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Urban horticulture: reducing food miles to improve cities microclimate and environmental sustainability

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“Ti abbiamo tagliato,
albero!
Come sei spoglio e bizzarro.
Cento volte hai patito,
finché tutto in te fu solo tenacia
e volontà!
Io sono come te. Non ho
rotto con la vita
incisa, tormentata
e ogni giorno mi sollevo dalle
sofferenze e alzo la fronte alla luce.
Ciò che in me era tenero e delicato,
il mondo lo ha deriso a morte,
ma indistruttibile è il mio essere,
sono pago, conciliato.
Paziente genero nuove foglie
Da rami cento volte sfrondati
e a dispetto di ogni pena
rimango innamorato
del mondo folle”.

*(*Hermann Hesse. *Quercia potata* da *Il coraggio di ogni giorno)*

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List of acronyms, abbreviations and notation

ARPA	Agenzia Regionale per la Protezione Ambientale
ASHRAE	American Society of Heating, Refrigerating and Air- Conditioning Engineers
BIA	Building Integrated Agriculture
CAAB	Agri-Food Centre of Bologna
CF	Carbon Footprint
CF	Characterization Factor
CO_2	Carbon dioxide
CO_2 eq.	Carbon dioxide equivalent emissions
CS	Case Study
CV	Cultivar
EEA	European Environment Agency
EF	Ecological Footprint
ELCD	European Reference Life Cycle Database
EPA	Environmental Protection Agency
ET	Evapotranspiration
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FU	Functional Unit
FW	Fresh Weight
GDO	Grande Distribuzione Organizzata.
GHG	Greenhouse Gases
GWP	Global Warming Potential
HDPE	High Density Polyethylene
HP	Horse Power
IBIMET – CNR	Istituto di Biometeorologia del Consiglio Nazionale delle Ricerche
ILCD	International Reference Life Cycle Data System
IPCC	Intergovernmental Panel on Climate Change
IRTA	Institute of Agriculture and Food Research and Technology
ISO	International Organization for Standardization
ITA	Italian Trade Agency
LCA	Life cycle assessment

LCC	Life cycle costing
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LDPE	Light Density Polyethylene
LED	Light Emitting Diode
MAGRAMA	Ministerio de Agricultura, Alimentación y Medio Ambiente
MJ eq.	Mega Joules equivalent
MMTCO$_2$	Million Metric Tons of a gas
PE	Polyethylene
PP	Polypropylene
PVC	Polyvinyl chloride
PVM	Predicted Mean Vote
ResCUE-AB	Research Centre in Urban Environment for Agriculture and Biodiversity
RQ	Research Question
RUAF	Resource Centres on Urban Agriculture and Food Security
SECH	Spanish Society of Horticultural Sciences
SETAC	Society of Environmental Toxicology and Chemistry
UA	Urban Agriculture
UHI	Urban Heat Island
ZFarming	Zero-acreage Farming

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Summary

Human population growth rates determine future population and cities sizes. By gathering together people and production, cities also concentrate the demand for fresh water and other natural resources, food included. In addition, because the urban sprawl has destroyed agricultural land, it is necessary to move some of the production from rural to urban areas. This means that it is necessary to re-think our cities, our productive cities.

In this dissertation are explored major strategies for contributing to the challenge of feeding people in urban areas. Particular emphasis is placed on local low-input cultivation systems. The environmental profile of different food supply chains, based on different 'food miles', was assessed. 'Food miles', first coined in '90s, measure the distance that food travels from where it is grown or raised to where it is consumed. The selected methodology to assess the environmental impact was the life cycle assessment (LCA). The impact category chosen was the global warming potential (GWP), thought midpoint methods, the IPCC 2013 100a. It contains the climate change factors of IPCC in a time-frame of 100 years; it is expressed in Kg CO_2 eq.

Nevertheless, it was also evaluated the urban garden's climate mitigation using ENVI-met software and the predicted mean vote indicator.

Here, it was confirmed the important value of gardens and horticultural activities in urban contexts. That, because there is an environmental improvement and the generation of ecosystem services.

Key words: Food Miles; Urban gardens; Horticulture; LCA; City; micro clime mitigation; ENVI-met; PMV; Human well-being; Large-scale production; Vegetables; Fennel; GWP.

Riassunto

Negli ultimi anni si è assistito ad un aumento della popolazione mondiale, e nel 2050 si stima che metà di questa vivrà in agglomerati urbani. Il fenomeno è noto come "urbanizzazione" ed indica lo spostamento delle civiltà dalle zone rurali a quelle urbane. Indubbiamente questa espansione avrà dei riscontri sull'ambiente e sulla disponibilità di risorse. Nelle città, si concentrerà sempre più la domanda di cibo e sarà necessario "ripensare" le aree urbane, in modo da farle diventare centri di produzione.

Il concetto di 'food miles', letteralmente "i chilometri del cibo", misura la distanza che i prodotti alimentari (e non solo) percorrono per arrivare dal produttore al consumatore. Attraverso diversi indicatori è possibile identificare l'impatto delle filiere produttive, quindi dell'emissione di anidride carbonica (CO_2) in atmosfera ogni qualvolta di produce e distribuisce un prodotto. L'intento generale sarà quello di ridimensionare quanto più possibile le filiere produttive.

Valutare e migliorare i sistemi di produzione all'interno delle città è l'obbiettivo di questo elaborato. Per attuare ciò, ci si è basati sull'analisi del ciclo di vita delle filiere produttive prendendo in considerazione il profilo ambientale di piccoli orti urbani o familiari, fino a quantificare le emissioni di CO_2 della produzione su larga scala per la grande distribuzione. Produrre e consumare localmente genera molti benefici, tra cui una mitigazione del microclima urbano. Questo è stato appurato attraverso un caso studio nel quale con l'utilizzo del software ENVI-met si è quantificata la diminuzione di temperatura in un contesto urbano dovuto alla presenza di un orto, nonché al miglioramento del benessere umano (predicted mean vote, PMV).

Questo elaborato e i casi studio presentati hanno confermato il ruolo positivo degli orti, nonché di altre attività legate all'orticoltura urbana. Oltre a migliorare l'accesso al cibo e la sua disponibilità, generano numerosi benefici e servizi ecosistemici.

Key words: Food Miles; Orti urbani; Orticoltura; Analisi del Ciclo di Vita; Città; mitigazione del microclima; ENVI-met; PMV; Benessere umano; Produzione su larga scala; Ortaggi; Finocchio; GWP.

Chapter I

Introduction: general issues on urban agriculture, objectives and case studies

1. Introduction

Human population growth rates determine future population sizes (McKee et al. 2004), and certainly in the past years population has increased and, in 2050, more than half of the world population will live in cities (UN 2013). Mulligan & Crampton (2005) show that between 1950 and 2010 in the world's largest cities the rate growth increased in average 10.53 times. This growth is also linked to the phenomenon of urbanization (Knox 2009), a rural-to-urban areas migration (Ray 1998), one of the most important element of the development, and a generator of social benefits (Bertinelli & Black 2004), but also social injustices. This migration is expected to be particularly prevalent in countries and regions which will be most affected by the changing climate. While urban populations generally enjoy a higher quality of life, many cities in the developing countries have large slums with populations largely excluded from access to resources, jobs, and public services (Buhaug & Urdal 2013).

This growth and cities expansion affect the environment through the so-called "Population Impact" or through the more commonly used indicator the "Ecological Footprint" (EF)[1]. By gathering together people and production, cities concentrate also the demand for fresh water and other natural resources, food included, and inevitably concentrate waste generation (Newman 2006).

Agriculture alone releases between 10 and 12 % of the global quantity of greenhouse gases emissions; this percentage is expected to increase in the future due to the escalating demand for food (Smith et al. 2007).

Agricultural land use is low density but has been very damaging in many places. However hunter-gatherer and agricultural land use can also be adapted to ensure that regional ecosystems are functional and biodiversity is supported (Newman 2006).

In addition, because the urban sprawl has destroyed agricultural land, forest cover and filled up the water bodies in the periphery of cities (Ghosh 2004), it is necessary to move some of the production from rural to urban areas. This means that it is necessary to re-think our cities, our productive cities, because "rural areas" are disappearing.

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[1] Ecological Footprint accounting measures the *demand* on and *supply* of nature. On the demand side, the Ecological Footprint measures the ecological assets that a given population requires to produce the natural resources it consumes (including plant-based food and fiber products, livestock and fish products, timber and other forest products, space for urban infrastructure) and to absorb its waste, especially carbon emissions (http://www.footprintnetwork.org).

Urban problems

Personal insecurity, poverty and environmental degradation may force people to flee the countryside. Other causes can be traced to the increasingly arid soils caused by desertification, and soil salinization. Urban centres tend to offer better health care and other social services. Even if located in an urban area, high population growth may cause serious environmental problems: water scarcity and contamination, land shortage and insufficient sanitation. Although opportunities for employment are usually better in urban areas, the labour market may struggle to absorb fast-growing populations. The higher perceptible inequality in income and privileges among city dwellers is another latent source of urban frustration. Grassroots demands for democratic and economic reforms and a gradual fading of the rural experience are potential contributing risk factors. Strong urban population growth is not necessarily a significant threat to peace and stability; yet, earlier work suggests that within the context of economic stagnation, little job creation, and poor governance it can result in increased risks of violence and political turmoil (Buhaug & Urdal 2013). Economic shocks such as recession or stagnation of local and national economies may increase the differences and the importance of economic privileges, causing the levels of dissatisfaction and complaints to lead to violent reactions (Brennan-Galvin 2002).

Hunger and malnutrition

In an urban context, finding a solution for food production and distribution becomes a crucial issue. Potentially, food demand may increase (Tilman et al. 2011). Rapid urbanization, as reported before, is generating poverty in the cities, increasing food price (Cohen & Garrett 2010), therefore thinking new cultivation systems (Foley et al. 2011) may be essential as well as arranging *ad hoc* policies and solutions to achieve food security (Pothukuchi & Kaufman 1999). Food security is closely linked to the availability of arable land (Rockson et al. 2013) and climate change (Wheeler & von Braun 2013). This concept was first introduced in 1974 at the World Food Summit and, it is important to underline, is the relation between nutritional security, healthy life and the access to food, clean water and to proper sanitation (Pinstrup-Andersen 2009; Dixon et al. 2007). In fact, food security is defined as the situation in which all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO 2003). FAO (2009) reports that currently food production must increase by 70%. However, the problem of hunger has more to do with inequalities in distribution, and increasing food production is only part of the solution: the concept of food security has shifted from simply being a question of availability of food (at the national or even local level) to the more complex issue of access (at the household or individual level) (Armar-Klemesu 2000).

Also, this unequal access compromises the availability of dietary diversity, calories, and gastronomically satisfying food experience, generating nutritional inequalities and diet-related health inequities in rich and poor cities alike (Dixon et al. 2007). Regarding access to food, the most significant difference between urban and rural areas is that people in rural areas can often produce their food, while people in urban areas are more dependent on food purchases (Armar-Klemesu 2000). In Figure 1 are reported some important determinant food, nutrition, and health security.

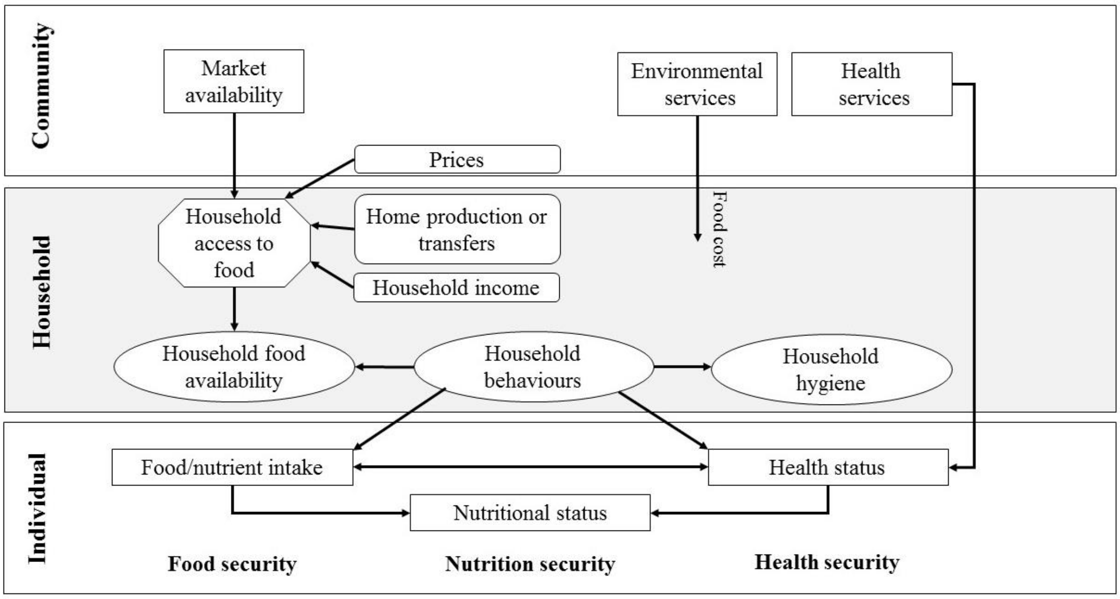

Figure 1 Determinant of food, nutrition and health security (source: adapted from Cohen & Garrett 2010).

