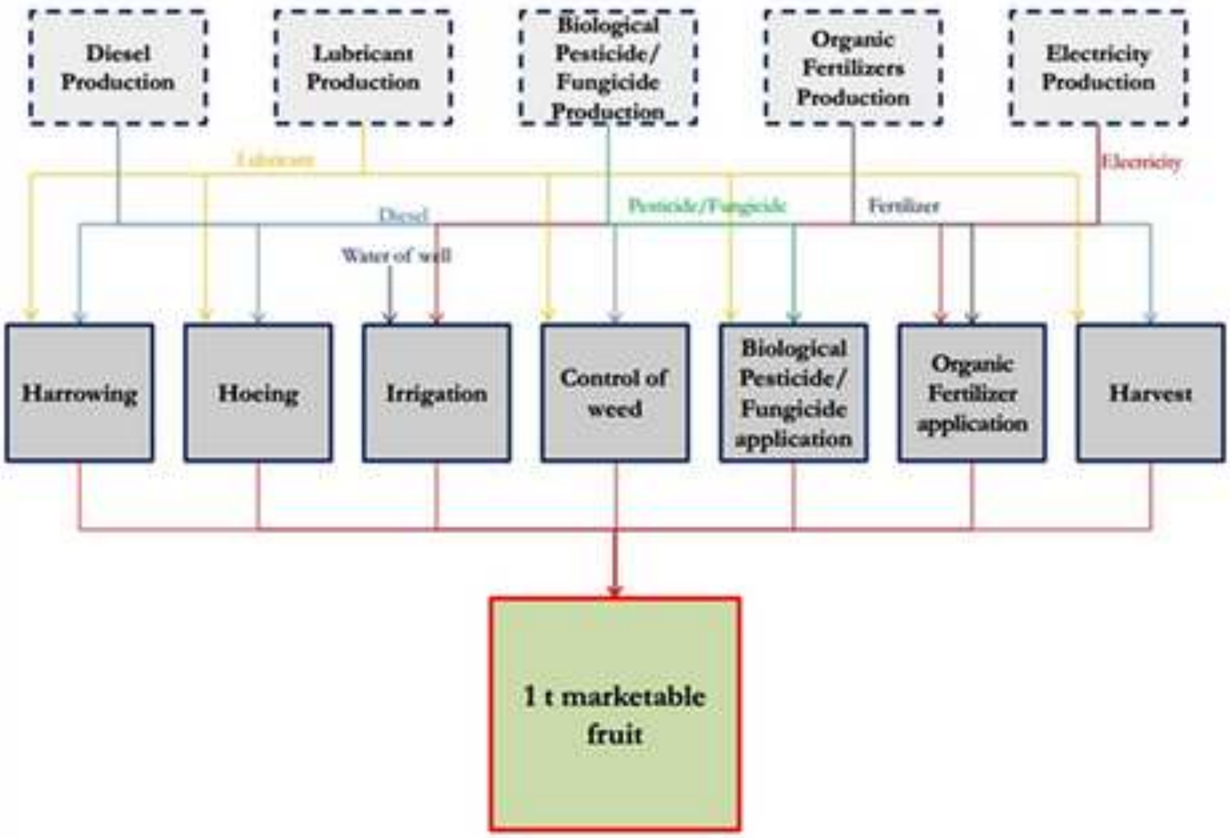
a)



