Energy-environmental assessment of the UIA-OpenAgri case study as urban regeneration project through agriculture.

ABSTRACT

Sustainable agriculture is strongly promoted by Agenda 2030 and peri-urban agriculture is considered strategic for agri-food sustainability. Although, innovative farming practices are being implemented, the analysis of their impacts often does not reach the required depth. Within the EU project 'UIA-OpenAgri - New Skills for new Jobs in Peri-urban Agriculture', a regeneration process of a peri-urban area in Milan (Italy) was started, through the development of an innovative food hub. 28 innovative foodchains are assessed by a Life Cycle Assessment approach based on primary data collected from the involved start-ups. Non-Renewable Cumulative Energy Demand and the Global Warming Potential indicators are assessed and coupled with the productive land indicator. To effectively support involved operators in planning sustainable agriculture practices, the results are presented with GIS maps and insights for improving economic sustainability of involved start-ups are presented.

The study shows that the impacts related to the practices implemented (i.e. organic agriculture, including intercropping, agroforestry, ancient grains, etc.) decrease by an average of 55% in energy consumption and 65% on Global Warming Potential if compared to conventional ones. Then, these practices can provide a positive contribution to the Agenda 2030 goal of ensuring sustainable farm production practices.

KEYWORDS

Peri-urban agriculture; Urban regeneration; Cumulative energy demand; Global Warming Potential; Life Cycle Assessment; Geographic Information System

1 Introduction

The agri-food sector is acknowledged as a relevant contributor to greenhouse gas (GHG) emissions, with relevant implications on economy, culture, health, territory and resources deployment (BCFN, 2018). Ensuring sufficient food supply for a growing urban population (UN, 2019) and, at the same time, improving the environmental sustainability of the food production systems are significant challenges pointed out by the United Nations (UN) in the Agenda 2030 for sustainable development (UN, 2015). The main goals of Agenda 2030 are to eradicate poverty and achieve sustainable development by 2030 worldwide and it includes 17 Sustainable Development Goals (SDGs). Among these, the SDG2 aims at ending hunger, achieving food security and promoting sustainable agriculture. This goal should be achieved through many sub-targets, i.e. to increase the productivity while at the same time maintaining ecosystems, adapting to climate change, improving the quality of soil and maintaining the genetic diversity of plants. Achieving this goal requires better access to food and the widespread promotion of sustainable agriculture.

In this context, reducing the community's reliance on distant food markets through the development of local food systems is strengthened priority advocated by the Food and Agriculture Organization of the United Nations (FAO, 2018). Small-scale food production would also ensure equal access to productive resources, knowledge, and market opportunities and require the distribution of responsibilities between national and local levels of government (Sachs et al., 2019).

To face these challenges, urban and peri-urban agriculture[1] may assume a strategic importance in ensuring the sustainability of food supply and distribution in urban areas (Duvernoy et al., 2018). In addition, urban and peri-urban agriculture is considered strategic for driving urban transition to a sustainable future by the Joint Programming Initiative Urban Europe (Urban Europe, 2019). Indeed, urban and peri-urban agriculture is interesting due to the promotion of local food procurement, biodiversity, carbon sequestration (Pérez-Neira and Grollmus-Venegas, 2018), reduction of wastes produced (Kulak et al., 2013), more attractiveness for new employers, participated agriculture (i.e. agricultural cooperatives) and social cohesion (Opitz et al., 2016). However, results from literature indicate that the economic profitability is controversial, therefore peri-urban agriculture should be sustained by municipal authorities and integrated into land use planning (Azunre et al., 2019). Furthermore, the assessment of these practices should involve not only the economic dimension but also the social and environmental ones (Yingjie, et al., 2019; Ardente et al. 2003).

[1] According to the comprehensive study of Opitz et al. (2016), peri-urban agriculture is here intended as a 'small- to large-scale agriculture that cultivates agricultural land predominantly at the fringes of cities. It is first and foremost economically motivated and is operated by professionals with medium to large distribution pathways from direct marketing up to global value chains.'

The quantitative assessment of the urban and peri-urban agriculture role at the urban scale in mitigating the environmental impacts of food systems has not been addressed until very recently (Benis and Ferrão, 2017). In this context, the Life Cycle Assessment (LCA) is a methodology widely adopted by the scientific community in the quantification of the environmental impacts associated to the whole food supply chain (Nemecek et al., 2016). In fact, the systemic and scientific approach of LCA, internationally standardized by the ISO 14040 (ISO, 2006a; ISO, 2006b), ensures the robustness of the results obtained and the comparability between different options. LCA is a useful support for assessing the environmental sustainability of different agriculture practices and for identifying options aimed at improving the global environmental performance of agricultural products (Castellani et al., 2017; Cellura et al., 2018; Cerutti et al., 2018; Longo et al., 2017).

For instance, in the study of Roy et al. (2009) the LCAs of both processed (bread, beer and tomato ketchup) and agricultural (dairy, meat, rice, sugar beet, potatoes, and tomatoes) food products, were reviewed. The authors pointed out that organic agriculture causes lower GHG emissions but higher land demand.

In the study of Borsato et al. (2018), authors reported values of carbon footprint, water footprint and energy ratio between the nutritional intake and the energy consumption for seven food categories (fruits, dry fruits, vegetables, pulses, cereals, oil crops, and animal products) based on reviewed studies. Results highlighted that higher environmental impacts are due to animal products while lower ones are due to vegetable ones. This is in accordance with the results from Clune et al. (2017), who elaborated a database with mean values of Global Warming Potential (GWP) for five food categories (fresh vegetables, fresh fruits, staples, dairy, ruminant livestock and non-ruminant livestock) and founded that a clear hierarchy emerges across them, with lowest impact for plants while highest for meat from ruminants.

Moreover, LCA can be used to identify the most environmentally impactful stages of a productive chain. Cellura et al. (2012) assessed five vegetables (peppers, melons, tomatoes, cherry tomatoes, and zucchini) cultivated in Southern Italy and observed that the use of materials for the packaging and the greenhouses construction were the most impactful stages for most of indicators, while cultivation activities accounted for the 20-46% of energy consumptions. In the study of Mistretta et al. (2019), an analysis of eight conventional and organic food chains (bread, potatoes, lettuce, yogurt, rice, milk, tomatoes, flour in an institutional catering in Northern Italy is developed. Results show that cultivation activities generate 66% of life cycle energy consumption and 69% of GWP.

Fewer studies are found in literature concerning urban and peri-urban agriculture. Among them, Pérez-Neira and Grollmus-Venegas (2018) use the LCA methodology in order to analyse the energy metabolism, carbon footprint and economic profitability of three small family farms in Seville, featured by different models of production and distribution. Authors adopt a cradle-to-consumption boundary and assume both hectares and kilograms of production as functional unit (FU). The Community Supporting Agriculture initiative shows the best results among the three case studies. Yingjie et al. (2019) perform an LCA in order to compare the carbon footprint of two farms for conventional vegetables production in Beijing. They assume a cradle-to-consumption system boundary and selected the amount produced in a specific year as FU. The results show better environmental performances for a small family farm, while for a large-scale one the best performances are traced when taking economic profitability into consideration. An urban community farm in London, organically producing vegetables and fruits, is assessed by Kulak et al. (2013) through an LCA approach. Results show that adopting organic and local food chains may reduce largely GHG emissions, compared to conventional food-chains, although they cannot satisfy the entire annual food demand. In the study of Rothwell et al. (2016), the supply chains of fresh vegetables are assessed in case of peri-urban farms in Sydney as opposed to a larger farm placed in Victoria State (Australia). Authors conclude that larger impacts occur for the delocalised production due to transportations, which further increases if combined with synthetic packaging. Benis and Ferrão (2017) apply the LCA methodology to evaluate to what extent urban and peri-urban agriculture in Lisbon metropolitan area would play a role in mitigating the environmental impacts of entire urban food systems in terms of greenhouse gases emissions and land use. Specifically, the authors assessed the potential benefits related to the transition toward healthy diet characterized by a higher share of vegetables and fruits compared to the current diet. Further, they assess the benefits which can be derived from the elimination of loss and wastage and from the reduction of transportation distances due to an increased efficiency of the food supply chain. The scenarios are compared based on the same diet energy content assumed as functional unit. The system boundaries include all the steps from cultivation to distribution. The study shows that higher environmental benefits are related to the adoption of the healthier diet. However, urban and peri-urban agriculture strategies enhancing the efficiency of the food supply chain, reducing losses and wastage and shortening transportation distances can further increase the mitigation potential.

The examined LCA studies reveal that the potential contribution of urban and peri-urban agriculture in reducing the energy and environmental impacts of food provision requires further analysis and scientific assessments. In this framework, this study aims at assessing the sustainability of an urban regeneration project through peri-urban agriculture in Milan (Northern Italy) and at providing a useful support towards the implementation of sustainable practices for the involved start-ups in compliance with some strategies of the "Driving urban transitions to a sustainable future" (Urban Europe, 2019). The assessment involves both environmental and economic dimensions of the sustainability concept. In detail, the environmental dimension is investigated by applying the LCA approach and the economic one by evaluating the food production costs. Different scenarios are investigated in order to provide a set of energy and environmental data that can represent a useful support in peri-urban agriculture planning and, in general, to regeneration process of deprived urban area. For spatially analysing the energy-environmental impacts of the farming practices, the representation of results through Geographic Information System (GIS) makes the information more accessible and understandable for stakeholders.