In this dissertation are explored major strategies for contributing to the challenge of feeding people in urban areas. Particular emphasis is placed on local low-input cultivation systems. Indeed, supporting the environmental sustainability concept, this work shows how it is possible to produce food using resources at rates that do not exceed the capacity of Earth to replace them (Godfray et al. 2010), and to reduce greenhouse gases (GHG) emissions (20-30% of which currently originate from agricultural activities) (Eigenbrod & Gruda 2015).

1.1 Food and the City

To find some solutions to the problem of food security, Longo (2016) suggests two main approaches:

- the environmental approach seeks to establish a sustainable food system;
- the social justice approach aims to eliminate poverty.

Both could contribute to the dimension of food security, which means to guarantee the production and supply of an adequate quality and quantity of food, and the ability of people to access food. Furthermore, in terms of contributions to development, urban agriculture improvements provide additional income and employment for poor and middle-income urban dwellers, and contributes to an ecological urban environment (Zeeuw et al. 2000). For the above mentioned reasons, new urban food production systems are now being included in town-planning (Redwood 2012; Morgan 2009), and urban agriculture is a broad subject (Ellis & Sumberg 1998; Mougeot 1999; Smit 2001). Including different cultivation systems, urban agriculture has a positive effect on human food consumers. According to Bohn & Viljoen (2011) both quality and quantity of vegetable and fruit uptake were increased crucially by home garden activities. One of the objectives of urban agriculture was to lessen the environmental, health, and social impacts of the food chain production by providing healthy, local food to people in a community. The goal of local production was to obtain “zero mile food”, meaning sustainable fruits and vegetables. This method did not just reduce or eliminate the environmental costs of transport, but could eliminate the packaging, pesticides (herbicides and insecticides) and monocultures used in the majority of the food industry which cause harm to the environment and, potentially, to consumers’ health (Longo 2016).

Urban agriculture became an attractive topic for architecture too, from Howard’s ‘garden city' of the XIX century (Pittari Jr 2003) to the most sustainable and low-energy food production techniques (Odom 2010; Lim 2014; Pascale et al. 2015). Urban agriculture could be an environment-friendly activity to cope with climate change. Indeed, to produce and distribute through an industrial and global supply-chain generate enormous environmental stresses which cause pollution of land, air, rivers and streams and threatens the health of farm workers

and other food producers. This is caused by the high use of input into the food production (Longo 2016).
From an architectural point of view, a good contribution was made by Le Corbusier. His *to it terrasse* could be the pattern of the currently rooftop garden, since his idea was to re-establish the contact between the man and nature (Fig. 2) (Corbusier & Jeanneret 1926).

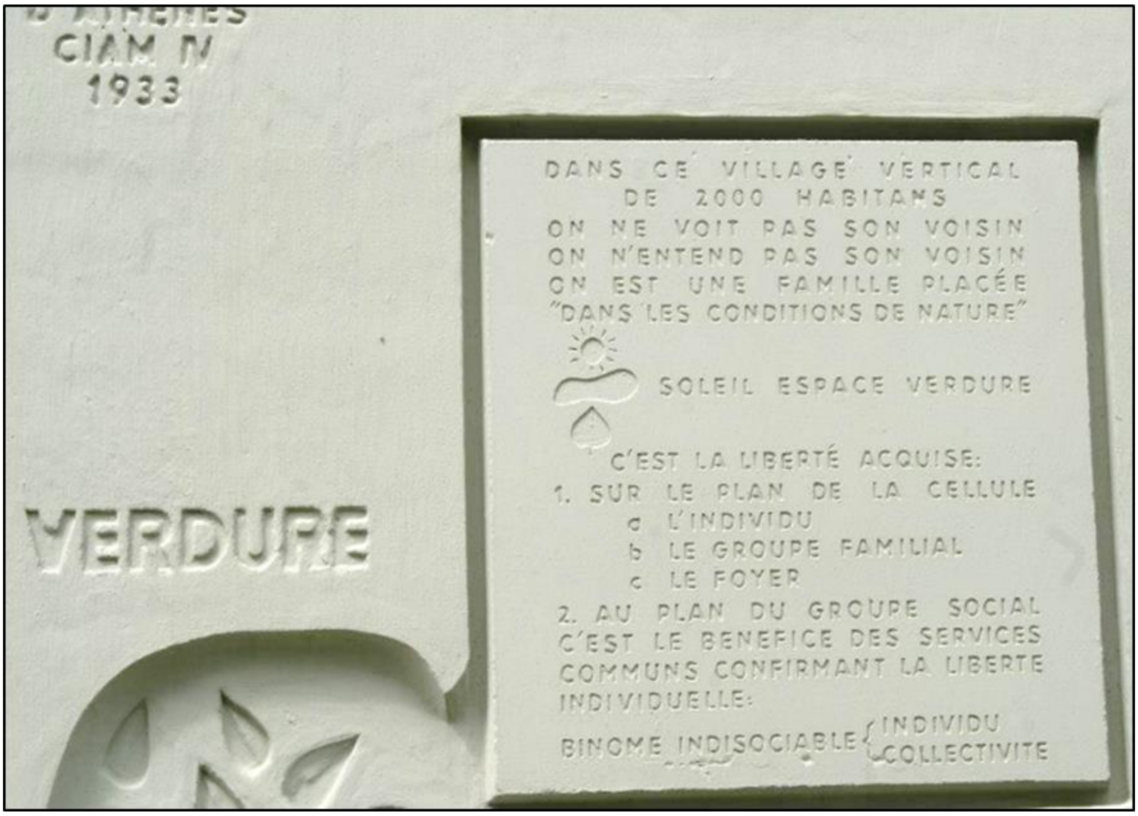

Figure 2 The Modular of Le Courbusier. Particular of the "Unité d'habitation" of Berlin that underlines the importance of food vegetable in a housing (Flatowallee 16, 14055 Berlin-Charlottenburg) ©Daniela Gasperi, 2013.

Specht et al. (2013) reports examples of innovative forms of green urban architecture aiming at combining food production and design to cultivate in and on buildings (e.g. LED cultivation) (Morrow 2008), and achieving the vertical farming or Skyfarming in urban areas shown in Despommier (2009; 2011) and Germer et al. (2011), and also indoor farming (Thomaier et al. 2015; Yeh & Chung 2009). The building integrated agriculture (BIA) has various definitions: according to Caplow (2009), BIA is the integration of greenhouses into the energy and resource cycle of the building, while Specht et al. (2013) define it using the term ZFarming (Zero-acreage Farming). ZFarming means cultivation not in an open field, and can include rooftops and terraces of any building (universities, schools, hospitals, supermarkets, prisons, etc.) (Fig. 3). A more highly developed commercial urban farming is a major component of the urban food system as it supplies urban residents with the more perishable fresh vegetables and animal products and by-products such as poultry, eggs and milk, and provides the diversity needed to ensure dietary quality, an important aspect of food security (Armar-Klemesu 2000; Tei & Gianquinto 2010). All together, these growing trends have led to the emergence of innovative practices to face challenges such as the scarcity of arable land in dense cities where available and affordable land is a rare commodity (Benis & Ferrao 2016). In addition, they could be a response to the need of investing in ecological infrastructure to meet demands of sustainability and resilience (Dieleman 2015).

Figure 3 ZFarming – Simplified soilless systems rooftop garden in Bologna (Via Gandusio, 12). Social building integrated agriculture, especially horticulture. ©Daniela Gasperi, 2012.

1.1.1 Food miles

Food and cities are linked by the concept of ‘food miles’, which was first coined in the ‘90s. This concept highlighted the negative environmental and socio-economic impacts of the increasing food transport (e.g. air pollution, soil pollution, loss of biodiversity, noise pollution, road accidents, and animal welfare). Watkiss et al. (2005) and Veleva & Ellenbecker (2001) consider food miles as an indicator of sustainable development: It measures the distance that food travels from where it is grown or raised to where it is consumed to estimate the environmental impacts (mainly CO_2 emissions), and the sustainability of foods (Schnell 2013; Van Passel 2013; Weber & Matthews 2008). Therefore, the calculation may include kilometres travelled as food is shipped from farms to processors, from processors to storage depots, from storage depots to vendors, and from vendors to consumers (Ballingall & Winchester 2010). Food miles can give a clear image of the globalization of the food system since they include the energy consumption of the transport and its carbon costs. In fact, the current organization of our food value chain (agricultural specialization, supermarkets, and large distribution centres) has an important impact on the total distance that our food travels (Van Passel 2013). Different studies investigated on 'vegetable miles' (Pirog & Benjamin 2005; Hill 2008; Coley et al. 2009). In order to reduce food miles, food systems need to be grounded in local ecologies (Murdoch et al. 2000), to source food from as close as possible to where it will be finally consumed. Linking 'food miles' and the concept of 'local' growth (Akaichi et al. 2016), and supposing that the latter could reduce the environmental impact, has become essential for consumers (Sirieix et al. 2007). These two concepts were promoted as powerful polemical tools in policy discourses centred around sustainable agriculture and alternative food systems (Lang and Heasman, 2004 *in* Coley et al. 2011).

However, some politicians and scientists argue that, since food miles ignores greenhouse gases emissions associated with food production, the distance travelled is not a good indicator of environmental sustainability. Nevertheless, the simplicity of the concept and the advertising campaigns urging consumers to substitute imported food with domestic food created the possibility of a change in consumer preferences in favour of local produce (Ballingall & Winchester 2010).

This dissertation will clarify this concept by analyzing case studies, while keeping in mind that increasing food trade (and therefore higher food miles) can have particular advantages, such as higher food export to the poorest countries, higher food diversity, higher food availability, and cheaper food. The most important tool to evaluate the environmental sustainability of food miles is the life cycle assessment (LCA), which will be more deeply analysed in Chapter III. Yang & Campbell (2017) studies on local food and food miles have shown that transport is a minor source of carbon emission, implicating that local food is not an effective mean of helping the environment. However, this dissertation aim is bring to light other potential benefits which food localization may uniquely enable including the recycling of energy, water and nutrients. 'Eat local', but especially 'eat seasonal', because fruit and vegetables, when grown in-season tend to have a lower carbon footprint than fruit and vegetables grown out of season, since they require different production techniques (such as the use of energy-intensive greenhouses) and transport modes (such as air-freight) (Pratt 2013).

1.2 Defining urban agriculture

Definitions of urban agriculture refer both to the production of crop and livestock goods within cities and towns (Zezza & Tasciotti 2010). Another study defines it as an industry located within (intraurban) or on the fringe (periurban) of a town, a city or a metropolis which grows or raises, processes and distributes a diversity of food and non-food products, (re)using mainly human and material resources, goods and services found in and around that urban area, and in turn supplies human and material resources, products and services largely to that urban area (Mougeot 2000). Orsini et al. (2013) made an excellent overview of this topic; however, a single definition of urban agriculture is yet to be achieved.

In some cities, urban households do grow crops and raise livestock, producing some of their food and supplementing incomes. Urban agriculture contributes to the urban ecosystem by reusing its waste to produce food and fuel reducing both the intake and the output in the resource stream. Urban agriculture has become a useful tool for the sustainable recycling of cities' waste (e.g. water, food, raw materials) (Binns et al. 2003; Orsini et al. 2013). Moreover it could use vacant spaces and water bodies as potential resource areas (Smit & Nasr 1992; Ghosh 2004), and support the local food production and consumption (Feenstra 1997). Furthermore, urban agriculture reduces cities' ecological footprint, protects biodiversity and stimulates regional economies (FAO 2014). Growing food on private lands in the city is a political issue in that it challenges taken-for-granted ideas and practices of property and urban agriculture (Wekerle & Classens 2015).

A recent book presented the impressive results and case studies of the COST Action (Urban Agriculture Europe), a networking project funded by the European Union. The project aims to develop a common language to identify and communicate the potential of urban agriculture (Lohrberg et al. 2016) (Table 1). The main characteristics in which different kind of agriculture could be classified are actors involved, the location of production, the products, the technology used and the type of market (Dubbeling et al. 2010).