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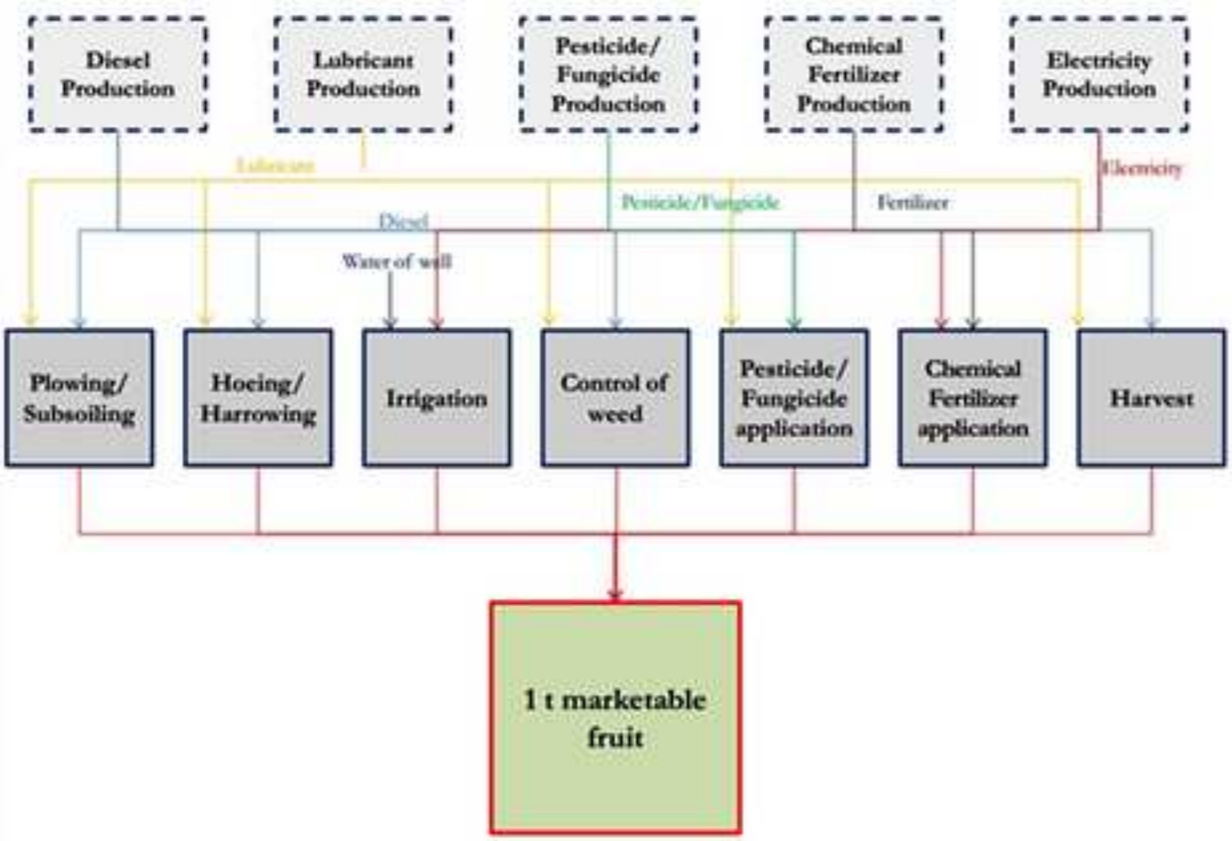