2 Methods

The examined peri-urban area is involved in the European Urban Innovation Actions (UIA) project 'OpenAgri - New Skills for new Jobs in Peri-urban Agriculture' (OA) (UIA-OpenAgri website). Such a project is particularly interesting as it proposes the creation of a coherent urban-rural food governance system, towards the implementation of a circular economy along the whole chain. At the core of the project, there is the settlement of a so-called 'Open Innovation Hub on Peri-Urban Agriculture' in a peri-urban area of Milan (Italy) to deliver innovation in the agri-food chain and focusing on new skills and jobs. The project site includes the agricultural area of 'Vaiano Valle', in which start-ups, selected through a public call, are beginning agricultural activities based on organic[2] and innovative farming practices, such as intercropping[3] and agroforestry[4], and mainly local chains[5]. Within the OA project, the analysis of the main impacts, related to energy and matter main flows of food production has been carried out, and pertinent indicators and indexes to quantify and monitor them have been defined and calculated.

The methodology proposed in this paper is illustrated in Figure 1. More in detail, it is based on primary data collected through extended experimental studies carried out in the period April-July 2019, including meetings, on-site visits, interviews and follow-up activities with farmers involved in the OA project. In detail, semi-structured interviews, including both qualitative and quantitative questions on crops cultivation planning and the food chains stages, have been carried out. Data on raw materials, farm machines and related fuels, routes and related transport consumptions, as well as harvest yields, have been collected and periodically updated by means of phone calls with the representatives of the start-ups.

The environmental assessment of the agri-food items produced in the examined peri-urban food hub has been carried out through a Life Cycle Assessment approach according to the ISO 14040 series of standards (ISO, 2006a; ISO, 2006b). The non-renewable primary energy consumption and the global warming potential are provided as results. In addition, also the productive land (PL) needed for the different productions is assessed. These three indicators are selected following a debate involving the partners of the OA project and other local stakeholders in order to provide understandable and 'ready to use' metrics on the environmental burden of food production. In order to provide decision makers with a synoptic view of the aspects analysed, the results obtained are represented through a spatial analysis accomplished through GIS tool. Moreover,

[2] Organic agriculture: crop management able to produce food obtained with organic methods in accordance with the Council Regulation (EC) No 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing Regulation (EEC) No 2092/91 and subsequent amendments and additions (Caputo et al., 2017).

[3] Intercropping: farming practice involving two or more crop species growing together and coexisting for a time, which can provide several advantages versus the monocrop system including better land use efficiency, maintenance of soil fertility, reduction of disease and pest incidence (Monti et al., 2019).

[4] Agroforestry: farming management practice characterized by the deliberate inclusion of woody perennials on farms, which usually leads to significant economic and/or ecological benefits between woody and non-woody system components (UNEP, 2017).

[5] Local agriculture: crop management able to produce food whose main ingredient is produced within a defined area (geographic area, distance in km, etc.), indicated by the client. In this case, a distance of 50/60 km is considered as in (Caputo et al., 2017).

according to the cash flows of the involved start-ups and on available statistics on the food market, some economic feasibility insights are provided.

The methodology is applied to five scenarios, described in Section 2.3.

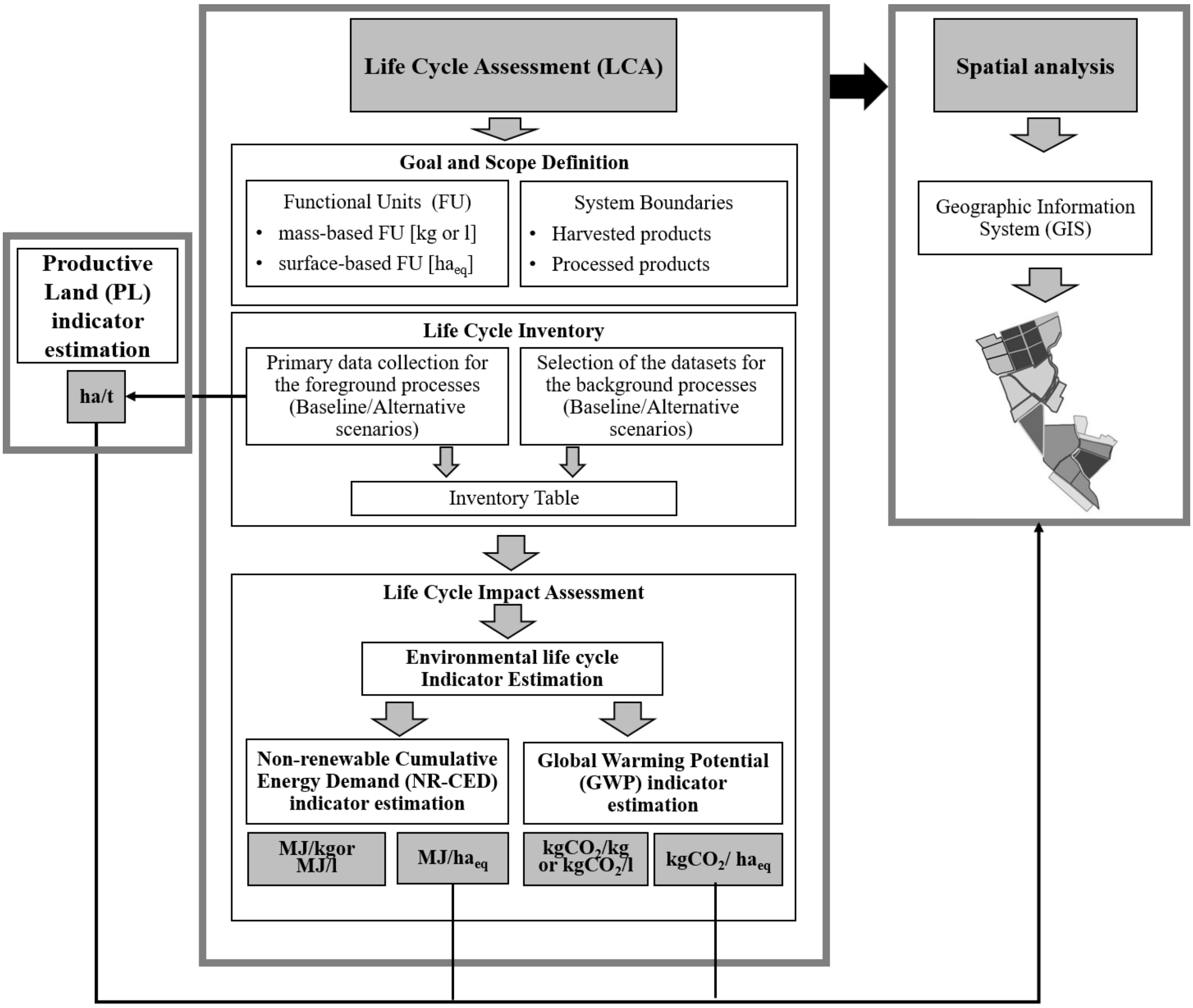

Figure 1. Flow-chart of the methodological approach adopted.

2.1 Goal definition

The goals of the Life Cycle Assessment study are:

- to assess the life cycle energy and environmental impacts related to the peri-urban agriculture area, considering the dual perspective of 'sustainable food production' and 'sustainable planning and management of the territory';
- to identify the hot-spots along the agri-food supply chain;

- to identify potential environmental improvements related to different agricultural practices and different selected crops.

2.2 Study site

The system examined is an innovative hub including 33 hectares of agricultural land. This is a peri-urban land located in a flat area in the South-East of Milan (Lombardy Region, northern Italy). The land, named ‘Vaiano Valle’, is undergoing an urban regeneration process because it belongs to a critical zone of the metropolitan area due to social and economic deprivation (Figure 2). Since autumn 2018 5 start-ups have been starting agricultural activities involving 26 different food chains and 2 processed products, mainly based on sustainable farming practices, as summarized in Table 1. According to the nomenclature adopted in Table 1, for sake of simplicity, the involved start-ups are identified hereafter with letters from A to E. Data for modelling the activities of the considered start-ups are based on the following assumptions. All agricultural activities (i.e. from the land preparation to the harvest) for start-ups A, B and C were accomplished between autumn 2018 and summer 2019. Activities related to the processed products of start-ups B and C are still at the planning stage, thus data from technical literature are used. Regarding the start-up D, the agricultural activities are still at the planning stage, therefore data estimated by entrepreneurs are used. Moreover, in this particular case, which foresees the implementation of an agroforestry system, data on raw materials and transportations are accounted only for the food products. Data on farm machineries are estimated by the farmers for both food products and perennial trees, by weighting their impact on the cultivated surface of food crops. About the start-up E, the agricultural activities are still at the early planning stage, thus data used are both estimated (in case of farm machineries time of use) and from technical literature (in case of mass of seeds, transports and harvests yields). Moreover, even if most of the area is dedicated to polifita grass while only a smallest share to the cultivation of peppers, the activities along the whole land have been considered.