Table 1 Representation of dimensions of urban agriculture. Interesting research questions to help the investigation on this topic (source: adapted from Lohrberg et al. 2016).

Investigating question	*Dimension*
Where does urban agriculture take place?	SPATIAL (Yokohari et al. 2008; Jackson-smith & Sharp 2008; Lichter & Brown 2011; Zasada 2011)
What does urban agriculture produce (food/non-food)?	FUNCTIONAL (Tornaghi 2014)
Why does urban agriculture take place?	MOTIVATIONAL (McClintock 2010; Tei & Gianquinto 2010; Gasperi et al. 2012)
Where are the products from urban agriculture consumed?	MARKET (RUAF 2015)
How did urban agriculture come into being?	ORIGIN (Daugstad et al. 2006)
Who performs urban agriculture?	ACTOR (Primdahl et al. 2013)

The multifunctional role of urban agriculture

Urban agriculture, and in particular urban horticulture, could generate different benefits: first of all, the food production and food security, then other below illustrated:

- Food production

This role has been analysed in the previous parts. However, it is important to remark the influence on self-sufficiency. Cultivation methods can contribute to communities and families’ food security, producing fresh fruit and vegetables.

- Social and educational

Urban agriculture activities have an impact on the social inclusion and education of minority groups: a reduction of gender inequalities of 65% is assessed (Orsini et al. 2013), and women became more independent. It encourages the socialization. Furthermore, urban agriculture could improve historical and cultural areas. Gardens could also be a strategic tool for education: many projects are developed in schools, with some great results (Skelly & Bradley 2000; Passy 2012; Beery et al. 2014).

- Therapeutic

According to the psychologist Benjamin Rush, working the soil has a curative effect on mental illness and through the process of sweating removes from the body some poisons that cause mental illness (Rush 1947). An interesting work develops the history of this role and confirms the benefits generated by the man-nature relationship, especially for the elderly and young people (Righetto 2015).

- Environmental, ecological and aesthetical

Gardens could have a positive effect on the city because they improve its microclimate quality (e.g. air, temperature, humidity) (Konijnendijk 2003; Harris & Manning 2010), and preserve the biodiversity by maintaining native species and building shelters for the fauna (Salick 2006). Urban agriculture could generate a lot of ecosystem services (Camps-Calvet et al. 2016). In addition, these urban gardens have a positive aesthetical impact on the landscape (Fig.4).

Figure 4 Allmende-Kontor, urban gardens in the former airport, Berlin-Tempelhof. Top left: talking about "the roles of urban horticulture"; other pictures show environmental, ecological and esthetical contributes of gardens. ©Daniela Gasperi, 2013.

1.3 Motivation of the research and structure of dissertation

Since urban horticulture is a multifunctional topic, the following case studies were examined through a multifunctional approach. For that reason, to evaluate benefits of farming practices, collaborations with sociologists, scientists, and public administrators were developed.

To evaluate climate mitigation and environmental profile of urban horticulture, on varying of ‘food miles’, were the main objective of studies. Table 2 shows trials, which have been carried out.

Table 2 Framework of dissertation and main benefits underlined in the case studies.

Chapters	Case study	Benefits	Methods	‘Food miles’
Chapter II	Urban garden (Bologna, IT)	Environmental mitigation (temperature, humidity, wind intensity, etc.); Human well-being	ENVI-met PMV	Km:0 - 50
Chapter III	Home garden (Padua, IT)	Improved food access and food security; Reducing costs; Recreational activity; Environmental friendly	LCA	Km:0 - 50
Chapter IV	Rural production (Abruzzo, IT; Emilia-Romagna, IT; Valencia, ES)	Large scale production and distribution; GDO	LCA	Km: > 100

1.3.1 Objectives and research questions

The objective of this research is to quantify the environmental impact of food production in developed countries: Italy and Spain. In many cities, the presence of urban garden is relevant, so we want to investigate their importance from an environmental point of view. Since the central theme of the present dissertation is the evaluation of the environmental impact of food miles different trials are presented. Two of them regard the environmental impact and benefits generation of urban or home gardens, and the environmental profile of a large-scale off-seasonal fennel production.

Therefore, the research questions are:

- RQ1: Could allotments or home gardens mitigate the urban climate conditions? Have they any effect on human well-being?
- RQ2: Which is the environmental profile of urban gardens? Are cultivation systems influencing factors?
- RQ3: Which are the environmental profiles of a large scale and an off-seasonal production?

Chapter II

Urban gardens & microclimate

This section presents an experiment about the contribution of urban gardens to the mitigation of urban microclimate and generation of benefits for citizens of the city of Bologna (IT). This work was realized in collaboration with Istituto di Biometeorologia del Consiglio Nazionale delle Ricerche (IBIMET – CNR) of Bologna.

2. How could gardens contribute to the urban microclimate?

If appropriately planned and integrated into urban design, urban agriculture can contribute to the comfort of citizens, especially for what concerns human thermal comfort (Georgi & Zafiriadis 2006). Green spaces around apartment blocks and houses, as well as neglected spaces in the city, help to improve the physical climate because vegetation can (Deelstra & Girardet 2000):

- help to increase humidity;
- lower temperatures;
- help to break wind and intercept solar radiation, creating shadow and protected places;
- have a positive effect on increasing biodiversity.

In urban areas, average temperatures are higher than in the surroundings (Zoulia et al. 2009). Due to their albedo, roughness length and soil sealing, cities create their own microclimate, mostly referred to as the urban heat island effect (UHI) (Grimmond 2006). Albedo is an important parameter, since it affects the amount of incoming radiation on the site that is removed by evapotranspiration (average albedo are around 0.20±0.25 for vegetation) (Dimoudi & Nikolopoulou 2003). UHI is an environmental problem resulting in increases in energy consumption due to the increased cooling systems demand, and in unfavourable conditions for human health (Ihara et al. 2007). According to Kato & Yamaguchi (2007), UHI occurs as a result of increased sensible heat flux from the land surface to the atmosphere near cities, it refers to city overheat that is enhanced by the massive substitution of vegetated and impermeable areas by hard surfaces and buildings. The heat island effect reduces dramatically the microclimate regulating capacity of the urban hard surfaces which absorb heat during the day and radiate the heat overnight as infrared radiation (Alcazar et al. 2016). This last aspect strongly depends on the architecture's orientation and shapes and on the presence of overhanging façades (e. g. vertical gardens, galleries) (Ali-Toudert & Mayer 2007; Katsoulas et al. 2016). Façade greening is a promising countermeasure to reduce urban heat (Jänicke et al. 2015). To solve this problem trees and green spaces are being re-introduced into cities. Numerous studies confirm that they have a large effect at moderating the microclimate and also contribute to the cooling of cities as evapotranspiration from vegetation foliage reduces air temperature and increases humidity (Zoulia et al. 2009; Santamouris 2014). Green roofs, for example, reduce the proportion of infrared radiation returned to the air, so that the air temperature does not overheat and help to create an adapted microclimate able to provide comfortable conditions to humans (Alcazar et al. 2016). Bisson (2010) assessed thermal variations introducing parks instead of asphalt in areas of Milan (Italy), and results show that temperature decreases in a range set from 0.25 to 1.5 °C, while locally the difference can vary to 3 °C. The UHI in New York City is characterized by an annual average difference of temperatures between urban and rural sites of about 2.5 °C (Gaffin et al. 2009). Another study simulates the microclimate of single quarters of a typical central European city (average building height is about 12 m, and the 'green' is identified as home gardens, parks, courtyard, etc.). It confirms that moist natural soils lead to a cooling of air temperature, but, on the contrary, dry natural soils can reach nearly the same temperature as asphalt or concrete (Huttner et al. 2008). Some quantitative values caused by wind speed and direction are reported in Kim & Baik (2004).

Usually "greening" simulations deal with green roof or parks (Ng et al. 2012). Results from Noro & Lazzarin (2015) show that 'green ground' scenario allows a decrease in air temperature comprised between 1.4 °C and 3 °C, respectively during the night and the day. The same items for the 'cool pavements' scenario are, respectively, 1.8 and 4 °C. A similar trial, carried out in a square of Bologna after removing some trees, show that a difference in the air potential temperature close to 1 °C in some areas, especially at 3 p.m. when the largest surface warming is present (Georgiadis et al. 2017).

In literature, studies related to microclimate improvement due to the presence of urban gardens are missing. However, in a case study carried out in Chania, Crete, Greece, some interesting results are shown: urban gardens induce a decrease of -3.5 °C in surface temperature, when compared to the scenario's value without the presence of green (Tsilini et al. 2015).

The goal of this study is to investigate microclimatic variations linked to modified parameters. The focus of the analysis is, in particular, on the difference between a "grey" infrastructure and a "green" one (Susca et al. 2011). To introduce scientific evidences on micro-climatic effects of urban horticulture, may help politicians in adopting new policies regarding the introduction of green areas such as allotment or home gardens into the cities. Furthermore, it might help to create a comfortable living space from a thermal point of view, since it is a necessity in today microclimate conditions (Lenzhölzer & Koh 2010).

2.1 Materials and methods

2.1.1 Case study

The experiment took place in a garden (25 m^2) and a terrace (20 m^2) of a private house (Via Arienti, 13 – S. Stefano District) close to the Bologna city centre (Fig. 5). The city centre of Bologna presents a characteristic architecture: low-rise buildings, with relatively narrow roads and a constant presence of arcades and courtyards. The studied garden is similar to a medieval garden, where aromatic and medicinal plants, vegetables and some fruit trees are present.

Figure 5 Segment of urban space reproduced by ENVI-met.

In the experimental site, for 15 days starting on June 16, 2015, a weather station Vaisala WXT510 (Fig. 6) was installed at an altitude of 2 m, where it collected meteorological data from 2 positions, since the thermocouples were placed close to the urban garden and exposed to the sun on the terrace. The station recorded:

- Air temperature (K)
- Relative humidity (%)
- Precipitation (mm)

- Wind intensity (m s^{-1}) and direction (°, sexagesimal degrees).

These data were used by the ENVI-met software; other types of measurements refer to the elaboration of a long-term meteorological monitoring of the ARPA reference station located on Torre degli Asinelli (2010-2014)[2].

Figure 6 Weather station "City runner" located in the field experiment in Bologna, Italy.

In addition, the thermal comfort is detected using the predicted mean vote (PMV) index, which is the result of interaction of six factors: environmental factors (air temperature, relative humidity, air speed and mean radiant temperature) and personal factors (clothing insulation ratio and activity or metabolic heat rate) as described in Figure 7 (Sugiono 2016).

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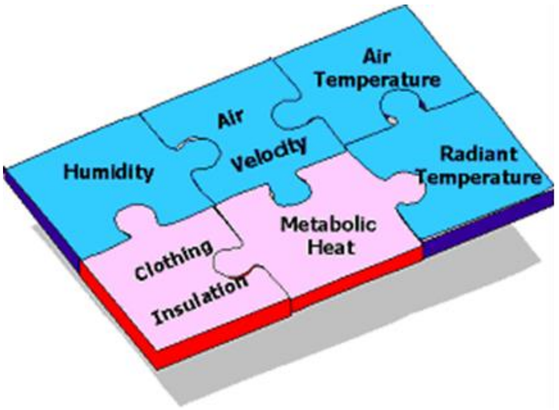
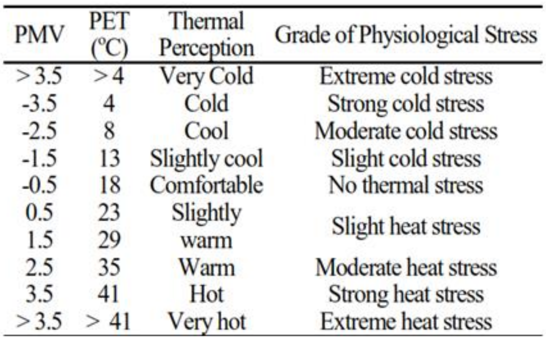
[2] The main characteristics are Longitude 11.346758°, Latitude 44.494199° and height above sea level 148 meters and the measurement station is operated by the local environmental protection agency.