Figure

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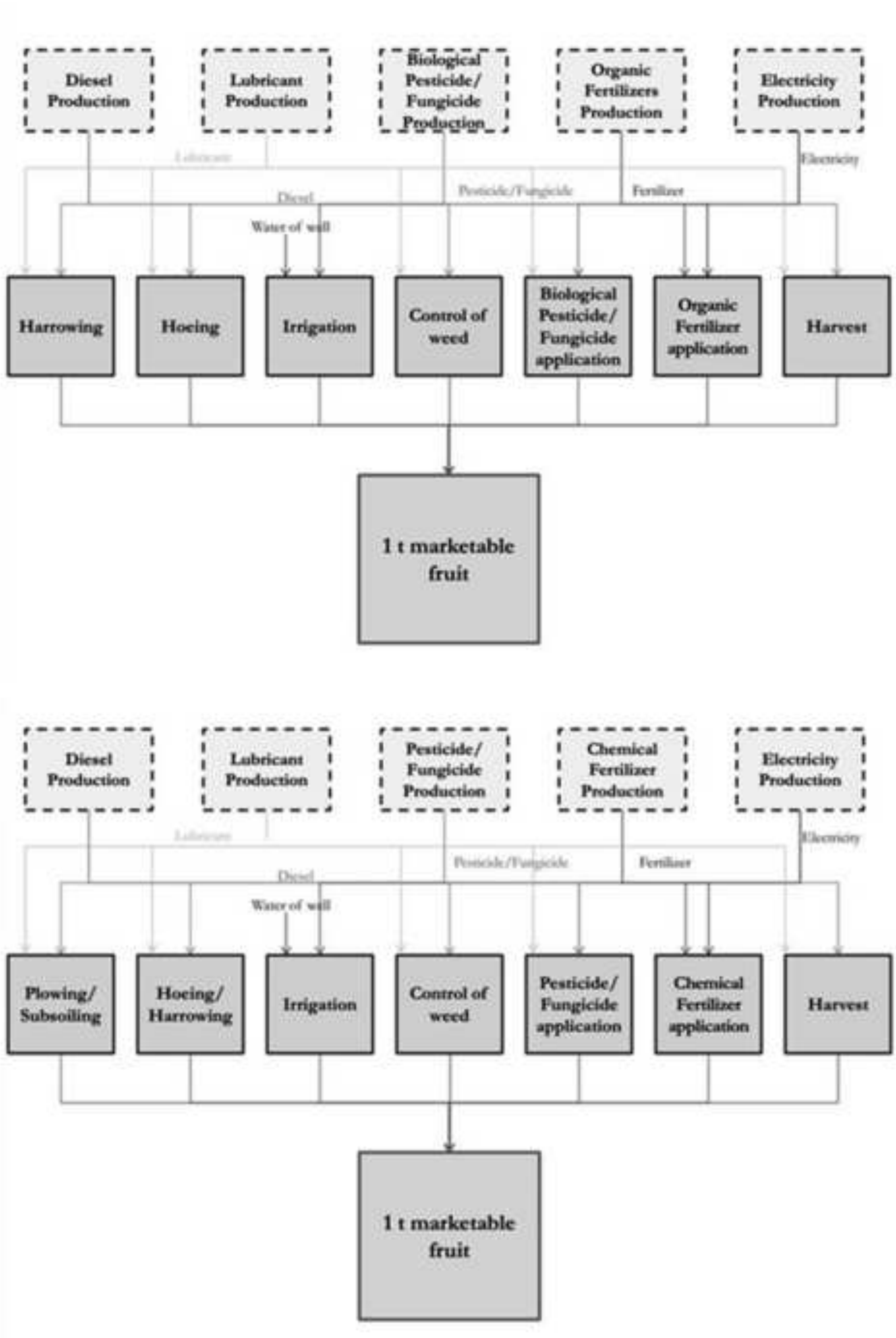
a) b)