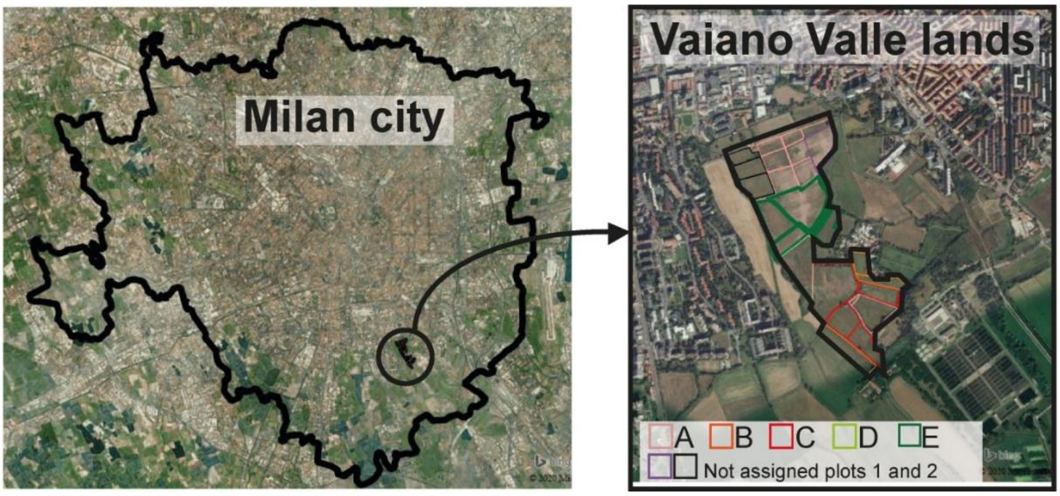

Figure 2. Study site map.

Table 1. Features of the 5 start-ups.

START-UP	PLOT AREA [ha]	FORESEEN CULTIVATIONS	CULTIVATED NET AREA [ha]	FARMING PRACTICE	PROCESSED PRODUCTS
A	5.40	Barley	0.30	Intercropping - organic	-
		Lentils			-
		Chickpeas	1.00	Organic	-
B	2.38	Barley	2.00	Organic	Beer
C	6.40	Spelt	6.00	Organic	Bread
D	2.20	Vegetables (black / kohlrabi / savoy cabbages, chards, Asparagus, artichokes, sweet potatoes, radishes, maize, beans)	0.88	Agroforestry – organic	-
		Fruits (cherries, apples, sorbs, plums, peaches, mulberries, pomegranates, figs and berries)	0.20		-
E	6.60	Chili peppers	0.003	Organic	-

2.3 Scope definition

Based on the main goals of the study, two functional units are considered:

- a mass-based FU, i.e. per ‘kg’ of harvested products or ‘kg’ and ‘l’ of processed products for the sustainable food production perspective;

- a surface-based FU, i.e. per equivalent hectare ‘ha_{eq}’ for the sustainable planning and management of the territory perspective.

The system boundaries chosen are ‘from-cradle-to-farm gate’ and include the production of the seed/tree seedling, the production of fertilizers (if the case occurs), the preparation of soil through ploughing, swathing, mowing, harrowing, the mechanical sowing and harvesting (if the case occurs), the plants pruning and chipping (if the case occurs), and the transports.

In addition, for start-ups B and C, since the processed products are beer and bread, respectively, the transformation processes performed are also taken into account.

The eco-profiles of materials and energy sources used to model the agri-food supply chains are based on the Ecoinvent 3 database (Wernet et al., 2016) accessed through the SimaPro tool (SimaPro website).

The system boundaries are illustrated in Figure 3.

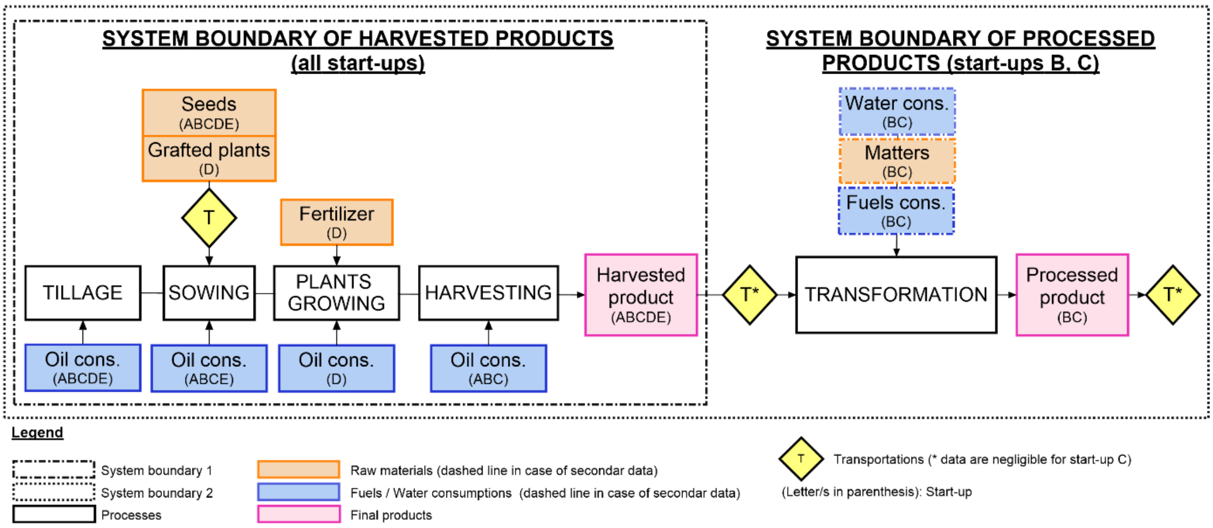

Figure 3. Adopted system boundaries.

Since this research group was committed to give suggestions about the definition of a set of indicators able to take into account the interests of the stakeholders involved in the OpenAgri project, three synthetic indicators, two of which determined through the Life Cycle Assessment methodology, were selected in order to provide a clear insight on the outcomes in terms non-renewable primary energy consumption, global warming potential and consumed land on the results of the project.

Cumulative Energy Demand model (Frischknecht et al., 2007) is applied to calculate the NR-CED indicator, and the IPCC 2013 model (IPCC, 2013) is used to estimate the GWP over a time horizon of 100 years. Further, according to the aims of the overall project, another indicator is provided, i.e. the PL, which is calculated as inverse of the crops' yields [ha/t]. PL estimation is based on primary data or statistical data, depending on data availability (MIPAAF, 2016).

For each crop, to calculate the above three indicators per equivalent hectare, the produced masses, NR-CED and GWP per year are divided by the net area devoted to related crop. The calculation is carried out including doubled areas for both the intercropped and the rotational cultivations and excluding the areas devoted to other activities (e.g. maintenance), in order to avoid misleading information, as underestimating the impact of farms which use only a small area of the assigned plot. For the sake of comparability, such evaluations only regard the harvested products.

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The value of NR-CED, GWP and PL per equivalent hectare is calculated through the following Equations 1, 2 and 3.

$$I_{ha,NR-CED} = \frac{\sum_{i=1}^{n}\left(I_{NR-CED\,crop-i}\right)}{\sum_{i=1}^{n}\left(A_{crop-i}\right)} \tag{1}$$

$$I_{ha,GWP} = \frac{\sum_{i=1}^{n}\left(I_{GWP\,crop-i}\right)}{\sum_{i=1}^{n}\left(A_{crop-i}\right)} \tag{2}$$

$$PL = \frac{\sum_{i=1}^{n}\left(A_{crop-i}\right)}{\sum_{i=1}^{n}\left(P_{crop-i}\right)} \tag{3}$$

where:

$I_{ha,NR-CED}$ = indicator of annual NR-CED per equivalent hectare for the Vaiano Valle area [MJ/ha_{eq}]

$I_{NR-CED_{crop-i}}$ = indicator of annual NR-CED for the i[th] crop [MJ]

A_{crop-i} = productive land area of the i[th] crop [ha_{eq}]

$I_{ha,GWP}$ = indicator of annual GWP per equivalent hectare for the Vaiano Valle area [$kgCO_2eq/ha_{eq}$]

$I_{GWP_{crop-i}}$ = indicator of annual GWP for the i[th] crop [$kgCO_2eq$]

PL = indicator of productive land per equivalent hectare for the Vaiano Valle area [ha_{eq}/t]

P_{crop-i} = annual food production for the i[th] crop [t]

Furthermore, in order to provide each start up with a set of indicators useful for obtaining, for example, an environmental certification or an environmental management system, the NR-CED, GWP and PL indicators are calculated with reference to the individual start up. Specifically, the following Equation 4 is used for the estimation of the NR-CED indicator of each start up. The same principle is applied for calculating GWP and PL indicators of each start up.

$$I_{ha,NR-CED,su_j} = \frac{\sum_{i=1}^{n}\left(I_{NR-CED_{crop-i}}\right)_{su_j}}{\sum_{i=1}^{n}\left(A_{crop-i}\right)_{su_j}} \quad (4)$$

where

$I_{ha,NR-CED,su_j}$ = indicator of annual NR-CED per equivalent hectare for the j[th] start-up [MJ/ha_{eq}]

$I_{NR-CED_{crop-i}}$ = indicator of annual NR-CED for the j[th] start-up [MJ]

A_{crop-i} = productive land area of the j[th] start-up [ha_{eq}].

2.4 Life Cycle Inventory: Baseline and alternative scenarios

First, a baseline scenario (S1) is defined to assess the designed organic farming practices based on the current state of progress of the activities planned as described in Section 2.2.