PMV	PET (°C)	Thermal Perception	Grade of Physiological Stress
> 3.5	> 4	Very Cold	Extreme cold stress
-3.5	4	Cold	Strong cold stress
-2.5	8	Cool	Moderate cold stress
-1.5	13	Slightly cool	Slight cold stress
-0.5	18	Comfortable	No thermal stress
0.5	23	Slightly warm	Slight heat stress
1.5	29		
2.5	35	Warm	Moderate heat stress
3.5	41	Hot	Strong heat stress
> 3.5	> 41	Very hot	Extreme heat stress

Figure 7 (Left) the six factors affecting thermal comfort are both environmental and personal. These factors may be independent of each other, but together contribute to an employee's thermal comfort (Source: http://www.hse.gov.uk). (Right) PMV scales with therm.

Numerous researches address this topic (Cena & De Dear 2001; Masmoudi & Mazouz 2004; Berkovic et al. 2012; Cameron et al. 2012; Salata et al. 2015). Ideally, the PMV is a human biometeorology index (Mayer & Höppe 1987), which assesses the thermal comfort equation based on body heat balance in steady state condition (Yao et al. 2009). These values base on the American Society of Heating, Refrigerating and Air-Conditioning Engineers scale (ASHRAE) (Table 3).

Table 3 ASHRAE scale (modified from Nicol 2004).

Description	Hot	Warm	Slightly warm	Neutral	Slightly cool	Cool	Cold
Numerical Value	3	2	1	0	-1	-2	-3

Secondary data

The study used secondary data, elaborated from recorded datasets from the Torre degli Asinelli meteorological station. The data considered (*n*=43430, excluding not received data) in 2010-2014 were divided in different classes according to wind direction (°) and intensity (m s^{-1}). Concerning wind direction, the first class includes values between 0° and 15°, while the last one includes values between 345° and 359°; since 360° correspond to 0° (N, North). Most of the values corresponds to wind direction comprised between 285° and 315° (W-NW, ~30%), out of which around 62% presents a wind intensity of 2-5 m s^{-1} (Fig. 8).

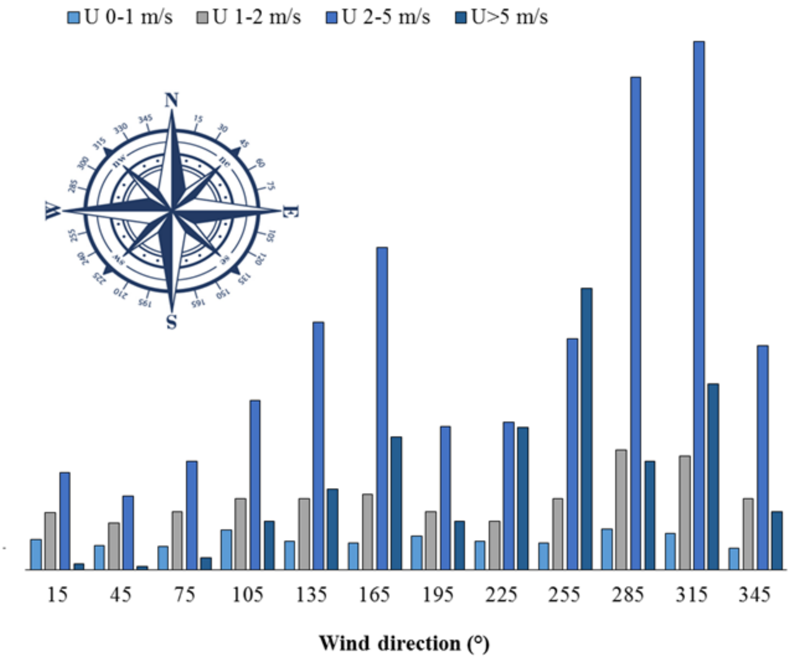


Figure 8 Meteorological data 2010-2014.

The experiment was carried out in June 2015, and the analysis considered also the historical data trend related to June 2010-2014. The same classification was done limiting the analysis on data coming from measurements in June in the considered years (*n*=3588). Most of the values corresponds to wind direction of 255° (W, ~18%, and intensity > 5 m s^{-1}, ~50%), and between 135° and 165° (~22%) (Fig. 9).

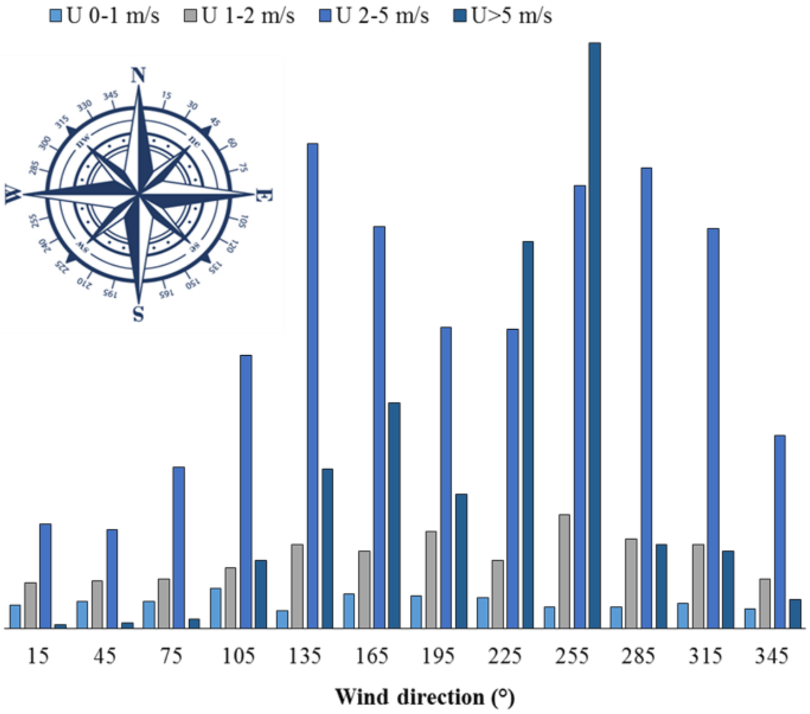


Figure 9 Meteorological data June 2010-2014.

2.1.2 ENVI-met software, setup for the numerical simulations and model validation

ENVI-met[3] is an environment and micro-climatic simulation software, a radiative transfer model and a vegetation model (Bruse & Fleer 1998). The model includes the simulation of aerobiological flow around and between buildings, exchange processes at the ground surface and at building walls, building's physics, and impact of vegetation of the local microclimate, bioclimatology, and pollutant dispersion. It uses a uniform mesh with a maximum of about 250x250x25 cells with the horizontal extension ranging between 0.5-10 m and a standard vertical height of 1-5 m (Bruse & Fleer 1998; Bruse 2004). In this study, an ENVI-met model was constructed according to the actual geometry of the site. For the simulation of surface-plant-air interactions, the same hourly meteorological data from the reference weather station were used to generate the configuration file of ENVI-met. Time resolution in ENVI-met was set to 30 minutes output interval files for receptors and buildings and 60 minutes for all other files, and the hourly average values were used for both validation and analysis purposes. The model run for 96 hours starting at 6 a.m. on June 16, 2015.

Two scenarios were included into the model, characterized by a 165 x 120 x 30 grid with a spatial resolution of 1 m x 1 m x 5 m, and these initial conditions (to set the simulation):

- Wind speed and wind direction at 10 m: 0.8 m s^{-1}, 205° N;
- Surface roughness length (z0): 0.1 m;
- Air temperature (T_0): 22.5°C;
- Specific humidity at 2500 m: 7 g_{water}/Kg_{air}
- Relative humidity at 2 m: 58%

The exact geometry of vegetation (i.e. leaves and branches) is not explicitly modelled in ENVI-met. The presence of vegetation is accounted for by introducing additional parameters in the governing equations to mimic its effect (e.g. flow resistance or pressure drag induced by the plant) (Vos et al. 2013). One of the limitation of this study is that the ENVI-met software does not recognize the evapotranspiration of vegetables crops, but

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[3] Free software is available at http://www.ENVI-met.com.

the classification considers a general difference between grass and tree species. The evapotranspiration (ET) is the combination of two separate processes where the soil surface and crop lose water due to evaporation and transpiration respectively. The ET is influenced by water parameters, crop factors and management and environmental conditions (Allen et al. 1998). Ideally, green grass was chosen, assuming that vegetables have the same evapotranspiration.

2.1.3 Research questions

The aim of the study is to evaluate the potential effect on microclimate of home garden as urban green infrastructure. To do so, we evaluate a case study in the city of Bologna (Italy), comparing two different scenarios.

Fist scenario: Presence of "green" (Fig. 10). All related simulations were carried out at 1 p.m. and at 2 a.m. (night-time) at a height of 1.50 m.

Figure 10 First scenario: presence of "green".

Second scenario: Absence of "green", meaning bare soil (Fig. 11). In both cases, original buildings (dislocation and height), and trees are sketched n the 3D model.

Figure 11 Second scenario: absence of "green.

2.2 Results

In this chapter are reported the main results obtained by the meteorological station data located on the terrace. These data were compared with ENVI-met simulation of the same conditions in order to validate the reliability of model simulations. Finally, the results of the two different scenarios are shown to quantify the real effect of the urban garden in terms of air and surface temperature, PMV and surface turbulent fluxes. The most significant result demonstrates that air temperature is +0.4°C higher in the *second scenario* compared to *first scenario*, the one with the presence of "green".

2.2.1 Meteorological data

First of all, ENVI-met model is validated through a comparison of measurements and simulations results of the two paving materials: grass and asphalt, both on summer time (June). The measurements were done in one courtyard in the city centre of Bologna. For the measurement and simulations, sunny days were chosen to avoid discrepancies between measurement simulation results due to cloudiness.

The ENVI-met model was set to give output results in two points of the simulated area (Fig. 12).

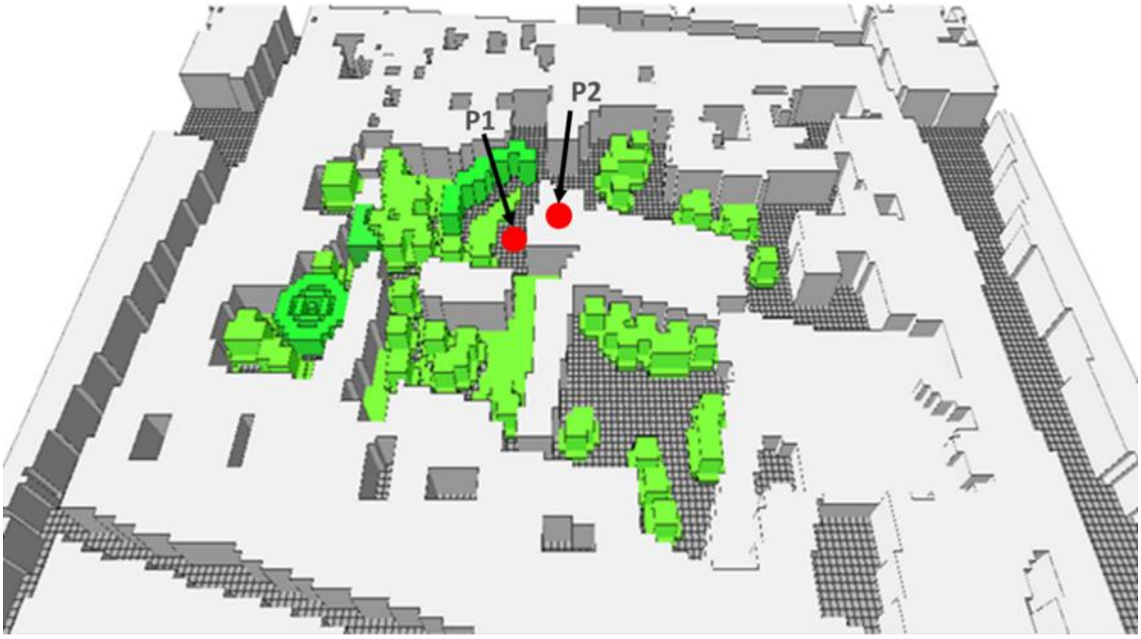

Figure 12 Location of two points where the ENVI-met model was forced to give out temporal series of meteorological parameters.

Simultaneously, the meteorological station recorded data on the terrace (point P2). The wind in June 2015 had a preponderant direction of 225° (SW, ~ 33%), in about ~ 70% has an intensity 0-1 m s^{-1} (Fig. 13).