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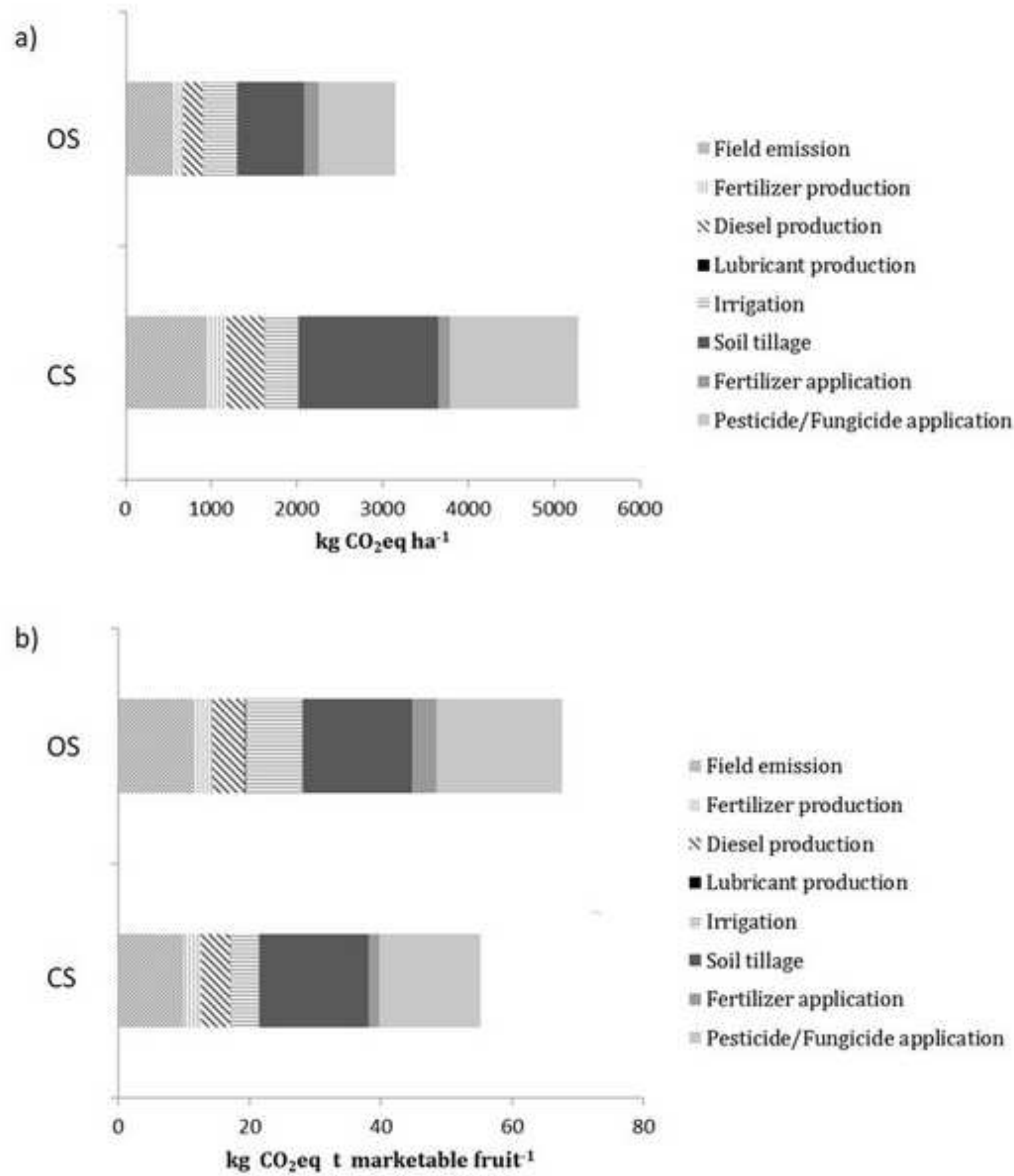