Concerning start–up A, an organic agricultural practice is considered for chickpeas, lentils and barley. The cultivation processes involve the employment of a plough and a harrow for the tillage processes. Sowing takes place mechanically through a sowing machine fuelled with diesel. Finally, the transport process related to the seeds supply is considered. In detail, chickpeas and lentils come from Central Italy, while barley is local.

With reference to start-up B, the organic cultivation of barley and the brewery are assessed. The tillage processes are accomplished with a plough and harrow, followed by mechanical sowing and mechanical harvesting. The barley seeds are shipped from a distance of 60 km; thus, the harvest is considered to be shipped to a local storage, the malt to a factory placed in a neighbouring region and, lastly, the produced beer to a town near Milan to be sold to consumers. The beer production from barley in start-up B is modelled based on a study referred to brewery in UK (Amienyo and Azapagic, 2016). Based on the data reported in that study, a productivity of 13.7 litres of beer from 1 kilogram of barley is considered. The production process also requires water, hops, yeast, diatomaceous earth, sodium hydroxide, phosphoric acid, sulphuric acid, carbon dioxide and heat. The water consumption is assessed by means of the European dataset of tap water production. Dataset for modelling the production of hops and the yeast were not available. Then, according to Amienyo and Azapagic (2016), they have been assimilated to the barley. The diatomite for beer filtering has been neglected, since the dataset was lacking. The sodium hydroxide, the phosphoric acid, the sulfuric acid and the carbon dioxide are modelled with the proper datasets.

Concerning start-up C, the organic cultivations of spelt and the baking are assessed. In detail, plough and a harrow for the tillage processes, seeder and, the harvester are considered in the analysis. For start-up C, both spelt seeds and baking are local. The baking is split into the flour production phase, which is modelled on the basis of the LCA food dataset (LCA food website) and the bread production one, which is modelled based on field report (Caputo et al., 2015).

For start-up D, first land preparation is considered as performed with a mower and a swather, then an auger for perennial trees planting, a chainsaw for trees pruning and a chipper for woodchips production towards soil protection, while both manual sowing and harvesting are planned within a Community Supported Agriculture. About transports, the shipment of grafted plants from a neighbouring region is considered.

Regarding start-up E, a tractor and a shredder have been considered for tillage and a seeder for mechanical sowing. Seeds is assumed as local.

The routes travelled for the provision of seeds to the agricultural lands and, in case of processed products, in the next steps of the food chains are accounted for by considering a lorry with a weight of 16-32 tons and Euro 5 emission class.

Three alternative scenarios are defined for assessing the effect of possible changes in terms of the farming practices. Additionally, a scenario regarding the delocalized and conventional production of the foreseen food chains is assessed. The assessed scenarios are the following:

- an ‘upgraded’ scenario (S2) is defined to assess the effects of possible improvements compared to the current practices. In detail:
  - for start-up A, an increment of productivity is forecasted according to MIPAAF decree (MIPAAF, 2016); in particular, for legumes an opportune irrigation technique is accounted to this end;
  - for start-up B, an increment of productivity according to MIPAAF decree (MIPAAF, 2016) due to use of fertilizer (i.e. urea) and localization of the brewing into a closed building whose refurbishment is one of the tasks of the OpenAgri project are considered;
  - for start-up C, an increment of productivity was taken into account according to MIPAAF decree (MIPAAF, 2016);
  - for start-up D, an increment of productivity according to start-ups estimates and MIPAAF decree (MIPAAF, 2016) and due to vegetables irrigation is considered;
  - for start-up E, the addition of cabbage cultivation on a 1 ha land, productivities according to MIPAAF decree (MIPAAF, 2016) and additional consumptions due to irrigation are considered

  As prior assumption valid for all interested start-ups activities, it should be pointed out that the accurate assessment of water consumptions and related energy-environmental impact has been a hard task, because it depends on many climate and agronomic factors (rainfall, crops characteristics and growing period and the related mismatch). Furthermore, in the project OA, the irrigation system has to be realized yet and, as such, there is a large degree of uncertainty on its final design and features. Hence, considering such uncertainty, it has been decided to model the irrigation system considering a range of possible values. In detail, a dataset including electricity and oil consumptions, machinery and additional infrastructure such as pump or water pipe, is considered;
- an ‘organic monoculture’ scenario (S3) is defined in order to minimize the energy-environmental impacts. To that end, the least energy-environmental impacting food chain, chosen among the ones already operating due to higher quality of primary data, i.e. the cultivation of spelt towards baking (start-up C), has been extended to the entire project area;

– a ‘conventional monoculture’ scenario (S0b) is defined in order to assess the use of lands for the cultivation of silage maize as animal feed. Maize grains are assumed locally supplied and are modelled with the Swiss maize grain dataset towards production of animal feed;

– a ‘conventional delocalized’ scenario (S0a) is defined in order to assess the effects of producing the same food products with conventional practices (including consumption of agrochemicals, larger use of farm machineries, orchards facilities realization) and importing them from other Italian regions or even European countries (legumes from Tuscany, cereals from France, except for maize assumed as local, chards, radish and asparagus from central Italy, cabbages, artichokes and chili peppers from south Italy, potatoes from France, apples, prunes, sorbs, peaches and strawberries from different regions in northern Italy, cherries, pomegranates and figs from south Italy).

Table 2 summarizes the scenarios features while Table 3 the related input data.

Table 2. Scenarios features.

Land plot of start-up	S1	S2	S3	S0a	S0b
A	Organic chickpeas, intercropped lentils and local barley	As S1a with greater yields		Conventional not local chickpeas, lentils and barley	
B	Organic local barley + not local brewing	Local fertilized barley with greater yields + local brewing		Conventional not local barley + brewing	
C	Organic local spelt + local bakery	As S1a with greater yields	Organic monoculture of spelt (i.e. the least impacting food chain in S2)	Conventional not local spelt + bakery	Conventional monoculture of local silage maize (as animal feed)
D	Agroforestry - Organic local fertilized vegetables and fruits	As S1b with greater yields		Conventional not local vegetables and fruits	
E	Organic local chili peppers	Organic local irrigated chili peppers and fertilized cabbages		Conventional not local chili peppers and cabbages	

Table 3. Input data for the assessed start-ups with reference to defined scenarios[6].

START-UP	CROPS	CROPS YIELD [t/ha]			FERTILIZERS [kg/FU]		FARM MACHINERY TIME OF USE [s/FU]		WATER DEMAND [m³/FU]	TRAVELLED DISTANCES [km]		
		S1	S2	S0a	S1	S2	S1	S2	S2	S1	S2	S0a
A	Chickpeas [PR]	0.50 [PR]	2.03 [T]	2.53 [T]					0-0.25 [T']	400 [C]	400 [C]	300 [T]
	Barley [PR]	0.57 [PR]	4.59 [T]	5.74 [T]	0 [PE]	0 [PE]	50.6 [PE]	33.8 [C]	0	35 [C]	35 [C]	1000 [T]
	Lentils [PR]		1.22 [T]	1.52 [T]					0-0.25 [T']	400 [C]	400 [C]	300 [T]
B	Barley for brewing [PR]	3.50 [PR]	5.74 [T]	5.74 [T]	0 [PE]	0.02	11.7 [PE]	10.5 [C]	0	338 [C]	60 [C]	1150 [T]
C	Spelt for baking[7] [PR]	3.48 [PR]	4.17 [PE]	3.91 [T]	0 [PE]	0 [PE]	4.3 [PE]	4.3 [PE]	0	35 [C]	35 [C]	1146 [T]
D	Black cabbages [PE]		24 [T]	30 [T]					0-0.08 [T']			
	Kohlrabi cabbages [PE]						7.6 [PE]	6.2 [C]				850 [T]
	Savoy cabbages [PE]		34 [T]	43 [T]					0-0.06 [T']			
	Chards [PE]		20.6 [T]	25.8 [T]					0-0.10 [T']			200 [T]
	Asparagus [PE]	10 [PE]	20 [PE]	9 [T]	6 [PE]				0-0.07 [T']			
	Artichokes [PE]		15.5 [T]	43 [T]		6 [PE]	10.4 [PE]	7.6 [C]	0-0.10 [T']	150 [C]	150 [C]	1000 [T]
	Potatoes [PE]		36.6 [T]	46 [T]					0			
	Maize[8] [PE]			12 [T]			7.6 [PE]	6.2 [C]	0-0.10 [T']			50 [T]
	Beans [PE]		20 [PE]	29 [T]					0			300 [T]
	Radishes [PE]			25.8 [T]					0-0.07 [T']			200 [T]

6 PR: primary and real data – PE: primary data based on entrepreneurs' estimates – T: tertiary data – T': tertiary data that are used in S2 for the estimation of the maximum impacts related to irrigation - C: calculated data by the research group.