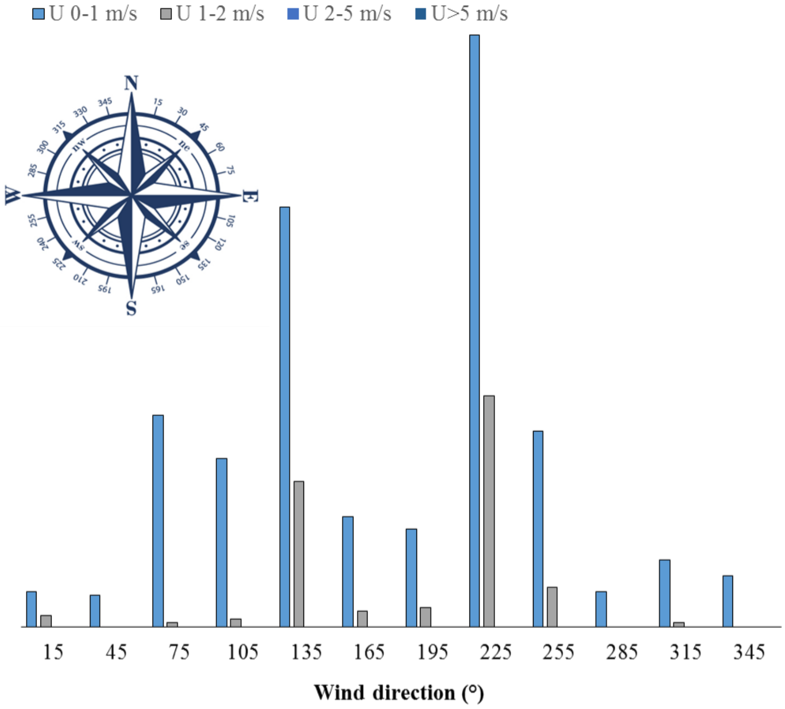

Figure 13 Meteorological data on June 2015.

The ENVI-met output of the temporal series of air temperature was compared with meteorological data. The blue points are data related to the air temperature detected between 15 and 21 June 2015 by meteorological station (data collected every 30 minutes). The orange points are the simulated air temperature at 2.5 m, and the grey ones simulate the air temperature at 12.5 m. (Fig. 14).

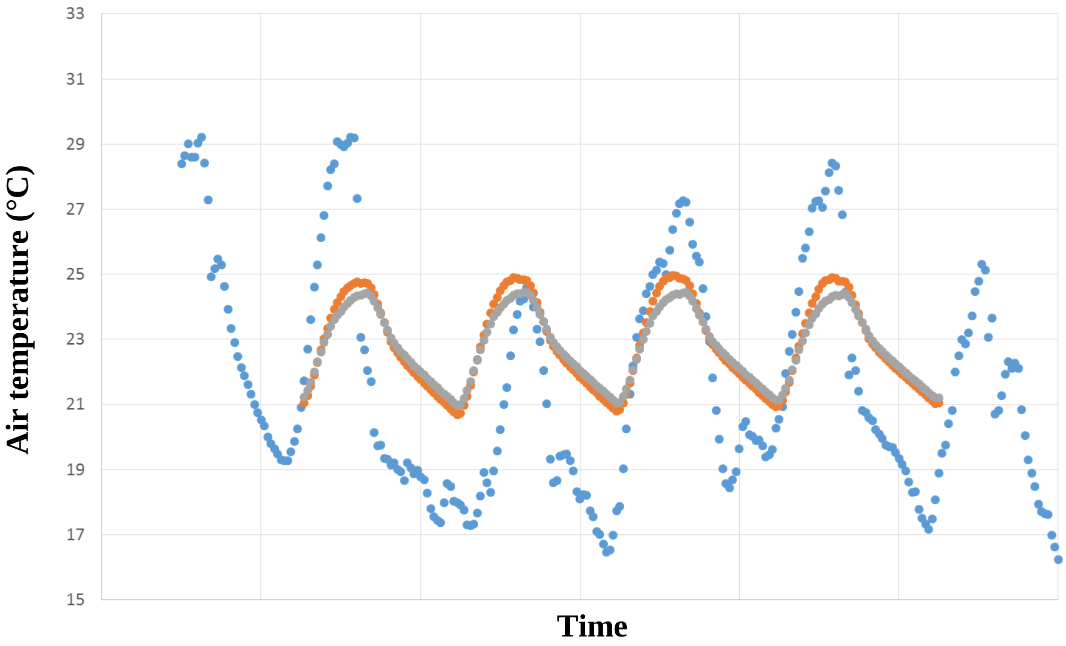

Figure 14 Air temperature trends measured by meteorological station and simulated with ENVI-met in two points.

The results show that the air temperature model is well representative in terms of temporal trends and it demonstrate as well that the absolute value is respected except in the case of maximal and minimal values. As found by Yang et al. (2013) it appears that the ENVI-met model tends to underestimate the vertical temperature gradient for near surface atmosphere. This result can be considered reasonable as observed by other literature researches (Yang et al. 2013; Teleghani et al. 2014; Kleerekoper 2016).

Figure 15 shows the absolute difference between the air temperature of the scenario without the urban garden and the one with urban garden. At 1 p.m. there is a difference of + 0.4 °C meaning that the urban garden has a mitigation effect on air temperature. The pattern is localized only above the green surface. Alternatively, during night-time (2 a.m.) the temperature difference pattern is more diffuse also over urban surfaces, but the mean difference is lower (about + 0.13°C) (Fig. 16).

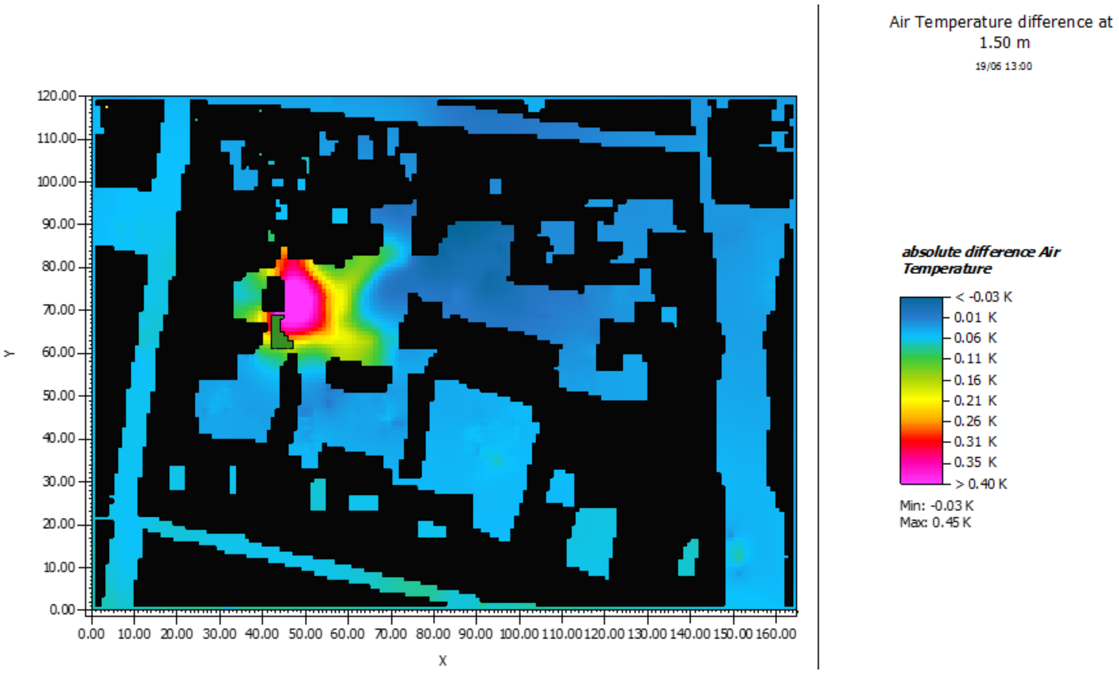

Figure 15 Difference of air temperatures (at 1.50 m) between scenarios, at 1 p.m.

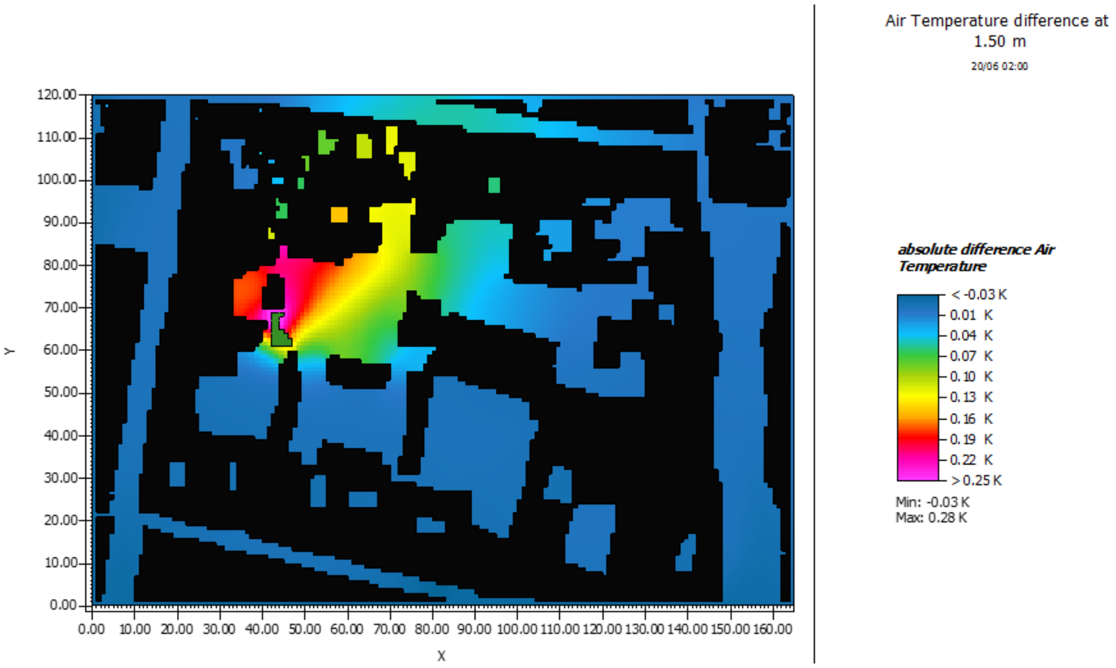

Figure 16 Difference of air temperatures (at 1.50 m) between scenarios, at 2 a.m.

The combination of wind vector and air temperature, detected at 1 p.m., are shown in Fig. 17 and Fig. 18. The temperature is lower in the case of the urban garden as compared with a scenario without green surface.

In the scenario without urban garden, the wind has more intensity (as shown by the length of the arrows), so greater flow, thus is more efficient for the transport (e.g. seeds, insects).

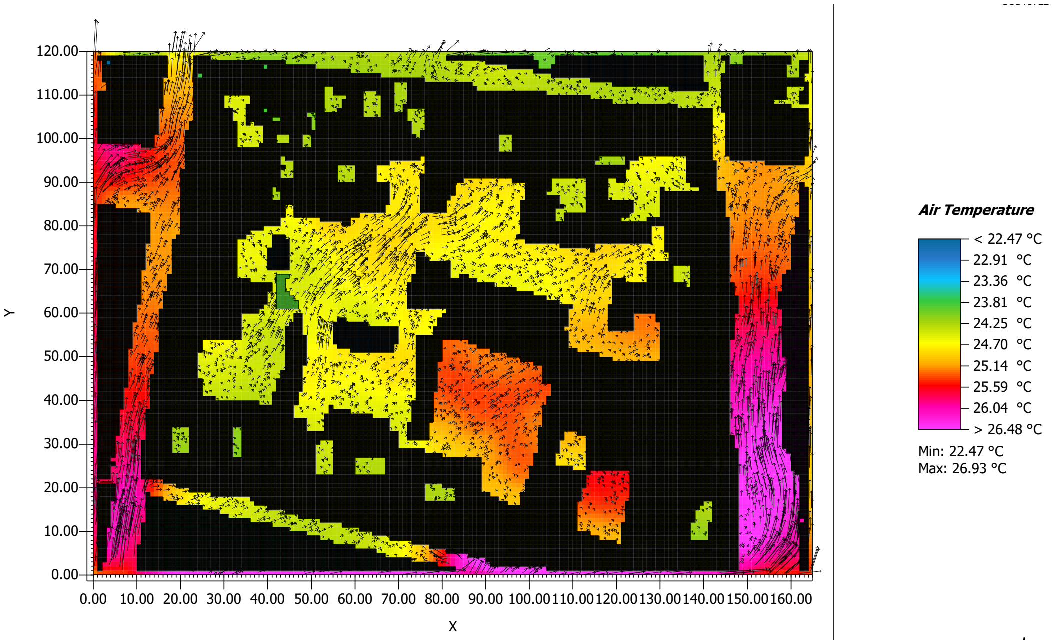

Figure 17 Wind vector at 1 p.m. Scenario with urban garden.