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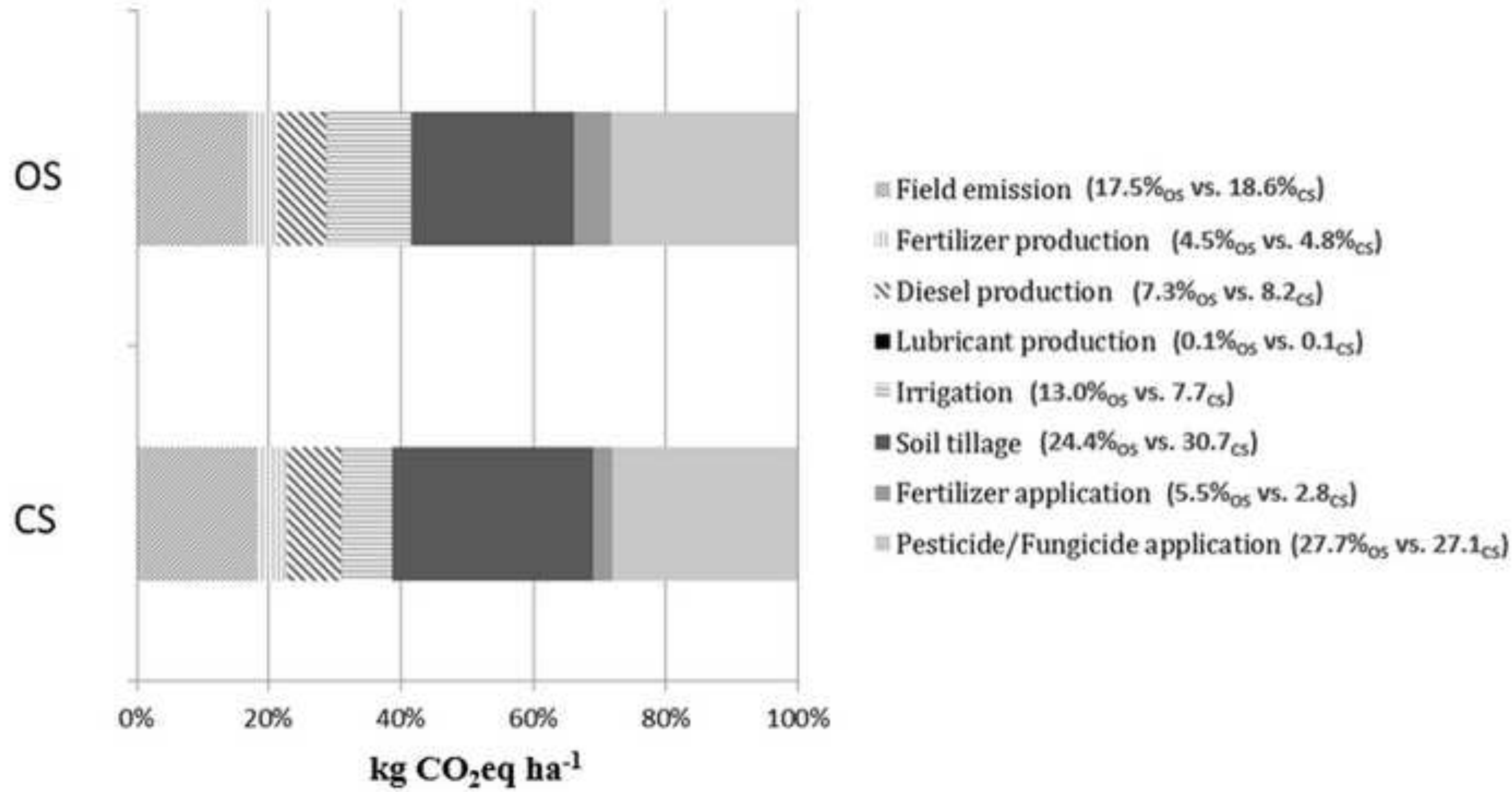