7 The values for spelt adopted in scenario S2 have been also adopted for the scenario S3 (organic monoculture).

8 The values of 59.37 t/ha and 50 km have been adopted for the scenario S0b (monoculture of silage maize).

	Cherries [PE]		10 [PE]	8.3 [T]	0.04 [PE]	0.04 [PE]	17.6 [PE]	17.6 [C]				850 [T]
	Apples [PE]	20 [PE]	25.7 [T]	32 [T]	0.03 [PE]	0.03 [PE]	8.8 [PE]	8.0 [C]				300 [T]
	Sorbs [PE]		20 [PE]	21.3 [T]				8.8 [C]				
	Plums [PE]	16 [PE]	17 [T]		0.04 [PE]	0.04 [PE]	11.0 [PE]	10.7 [C]				200 [T]
	Peaches [PE]		16 [PE]	15.1 [T]				11.0 [C]	0			
	Mulberries [PE]	10 [PE]	10 [PE]	10 [T]			17.6 [PE]	17.6 [C]				
	Pomegranates [PE]	20 [PE]	20 [PE]	25 [T]	0.03 [PE]	0.03 [PE]	8.8 [PE]	8.8 [C]				1000 [T]
	Figs [PE]	16 [PE]	16 [PE]	10 [T]	0.04 [PE]	0.04 [PE]	11.0 [PE]	11.0 [C]				
	Berries [PE]	12 [PE]	12 [PE]	3.35 [T]	1.08 [PE]	1.08 [PE]	14.7 [PE]	14.7 [C]				200 [T]
E	Chili peppers [PE]	12 [T]	12 [T]	15 [T]	0 [PE]	0 [PE]	2.6 [PE]	2.6 [PE]	0-0.07 [T']	0 [C]	0 [C]	1000 [T]
	Cabbages [C]	ND	24 [T]	30 [T]	ND	6 [C]	ND	13.0 [PE]	0-0.08 [T']	ND	0 [C]	850 [T]

3 Results

In the following subsections, the impacts assessed in the study are reported while referring to both the mass-based and the surface-based functional units as well as in terms of spatial analysis of the area.

3.1 Energy-environmental impacts per mass of food

In the following, the Non-Renewable Cumulative Energy Demand, Global Warming Potential for one year referred to a mass unit of food (kilogram or litre) are reported for each of the 26 harvested products and the 2 processed products for the baseline scenario S1 (Figure 4).

In detail, the start-up A food chains returned the largest impacts due to low productivity, with one of the most relevant contributions being due to raw material production, mainly to GWP. More in detail, the results show the highest NR-CED and GWP for chickpeas, mean for lentils and lowest for barley because the former require the largest amount of seeds but returned the lowest yield, and vice versa. It can be noted that, usually, the largest responsibility to the NR-CED is due to farm machineries, which account for the 76-94% of the total impacts, while the contribution of transports is not particularly relevant since goes from a negligible value for the local barley to 5% for chickpeas.

Better results are reported for the other cereals, whose impacts are dominated by farm machineries (94% in start-up B foodchain and 82% in start-up C foodchain). Regarding the brewing, the larger contribution to the assessed impact categories is due to raw materials (i.e., in decreasing order, yeast, hops and water) and chemical compounds production (i.e. carbon dioxide, sodium hydroxide, phosphoric and sulfuric acids) processes (71% of NR-CED), while the transportation is only the 7% of NR-CED, although not-local routes are included. Considering a productivity of 13.7 litres from 1 kg of barley mentioned in section 2.3, the NR-CED would increase up to 8.5 MJ/l and 0.63 kgCO_2eq/l. Regarding the baking, the spelt cultivation represents the 35% of NR-CED, while the processes are responsible for the 64%.

In the case of start-up D, the impacts of vegetables and fruits are very low if compared to the other food products assessed so far, i.e. below 1.0 MJ/kg and 0.1 kgCO_2eq/kg, except for berries. The largest contribution comes from farm machineries for all products, although with quite variable values (49-83% for vegetables and 75-86% for fruits). Conversely, the berries impacts are affected by a probably overestimated fertilizers mass (61% of NR-CED).

In case of start-up E, very low impact is for peppers, due to adopted techniques and to the considered yield. Anyway, also in this case the most important contribution comes from the machineries (72%).

In addition to the Life Cycle Assessment based indicators above described, also productive land , calculated as inverse of the crops' yields as mentioned in Section 2.3, is evaluated and reported togheter with GWP and NR-CED in the following Figure 4. The activity of start-up A requires the highest surface among the start-ups due to low productivity; start-ups B, C and E present low PL values due to good yields; in case of start-up D, low PL indicators indicate the use of greater intensive and productive agriculture.

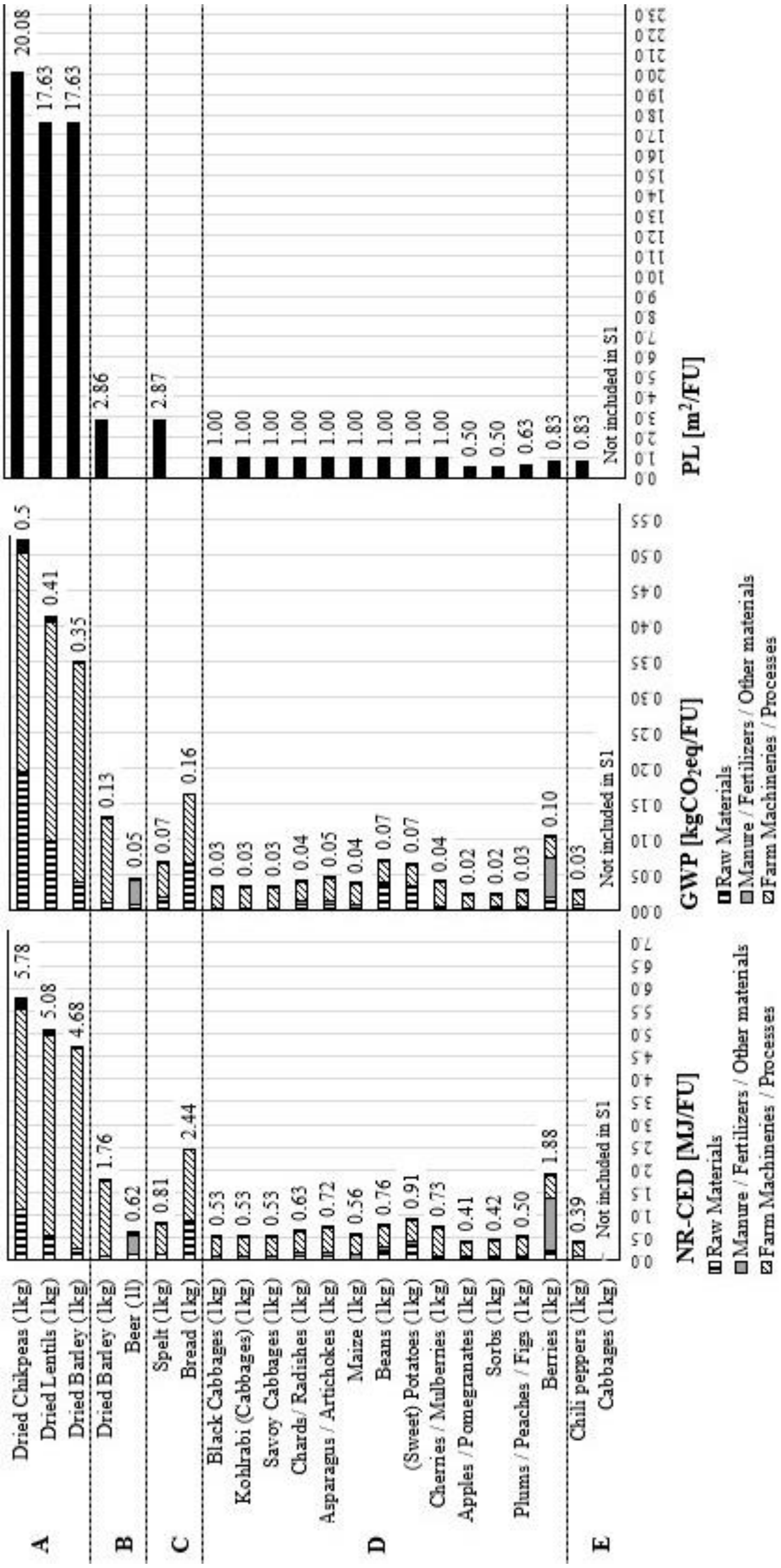

Figure 4. NR-CED, GWP and PL per mass unit of food in scenario S1.

The results of the other scenarios investigated are reported in Table 4 and compared with S1 following.

In case of start-up A, 'upgraded scenario' (S2), if compared with S1, show a reduction of NR-CED due to higher productivity. Comparable NR-CED occurs in the 'conventional delocalized' scenario (S0a), due to greater yields, while larger GWP occur due to greater use of agrochemicals and machineries. Relevant contributions in both NR-CED and GWP are also from irrigation in both scenarios.

In case of start-up B, the 'upgraded scenario' (S2) does not imply a greater change in both NR-CED and GWP, since the larger yield mitigates the effects of the use of fertilizer. Conversely, the conventional production of barley could imply about double NR-CED, whose responsibility is almost equally shared between machineries and chemical compounds, and larger GWP. In case of brewing, the localization of the foodchain reduced the transportation contribution to 0.05%, while in the 'conventional delocalized' scenario (S0a), transportations are the 23%.