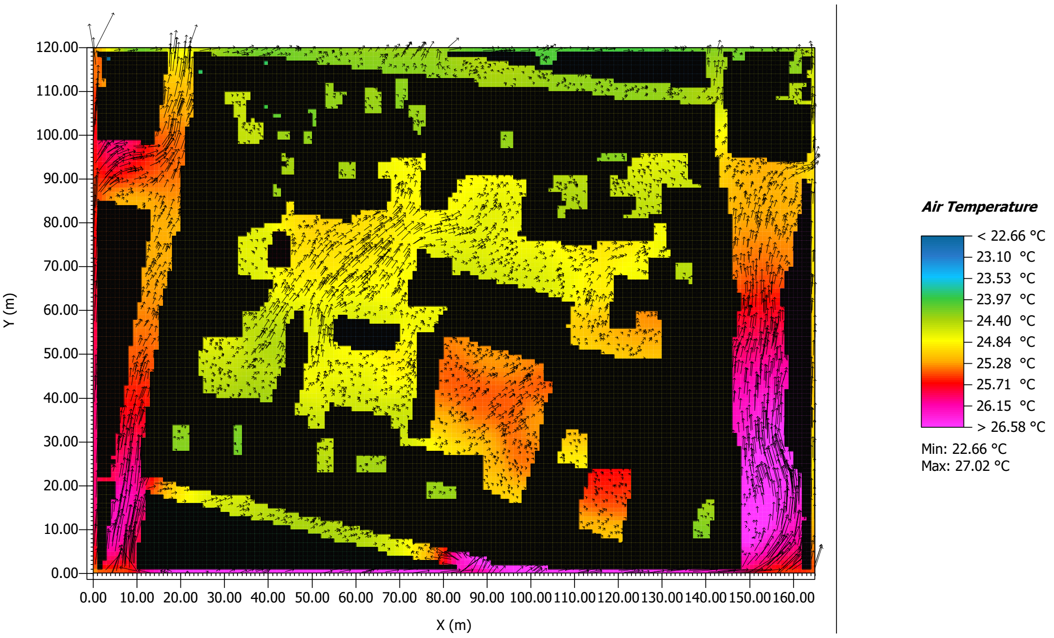

Figure 18 Wind vector at 1 p.m. Scenario without urban garden.

Figure 19 show the trajectory of a particle moved by the wind. In the first case (left, scenario with garden) the trajectory lines are thicker to indicate the higher friction with the vegetation, which causes the particle to be slower than in the second case. In the second case (right, scenario without garden) the particle has a higher speed and the lines are less dense.

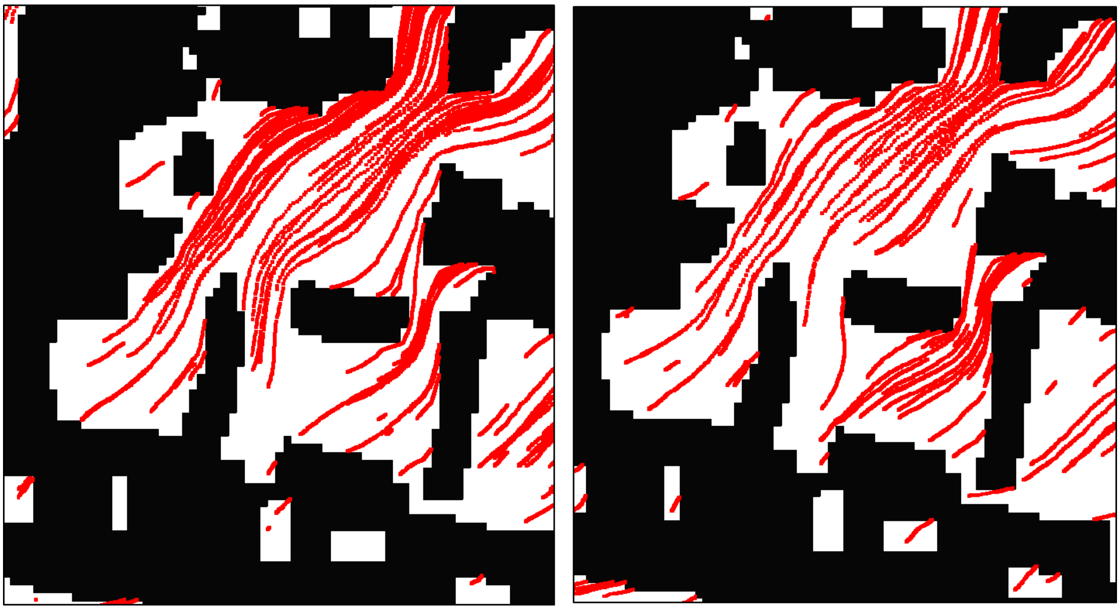

Figure 19 Particle trajectory. (Left) Scenario with garden; (Right) scenario without garden.

For what concerns the surface temperature the difference is wider. The larger difference occurs during the day when the bare soil has a temperature +18°C higher than the simulation with the presence of urban garden (Fig. 20).

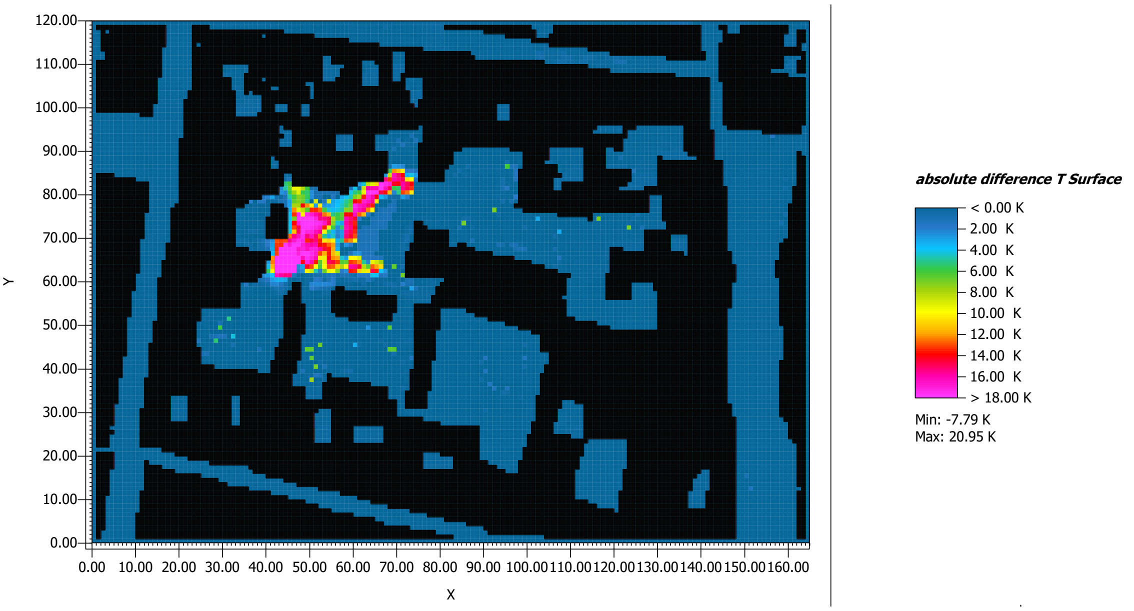

Figure 20 Difference in surface temperature between simulated case without the urban garden and the case with urban garden at 1 p.m.

During the night, the result is opposite: the surface with urban garden is hotter than the bare soil one. The reason for this difference is that the heat accumulated during the day by the soil is then released during the night resulting in a surface cooling (Alexandri & Jones 2008) (Fig. 21).

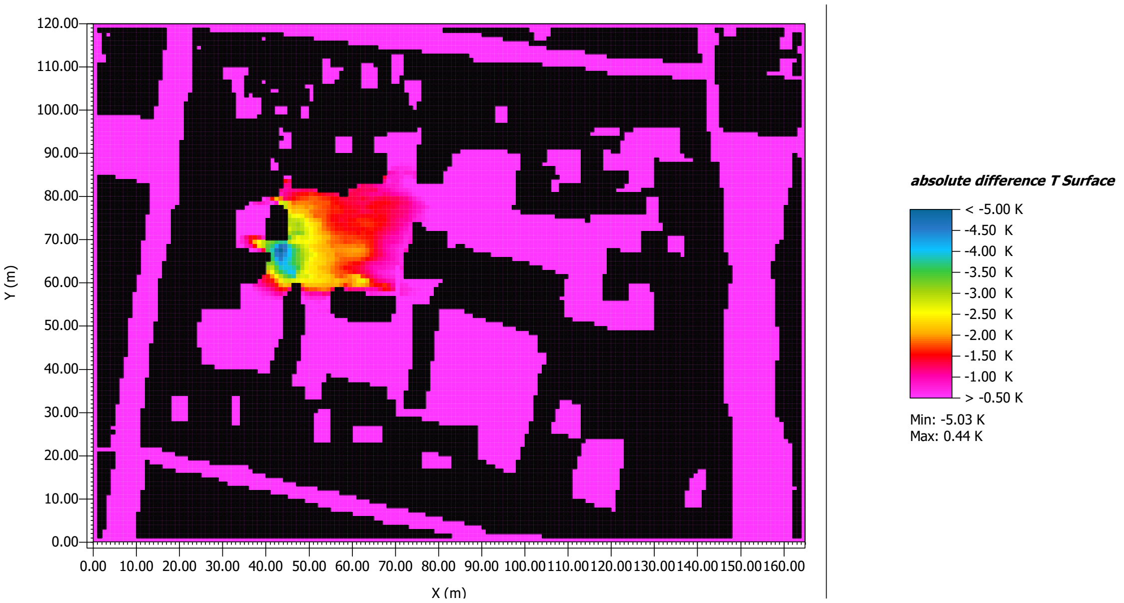

Figure 21 Difference in surface temperature between simulated case without the urban garden and the case with urban garden at 2 a.m.

For the latent heat, during the day, the absolute difference between the scenario without urban garden and with urban garden is around -100 W m^{-2}. Plants’ evapotranspiration processes give exchange fluxes that subtract heat to the atmosphere, reducing the air temperature. The effect of mitigation of the urban garden is highly confirmed by the fluid dynamic model (Fig. 22).

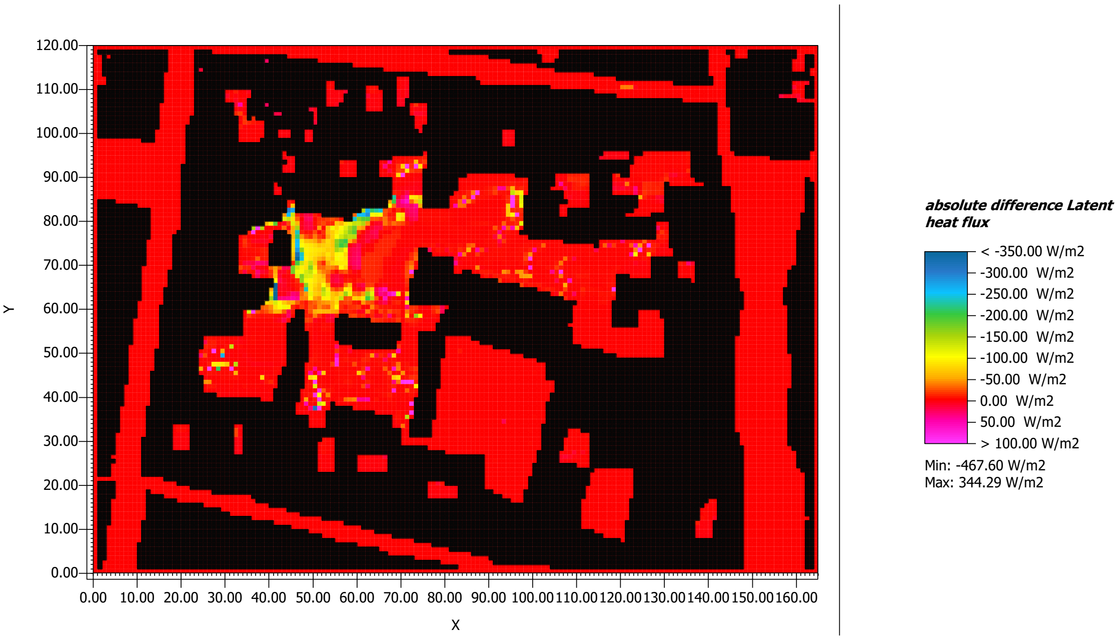

Figure 22 Absolute difference of latent heat flow at 1 p.m.

Similar results are shown for sensible heat flow absolute difference, with a value around -450 W m^{-2} (Fig. 23).