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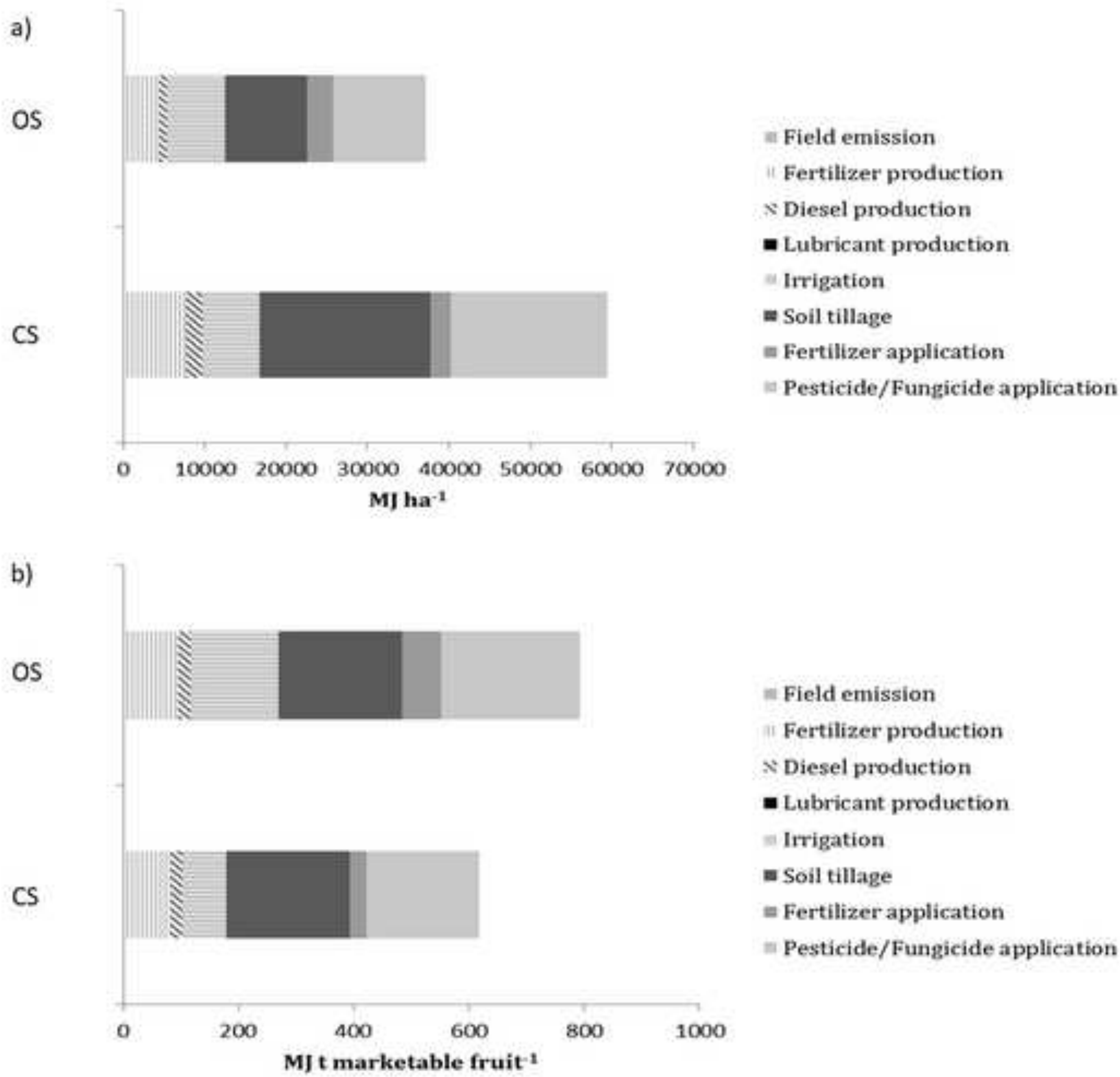