In case of start-up C, regarding spelt cultivation, the assumption on increased yield (S2) implies a slight improvement in NR-CED and in GWP compared to S1. Looking at the baking, a similar NR-CED is in both scenarios. Clearly, a conventional scenario would return in significantly greater energy-environmental impacts, due to both more impactful agronomic practices (use of compounds, more machines, etc.) and higher distances for the raw materials supply. Regarding the single contributions to the NR-CED in S1 and S2, the energy consumption for spelt cultivation is dominated by farm machineries (82%). In case of baking, the spelt cultivation phase accounts for the 33-35% of the energy consumption in S1 and S2. Clearly, since it is a fully local food chain, transportation consumptions are not relevant in both system boundaries. In S0a, the role of raw material and chemical compounds production is relevant, and transportations could increase up to 6%.

In case of start-up D, a slight decrease of both energy consumptions and GWP of vegetables is generally implied if considering null impacts due to irrigation, while a significant increase is to be expected if considering the maximum impact due to irrigation. In case of fruits, values of NR-CED and GWP in the upgraded scenario (S2) are comparable, due to absence of irrigation. For fruits, the largest responsibility in energy consumption lies in machineries (28-86%). Much larger energy consumptions and emissions would be implied in most cases in the conventional scenario, mainly due to machineries and manure / agrochemicals but also calculation assumptions.

In case of start-up E, the peppers impact increases in the upgraded scenario (S2) due to water demand. The new cultivation, i.e. cabbages, returns energy-environmental impacts lower than peppers, even in case of maximum impact due to irrigation. Larger impacts occur in case of conventional food chains.

With regard to the monoculture scenarios, the organic one implies minimization of the impacts, while the conventional one is based on impacts lower on average than the 'conventional delocalized' one. However, it is worth noting that a strong reduction in biodiversity and other environmental benefits is expected in both cases.

Table 4. Results obtained for the alternative scenarios.

START-UP	**CULTIVATIONS**	**NR-CED [MJ/FU]**				**GWP [kgC0$_{2eq}$/FU]**				**PL [m^2/FU]**			
		S2	**S3**	**S0a**	**S0b**	**S2**	**S3**	**S0a**	**S0b**	**S2**	**S3**	**S0a**	**S0b**
A	Chikpeas	3.24		2.70		0.25		0.72		4.93		3.95	
	Lentils	3.24		4.47		0.21		1.19		8.20		6.56	
	Barley	4.41		4.49		0.31		0.56		2.18		1.74	
B	Barley	3.18		4.49		0.20		0.56		1.74		1.74	
	Beer (1l)	0.58		1.49		0.04		0.15		ND		ND	
C	Spelt	0.68		6.57		0.05		0.82		2.40		2.56	
	Bread	2.36		6.27		0.16		0.65		ND		ND	
D	Black Cabbages	0.49		4.63		0.03		0.42		0.42		0.33	
	Kohlrabi (Cabbages)	0.49		4.63		0.03		0.42		0.42		0.33	
	Savoy Cabbages	0.37		3.23		0.02		0.30		0.29		0.23	
	Chards	0.59		1.15		0.04		0.10		0.48		0.39	
	Asparagus	0.73	0.68	3.28	1.91	0.05	0.05	0.28	0.29	0.50	2.40	1.11	0.17
	Artichokes	0.71		0.74		0.05		0.06		0.64		0.23	
	Maize	0.52		3.42		0.04		0.37		0.50		0.83	
	Fresh Beans	0.97		2.53		0.09		0.11		0.50		2.88	
	(Sweet) Potatoes	0.86		1.55		0.06		0.14		0.27		0.22	
	Radishes	0.59		7.02		0.04		0.60		0.50		0.39	
	Cherries	0.73		2.90		0.04		0.26		1.00		1.21	
	Apples	0.40		1.94		0.02		0.06		0.39		0.31	
	Sorbs	0.43		1.12		0.02		0.03		0.50		0.47	
	Plums	0.51		1.12		0.03		0.03		0.59		0.47	
	Peaches	0.51		1.58		0.03		0.14		0.63		0.66	
	Mulberries	0.74		2.39		0.04		0.21		1.00		1.00	
	Pomegranates	0.43		0.86		0.02		0.07		0.50		0.40	

	Figs	0.51	2.39	0.03	0.21	0.63	1.00
	Berries	1.88	13.32	0.10	1.34	0.83	2.99
E	Chili peppers	0.39	2.02	0.03	0.17	0.83	0.67
	Cabbages	0.24	4.63	0.01	0.42	0.42	0.33

3.2 Energy-environmental impacts per equivalent hectare

Figure 5 reports food production, Non-Renewable Cumulative Eergy Demand, and Global Warming Potential per surface unit of cultivated land and the cultivated land surfaced along scenarios and based on equations (1) and (2) in Section 2.3. Noteworthy, the values of NR-CED and GWP indicated over the black bars in S2 refer to the maximum impact for irrigation. It can be noted that, ranging from scenario S1 to S2, both the equivalent hectares and the production of food increase. This implies an increase also in energy consumptions and greenhouse gas emissions per land surface unit but a decrease per mass unit of food because the relevant increase of food production is not proportional to the increment in land use.

In S3, the lowest impacting scenario could be achieved by adopting an organic monoculture, although it would decrease the agricultural biodiversity and the types of food produced.

A scenario based on conventional and delocalized food production (S0a) would imply a dramatic increase of the energy consumptions and GHG emissions. In detail, comparing its results with the ones for S2 with maximum impacts due to irrigation, each year about 30 GJ/ha and 3.8 tCO_2eq/ha would be saved, while having a comparable productivity.

Relevant impacts are achieved also by supposing the settlement of a conventional monoculture of silage maize (S0b). Again, by comparing its results with the S2 with the greatest conservative assumptions, interesting annual savings (4.1 GJ/ha for NR-CED and 3.8 tCO_2eq/ha for GWP) would be reported.

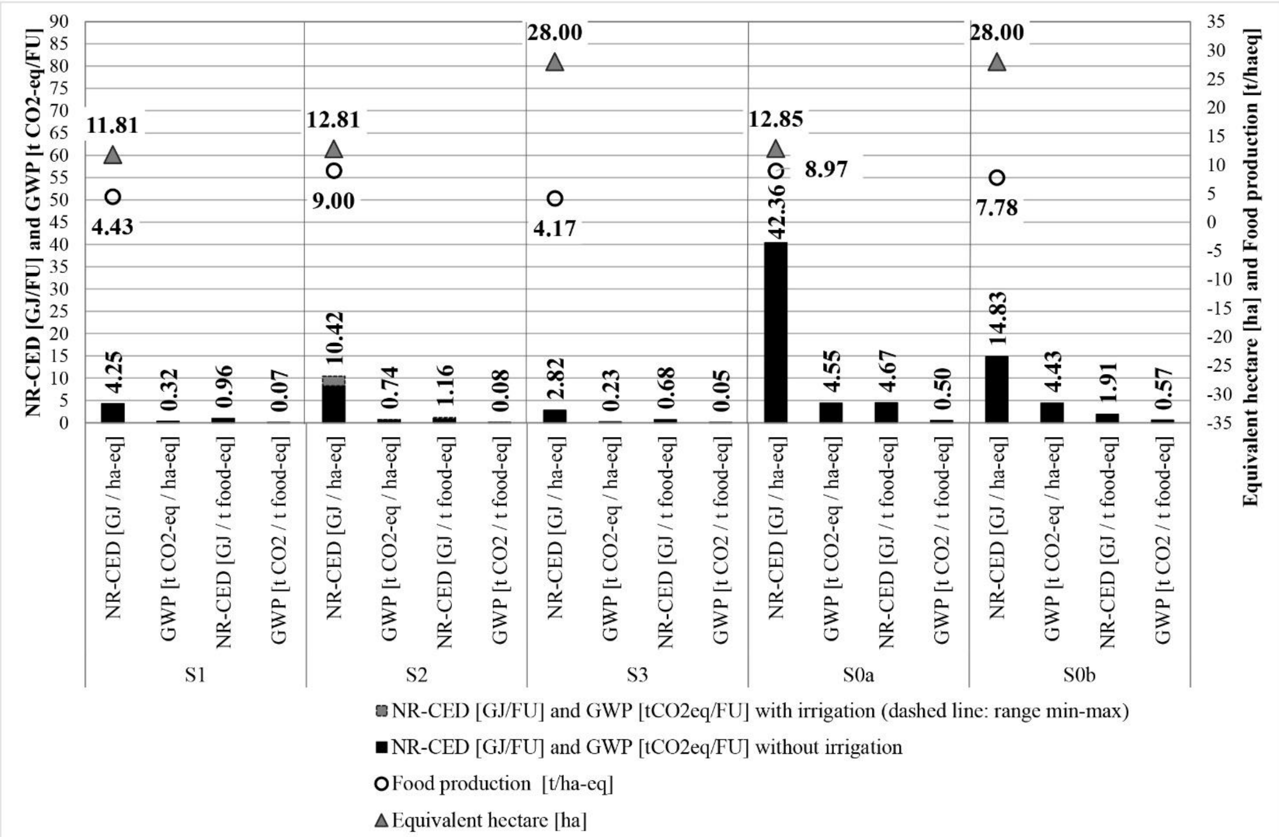

Figure 5 . Energy-environmental impacts per equivalent hectare.

3.3 Development of a set of GIS maps

As an innovative contribution to the representation of the results obtained through the Life Cycle Assessment, a set of a Geographic Information System maps of the cultivated area has been developed, as a support for the involved operators in spatially analysing and representing the effects on the energy and environment of peri-urban agriculture. More in detail, this representation consists of four types of maps showing the foreseen cultivations, the food production, the Non-Renewable Cumulative Eergy Demand and the Global Warming Potential, per unit surface of cultivated land, along all scenarios.