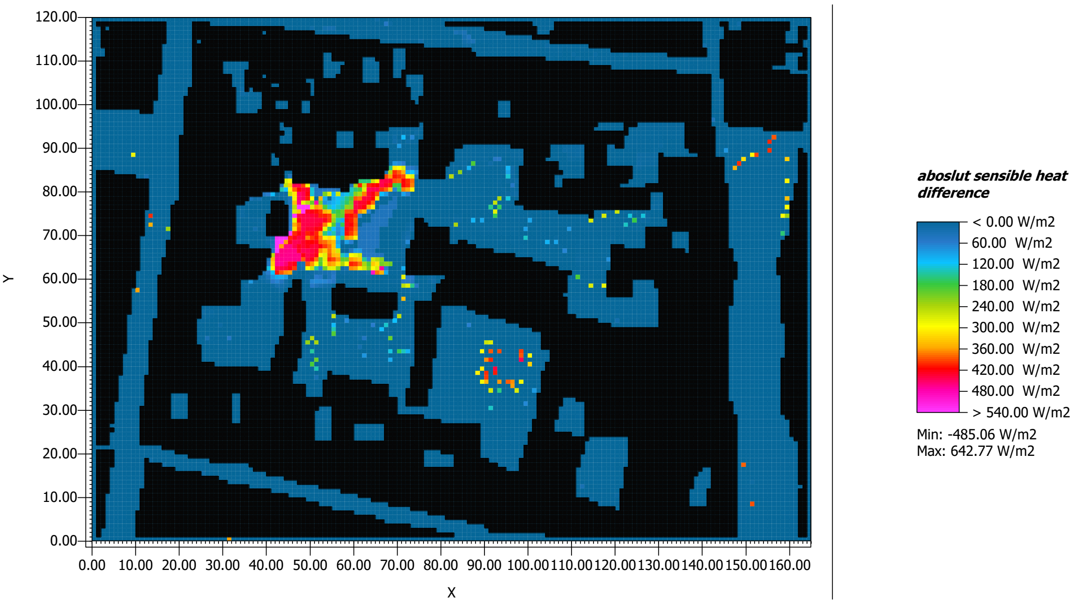

Figure 23 Absolute sensible heat difference at 1 p.m.

The predicted mean vote denotes that the human perception of temperature is lower in the *first scenario* rather than in the *second scenario* (Fig. 24). Figure 25 shows the absolute PVM difference between the simulation without and with urban garden at 1 p.m. The presence of the garden reduces the value by one point on the rating scale. From warm

(+2) to slightly warm (+1), obtaining an improvement of the microclimatic conditions and comfort of the place.

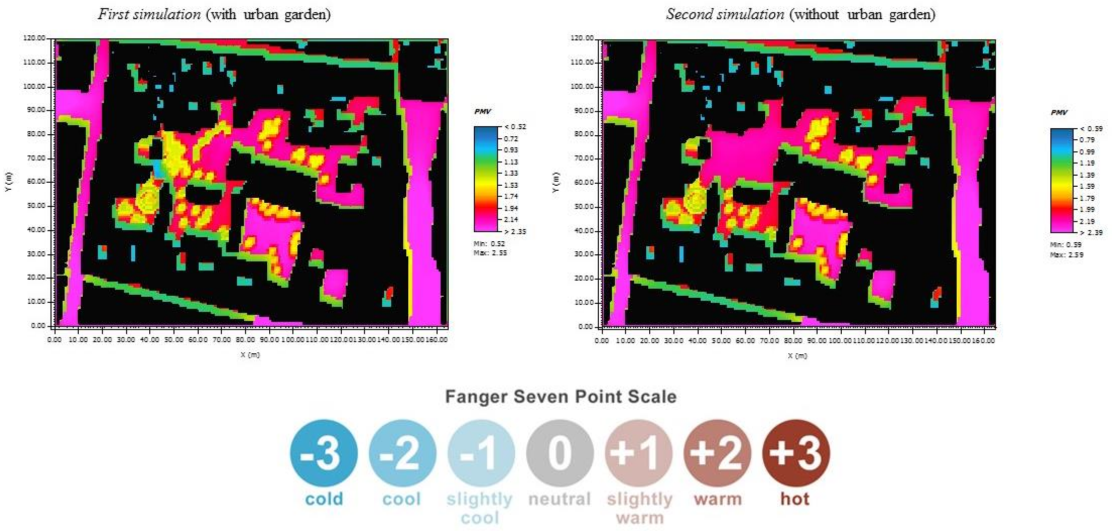

Figure 24 PMV for both simulations at 1 p.m.

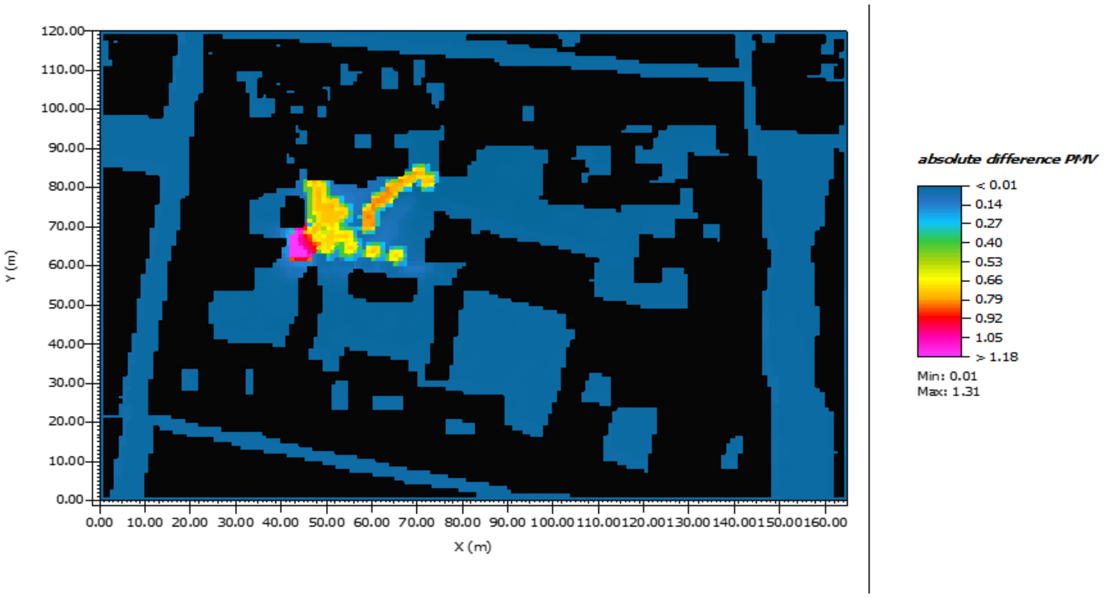

Figure 25 Absolute difference of PMV between simulated case without the urban garden and the case with urban garden at 1 p.m.

2.3 Discussion and conclusion

Global results

This case study confirms that vegetation could reduce the air and surface temperature, even if herbaceous crops and not trees were used for the simulation. Multiple receptor points are used to get an overview of the effect within the area. We may suppose that the same situation occurs in other seasons, but our study was limited to a period in which there were on-cycle crops and not so high temperatures. The results differed significantly by hours, and the wind direction has a significant influence, especially if we plan to create an ecological corridor through the city. It is possible to affirm that the presence of gardens is important to improve urban microclimate and outdoor thermal comfort in urban spaces. This main comfort is due to shading, especially in the case of trees, and evapotranspiration. This last factor is related to the size of the vegetated area (Boukhabla & Alkama 2012). Lower air temperatures are essential both to improve thermal comfort conditions of pedestrians and to limit energy use for cooling (Obiakor et al. 2012) during warmer months.

Limitations of the study

Due to the complexity of modelling the microclimate, some processes in ENVI-met were simplified and standardised. The accuracy of calculations depends heavily on grid size, details in the model and input parameters. Model limitations, for example, are the overestimation of daytime temperature since the heat storage in building surfaces is not calculated (Spangenberg et al. 2008), global radiation is somewhat overestimated, and for night-time calculations the missing heat storage in building surfaces leads to an underestimation.

In addition to the limitations reported in Kleerekoper et al. (2016), in this study a further limitation is caused by the choice of the vegetation. Unfortunately, in ENVI-met it is not possible to insert vegetable plants and modify the given values of evapotranspiration. Therefore, it was assumed that the vegetables had the same evapotranspiration values of grass.

Future research needed

This research could be a contribution and an input to study the mitigation of urban climate caused by the presence of urban or home gardens. Many studies are related to the presence of trees in the cities, but a few are concerned with gardens. This type of study could be useful to help the administration in urban planning, because it suggests an indicator of citizens’ well-being.

Chapter III

Home gardens and environmental impact

Urban gardens may contribute to the air temperature’s mitigation and improve human well-being. In this chapter, we aim to assess the global warming potential of local production through a comparison between different kind of system cultivations in the local and urban context. Cultivation data were collected by Prof. Giorgio Ponchia from the University of Padua.

3. Urban gardens: environmental profile of “Km 0” agriculture.

For gardeners, the garden is a significant aspect of identity. The number of people who garden and consider themselves environmentally friendly is growing (Kiesling & Manning 2010). Home gardens are here defined as a mixture of deliberately planted vegetation, usually with a complex structure and designed to produce natural edible products for the household or market (Kabir & Webb 2009). Furthermore, according to the definition by Kortright and Wakefield in Taylor & Lovell (2014), a home garden is defined as a fruit and / or vegetable garden on leased, owned, or borrowed land directly adjacent to the gardener’s residence; it may include plantings in containers or on rooftops (on soil or soil-less systems). This topic is strictly related with agroecology (Francis et al. 2003). In fact it is now commonly acknowledged that complementary use of resources in mixed cropping or agroforestry, as widely practised in smallholder farming, can lead to ‘overyielding’: grown in mixed stands, two or more crops and / or trees produce a higher yield than if cultivated separately (Dalsgaard & Oficial 1997). Urban and home gardens could be natural gardens with high level of biodiversity (Kumar & Nair 2007), in addition to positively influence diet and health of producers (Alayón-Gamboa & Gurri-García 2008). This is also stressed in Altieri (2009), who also argues that food systems will be rooted in the ecological rationale of traditional small-scale agriculture, representing long established examples of successful community-based local agriculture. Urban gardens, as well as agroecology, are related to the concept of sustainability (re-use and conservation of resources) by providing natural habitats, improving soil quality, reducing soil erosion, and mitigating the city heat island effect (Martin et al. 2014). The most common definition of agroecology is given by Gliessman (1998) as the application of ecological concepts and principles to the design and management of sustainable agroecosystem. Nowadays, it also includes new politically and socially oriented disciplines (Wezel et al. 2009). In spite of numerous agricultural systems, most traditional agroecosystems show similar remarkable features concerning: high level of biodiversity, ingenious systems and technologies, resiliency, traditional knowledge, and strong socio-cultural values (Altieri et al. 2012).

Other benefits created by gardens have been discussed in the main introduction of this dissertation. In this section an environmental profile of a home garden will be realized in order to integrate the food miles concept. Agriculture alone releases between 10 and 12%

of the global quantity of GHG emissions; this share is expected to increase in the future due to the growing food demand (Smith et al. 2007). Consequently, many climate change experts recommend the implementation of improved management practices in agriculture, particularly the increase of the production of foods with lower GHG emissions (Akaichi et al. 2016). Wise (2014) reports that, in addition to minimising transport emissions, local food production builds food system resilience by shortening food supply chains that can be vulnerable to a number of disruptions caused by fuel shortages, extreme weather events, local transport network failures and economic crises. Life cycle assessment methodology has proven to be an accurate, objective and transparent tool to quantify environmental impacts. First studies of LCA were applied to industrial systems where their influence on the global impact categories is more easily quantified. Lately a great interest in agricultural and food activities increased the LCA studies concerning this sector and in this case, their impact is highly related to more local impact categories, such as land and water use (Foresi et al. 2016). Below are reported the main indicators used for the environmental sustainability assessment (Wascher et al. 2015):

1. Enhance eco-efficiency in abiotic resource use (land/soil, water, nutrients): each food chain type is related to certain farming or gardening systems, which may or may not use abiotic resources more efficiently (good input-output-relation under given regional conditions).
2. Enhance provision of ecological habitats and biodiversity: each food chain type is related to certain practices, which may enhance the provision of ecological habitats (hedges, trees), cultivate a wider range of crops and livestock including breeding of traditional or rare species and increase biodiversity in the farming system and beyond.
3. Animal protection and welfare: Farming systems connected to certain food chains may result in different conditions for livestock.
4. Reduction of transport distance and emissions: a chain type may be related to a shorter transport distance (‘food miles’) and possibly a different mode of transport with less emissions and reduced use of road infrastructure (e.g. trains versus trucks).