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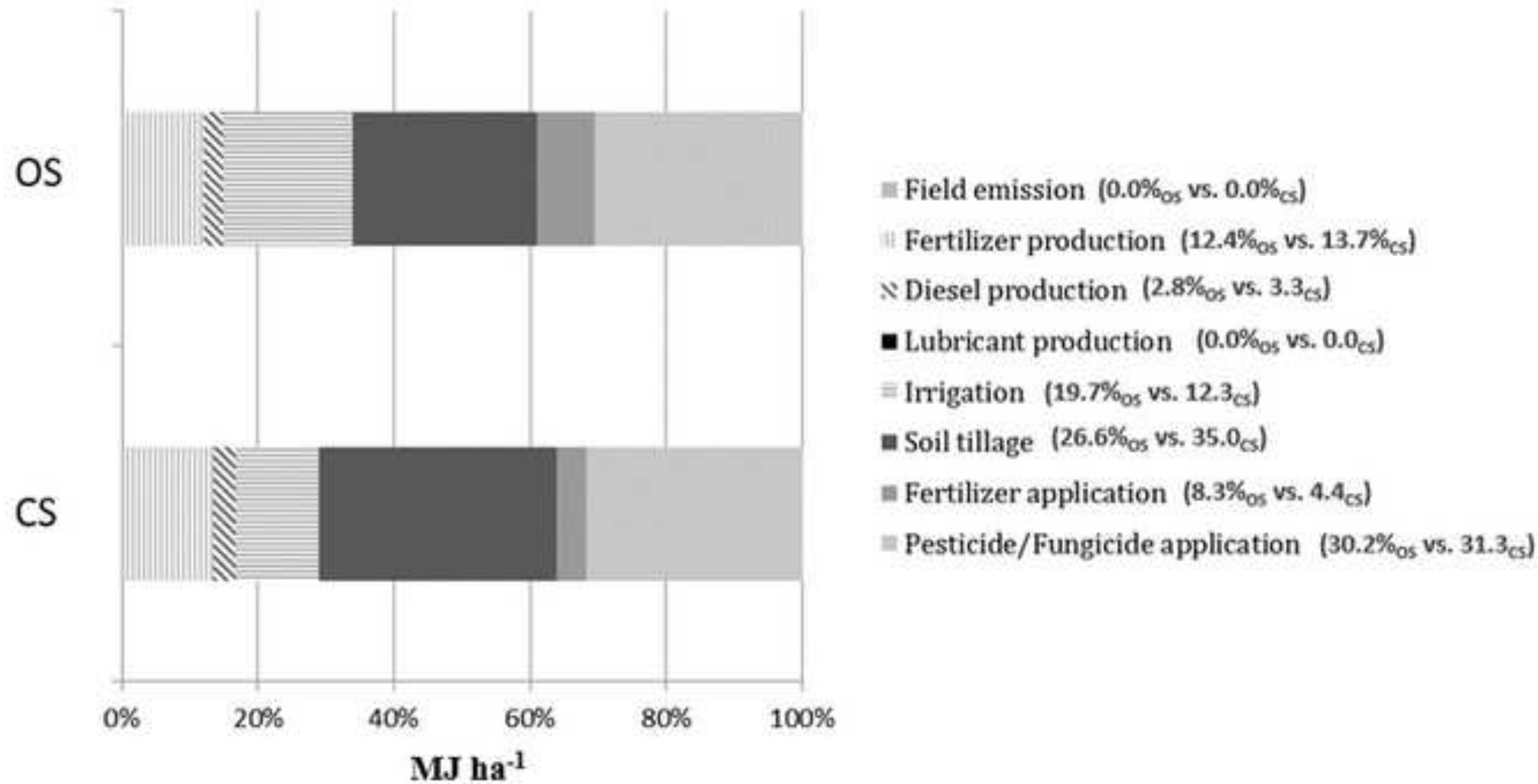

Table

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PED	MJ ha^{-1}	37092.22	59364.83
Delta-PED		**-38%**	
PED	MJ t^{-1}	793.27	617.91
Delta-PED		**+28%**	

Table 2. Differential (= Delta) fruit yield and LCA results of processing tomato cultivations in two different cropping systems (OS = organic cropping system, CS = conventional cropping system, MY = marketable yield, TY = total yield).

Figure

Figure 1. a) Boundaries of the cultivation of processing tomato in the organic cropping system (OS). b) Boundaries of the cultivation of processing tomato in the conventional cropping system (CS).

Figure 2. a) Life cycle GHG emission *per* hectare. b) Life cycle GHG emissions per 1 t of marketable fruit OS = organic cropping system. CS = conventional cropping system.

Figure 3. Contribution to total GWP impacts of the stages for the two cropping systems. OS =organic cropping system. CS = conventional cropping system.

Figure 4. a) Life cycle energy consumption per hectare. b) Life cycle energy consumption per 1 t of marketable fruit. OS = organic cropping system. CS = conventional cropping system.

Figure 5. Contribution to total PED impacts of the stages for the two cropping systems. OS = organic cropping system. CS = conventional cropping system.