Hence, the approach allows to assess the behaviour of a start-up, either according to one indicator along all scenarios or according to more indicators in one scenario, as well as to compare different start-ups behaviours. As an example, Figure 6 shows the four maps with reference to scenario S2[9], Figure 7 and Figure 8 show a set of maps regarding the same indicator (NR-CED and GWP, respectively) along selected scenarios.

[9] Noteworthy, the metrics of S2 refer to the most conservative conditions with greatest impact attributed to irrigation.

Summarizing, the maps clearly visualize the enrichment achievable in terms of biodiversity and lower energy-environmental impacts from the forecast agri-food activities. Accordingly, the project offers the opportunity of valorising an abandoned area with activities that allow boosting new skills and jobs in the district, through the cultivation of sustainable products which also feed a local market, both in terms of suppliers and customers.

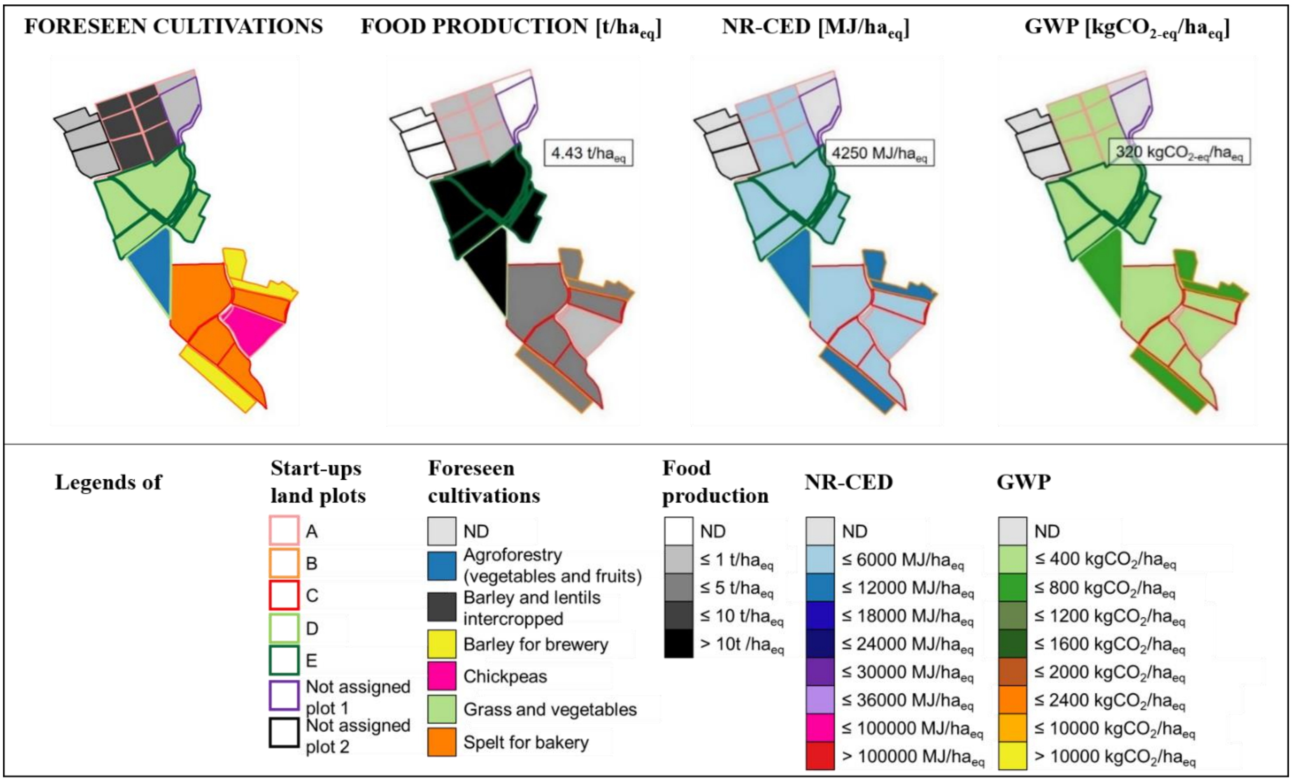

Figure 6. GIS maps obtained for scenario S2.

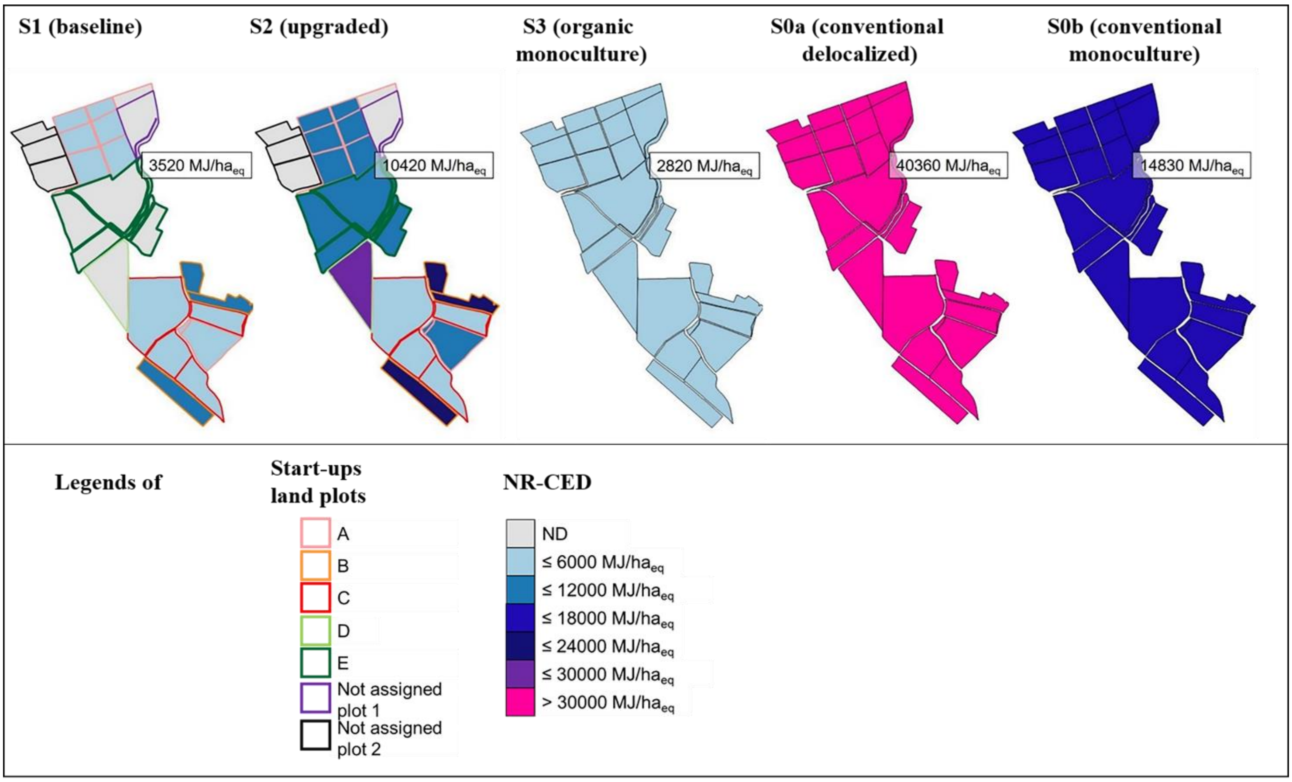

Figure 7. GIS maps of NR-CED along scenarios.

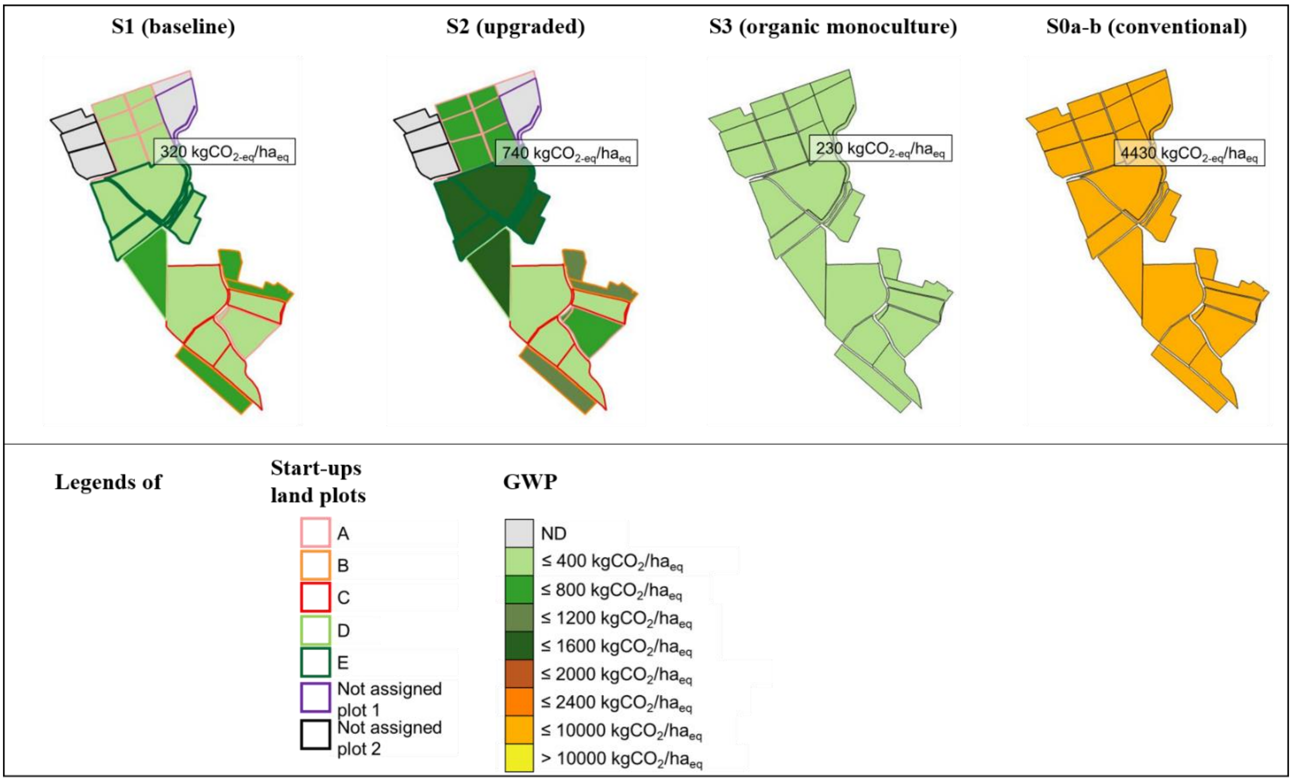

Figure 8. GIS maps of GWP along scenarios.

4 Discussion

From the previous subsection on the Life Cycle Assessment evaluated impacts per mass unit, interesting results for the foreseen food chains compared with the conventional agriculture practices emerged. These results are in line with previous researches, as discussed in subsection 4.1. Moreover, the results from the GIS analysis of the energy-environmental impacts show that the whole experience is promising since it has the potential to increase the local production of healthy food (e.g. organic agrochemicals free) and at the same time give new value to an abandoned urban area. However, during the project several issues in terms of available resources and facilities were raised, affecting also its replicability in other contexts. Therefore, to preliminarily assess the economic profitability of these foodchains, start-ups' productive costs are provided in subsection 4.2.

4.1 Comparison with evaluations from technical literature

From the examined technical literature (Borsato et al., 2018; Caputo et al., 2017; Cellura et al., 2012; Clune et al., 2017; Del Borghi et al., 2018; Kulak et al., 2013; Köpke & Nemecek, 2010; Mistretta et al., 2019; Nemecek et al., 2008; Quirós et al., 2014), provided values on the energy-environmental impacts of food chains similar to the ones analyzed in this study have been elaborated in order to obtain the share attributable only to the cultivation phase. Although literature data in some cases refer to either different case studies or average values, the related energy consumptions and greenhouse gas emissions were compared with the results of the study, in Figure 9. It can be noted that, in literature, cereals and legumes have the highest Non-Renewable Cumulative Eergy Demand values among food products. Conversely, vegetables and fruits can have Global Warming Potential values greater than cereals and fruits, probably because of larger variability in the reported agricultural practices. Concerning the results from this study, NR-CED of legumes are similar to literature, while lower values are traced in the case of cereals, followed by vegetables and fruits. In terms of GWP, data from literature are significantly higher than the data estimated in this study, possibly due to foreseen innovative and low-impact food chains.

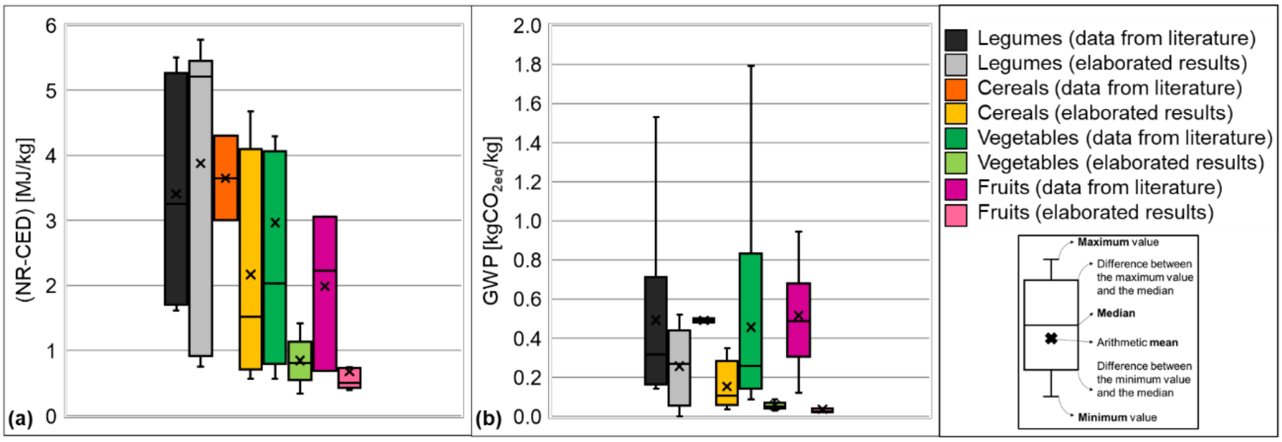

Figure 9. Comparison among annual (NR-)CED (a) and GWP (b) by food category.

4.2 Insights on economic feasibility of selected start-ups

Despite the objective of the OpenAgri project is to promote the development of jobs and skills to globally improve the conditions of the involved area and not to develop activities strictly business-oriented, the analysis of the economic performances of the involved start-ups cannot be overlooked. In order to provide a first estimation of the economic feasibility of the process, costs of production for three of the five start-ups in case of scenario S1 have been collected. Costs of start-up B, which comprise all the activities on field, the transports and the processing of barley into malt, account for 1.40 €/kg; costs for start-up C for spelt, which comprises all the activities on field, accounts for 0.21 €/kg while for bread production, which comprises storage, transportation and baking, account for 4.34 €/kg; costs for start-up D, which comprise all activities required on field for setting the agroforestry system and raw transportations, accounts for 3.33 €/kg. Such costs are in some cases higher than statistics of prices at source of organic products in Italy. Average 2019 prices, from data provided by the national Institute of the agri-food trade services (ISMEA website), are: for barley of 0.23 €/kg, for spelt of 0.29 €/kg, for fruits of 1.35 €/kg and for vegetables of 0.75 €/kg. Moreover, from (Caputo et al., 2017) a wholesale price of bread of 1.01 €/kg was provided. Therefore, it can be noted that, on the one hand, the products obtained by innovative farming techniques in small farms are more targeted on highly conscious customers, while, on the other hand, methods and measures for an optimization of the food chains in order to make them more economically sustainable should be investigated.

Moreover, it is interesting to highlight that for the start-ups producing cereals (B, and C) the main expenditure is due to farm machineries and processes (93% for barley, 80% and 69% for spelt and bread, respectively), while in the agroforestry system (start-up D) another relevant expenditure, together with farm machineries and processes (58%), is represented by the supply of raw materials, i.e. (perennials and fruit) trees and vegetables (39%).

5 Conclusions

Urban community farms can contribute to regenerate deprived urban areas, providing citizens jobs, leisure, healthier diets, food and environmental education, awareness and participation.

Furthermore, these initiatives can help to reduce both losses in biodiversity associated with conventional food production and improve the global metabolism of cities by promoting recycle and reuse practices, according to the new circular economy paradigms.

The OpenAgri project proposes the development of local food chains in order to give value to a peri-urban area, otherwise occupied by abusive activities or massive building construction. In this frame, a sample of five pilot start-ups is starting the farming activities targeted on production of sustainable food and on boosting a local market, both in terms of suppliers and customers.

Hence, as an added value, the project has avoided further conventional agri-food production.

In this frame, this study has been intended at integrating the Life Cycle Assessment-based evaluations on energy and environmental impacts of food production within the urban regeneration processes. To that end, it has also been accomplished the spatial representation of provided indicators in Geographic Information System. In this way, the impacts of the implemented practices have been compared against possible improvements and also against common agricultural practices, highlighting, in this last case, relevant savings even in most conservative conditions.

As lesson learnt, first it is recommended to select suitable areas in order to prevent possible criticalities related to disadvantageous field conditions (e.g. water availability, urban pollution, etc.).

Additionally, it is quite difficult to achieve a local chain in all steps and the five start-ups have all dealt with the issue in different ways, since the choice of local products is interesting only under determined conditions. Hence, based on these study findings and on a long-term perspective, the actors of the start-ups could be encouraged to improve the sustainability of their agricultural practices, through the choice of renewable energies-based farm machineries or more efficient practices and digital tools for the monitoring of the field conditions.

As another remark, for obtaining a more comprehensive assessment, elaborated information should be interpreted together with the ones on agronomic features and produced food nutritional content, costs of investment and operation, jobs opportunities and required skills.

Considering the limited availability of tertiary data on any food products and the not always geographic representativeness of existing LCA databases, this study also contributes to enrich technical literature with new information on the energy-environmental impacts of 26 crops plus two processed products for both organic and conventional scenarios.

In conclusion, a monitoring campaign is under development in order to update primary data and enlarge the adopted system boundaries.

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