5. Recycling and reduced packaging: a chain type may be related to reduction in the amount of packaging along the whole food chain and be able to recycle most or all of the input materials.

Several groups began to apply LCA to agricultural systems in the 1990s and the first attempts of LCA implementation in crops were mainly focused on extensive agriculture, (Brentrup et al. 2001; Brentrup et al. 2004; Dalgaard et al. 2008; Martìnez-Blanco 2012), biofuel (Halleux et al. 2008) or food production (Roy et al. 2009). LCA is recognized as a tool to quantify the environmental impact and could help in decision-making (Tillman 2000). For example, it could suggest which cultivation method or system is more sustainable (Notarnicola et al. 2012): e.g., conventional or organic (i.e. leek production in de Backer et al. 2009); on soil or soilless systems (Sanyé-Mengual 2015).

During the last decade, the progress in the development of LCA in the agri-food sector in terms of methodological robustness and data availability has also been the subject of a series of conferences and seminars (Guinée et al. 2006; Egilmez et al. 2014).

In Italy some research group are working on LCA (Cappellaro et al. 2008) applied to fruit production (e.g., de Menna et al. 2015; Cerutti et al. 2014) and vegetable crops (e.g., Cellura et al. 2012a). In Sanfilippo & Ruggeri (2009) there is an overview about food production (i.e. cheese, vegetable, meat, etc.). Environmental performances of citrus-based products (Beccali et al. 2009), tomato based products (Del Borghi et al. 2014) and, peppers, melons, tomatoes, cherry tomatoes, and zucchini in different typologies of greenhouses (tunnel and pavilion) were assessed in Cellura et al. (2012b).

Research question

In this section, we aim to assess the environmental impact in terms of GWP of a conventional home garden and, compare results with Sanyé-Mengual et al. (2015), to help growers choosing the most sustainable cultivation system or to improve some production phases.

3.1 Materials and methods

3.1.1 Case study

The experiment was carried out in a home garden located in Padua, Italy (Fig. 26). The garden had a surface of 25 m^2 divided into nine parcels of 2x1 m^2, and two of 3.5x1 m^2 surface.

Figure 26 Urban home garden ©Daniela Gasperi, 2013.

Homogeneous plant nutrition for crops was used, including a compost fertilization (1 Kg m^{-2}) and a mineral fertilization with NPK (6-12-24) at 75 g m^{-2} and NH_4NO_3 at 25 g m^{-2}. Pest control treatments were performed only once on crops a few days after transplanting using 25 L of copper oxychloride at concentration of 3.5 g L^{-1}.

The dripline irrigation system (10 drippers m^{-2}) had an average consumption of 5 L m^{-2} every day from May until September 2013.

The main cultivated vegetable crops are resumed in Tables 4-6.

Table 4 Description of analysed leafy vegetable crops. For some crops, which have more than one data, Simapro 8.0.3.14 uses averaged values in the simulation.

Species		Area (m^2)	Seedling or transplanting	Harvesting	Crop cycle (d)	Total production (Kg)	Crop yield (Kg m^{-2})	Crop yield (g m^{-2} d^{-1})
				Leaves				
White Cabbage	*Brassica oleracea*	1	30/03/2013	28/05/2013	59	4.7	4.7	79
Savoy Cabbage	*Brassica oleracea*	2	01/08/2013	28/10/2013	88	10	5	56
Chard*	*Beta vulgaris*	0.7	20/11/2012	30/04/2013	161	7	10	62
Chicory (cv. Catalogna)	*Cichorium intybus*	0.5	06/06/2013	27/07/2013	51	5.3	10.6	200
Chicory "Grumolo"	*Cichorium intybus*	1	30/03/2013	12/06/2013	102	6.7	6.7	65
			30/03/2013	10/07/2013				
			30/03/2013	07/08/2013				
Chicory "Treviso precoce"	*Cichorium intybus*	1.5	15/07/2013	30/10/2013	107	4.5	3	28
Lettuce "Cappuccia"*	*Lactuca sativa*	1.3	28/11/2012	04/04/2013	132	3.9	3	22
			28/11/2012	13/04/2013				
Lettuce "Cappuccia"	*Lactuca sativa*	1.2	06/06/2013	01/08/2013	56	3.5	2.9	51
Lettuce "Gentile"	*Lactuca sativa*	1	30/03/2013	04/06/2013	74	3.2	3.2	43
			30/03/2013	20/06/2013				
			31/10/2012	30/05/2013				
			31/10/2012	04/06/2013				
Spinach	*Spinacia oleracea*	1	03/11/2012	29/03/2013	146	3	3	20

*protected crops

Table 5 Description of analysed fruit vegetable crops. For some crops, which have more than one data, Simapro 8.0.3.14 uses averaged values in the simulation.

Species		Area (m^2)	Seedling or transplanting	Harvesting	Crop cycle (d)	Total production (Kg)	Crop yield (Kg m^{-2})	Crop yield (g m^{-2} d^{-1})
				Fruits				
Eggplant	*Solanum melongena*	1	20/04/2013	06/07/2013	120	7.7	7.7	64
			20/04/2013	30/09/2013				
Pepper	*Cápsicum annuum*	1.5	20/04/2013	25/07/2013	140	7.6	5.1	36
			20/04/2013	20/10/2013				
String bean	*Phaseolus vulgaris*	2	20/04/2013	27/06/2013	80	7.4	3.7	46
			10/05/2013	10/08/2013				
Tomato	*Solanum tuberosum*	2	20/04/2013	05/07/2013	112	24.8	12.4	110
			20/04/2013	15/09/2013				
			20/04/2013	05/07/2013				
			20/04/2013	15/09/2013				
Zucchini	*Cucurbita pepo*	2	20/04/2013	04/06/2013	68	15.6	7.8	110
			20/04/2013	20/07/2013				

Table 6 Description of analysed steam vegetable crops. For some crops, which have more than one data, Simapro 8.0.3.14 uses averaged values in the simulation.

Species		Area (m^2)	Seedling or transplanting	Harvesting	Crop cycle (d)	Total production (Kg)	Crop yield (Kg m^{-2})	Crop yield (g m^{-2} d^{-1})
				Steam				
Celery	*Apium graveolens*	1.4	20/04/2013	10/07/2013	86	5.3	3.8	44
			20/04/2013	25/07/2013				
			10/07/2013	29/09/2013				
Fennel	*Foeniculum vulgare*	4	25/08/2012	11/12/2012	108	33	8.25	76

3.1.2 Life Cycle Assessment

This part of the dissertation develops an assessment related to the environmental impacts caused by local production.

In order to do that the methodology chosen was that of life cycle assessment, which includes all inputs and outputs of a product system, from the extraction of raw materials to the waste disposal. This method was originally developed for use in industrial operations (Caffrey & Veal 2013), but since 1996 it has been used in agricultural applications, and some examples are reported in Hayashi et al. (2006).

The framework of LCA is regulated by the ISO 14040 (2006)-14044 (2006a) following a four-stage method to carry out the study (Fig. 27).

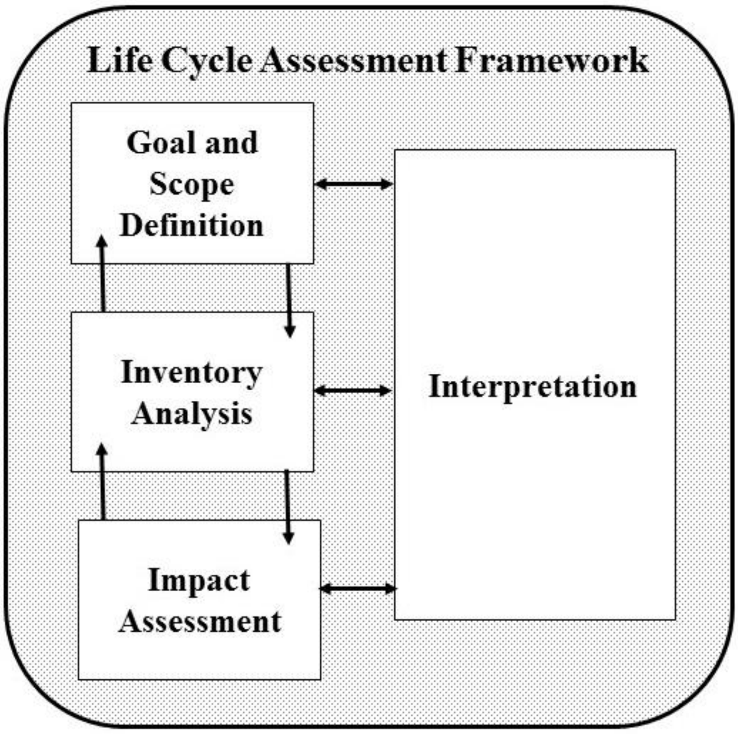

Figure 27 ISO 14040-2006 Life cycle assessment framework - The four phases of an LCA.

Reading international organization for standardization (ISO) (2006), it is possible to understand that:

- The scope of an LCA, including the system boundary and level of detail, depends on the subject and the intended use of the study. The depth and the extent of LCA can differ considerably depending on the goal of a particular LCA.

- The life cycle inventory analysis (LCI) is the second phase of LCA. It is a list of input/output data about the system being studied. It involves collection of the data necessary to meet the goals of the defined study.
- The life cycle impact assessment (LCIA) is the third phase of the LCA. The purpose of LCIA is to provide additional information to help assess a product system's LCI results to better understand their environmental significance.
- Life cycle interpretation is the final phase of the LCA procedure, in which the results of an LCI or an LCIA, or both, are summarized and discussed as a basis for conclusions, recommendations, and decision-making by the goal and scope definition.

a) *Goal and scope definition*

As previously stated, the purpose of this study is to detect the environmental profile of local urban production, and compare results with another kind of domestic production (soilless system cultivations).

There are many ways to proceed (Suh & Huppes 2005), and we chose to draw a flowchart of the whole process. It is useful to establish the FU (functional unit), which all data will refer to and the system boundary.

In this case, we chose the FU of 1 Kg of produced vegetables, and a "from cradle – to-farm gate" approach. The impacts of flows will refer to that unit and boundary (from the extraction of raw material until the harvest). System boundary is incredibly influential, due to the large amount of material processing of inputs and processing of materials past the farm gate (Caffrey & Veal 2013). In Roer et al. (2012) is clear that the system boundary sizes have a tremendous impact on LCA results, as do issues with data uncertainty and data sources (Fig. 28).

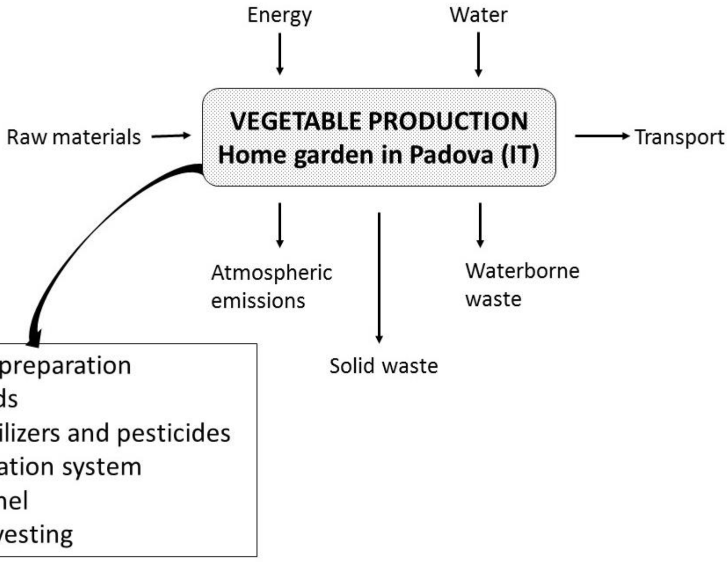

Figure 28 Schematic illustration about input and output considered in the inventory.

b) Life cycle inventory

LCI is the data collection portion of LCA, and it consists of detailed tracking of all the flows in and out of the product system, including raw resources or materials, energy by type, water, and emissions to air, water, and land (Table 7).

In this study we used different kind of sources:

- *Primary data:*

Data used for the cultivation system were collected in loco in the site of Padua.

- *Background data:*

The data related to the materials extraction and manufacture, to the energy mix consumption and transports are derived from the Ecoinvent Database[4], while the data used for the comparison between soilless system cultivation impacts refer to Sanyé-Mengual et al. (2015), who analyses a rooftop garden case study in Bologna, Italy.

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[4] http://www.ecoinvent.org The Ecoinvent Association was formerly known as the Ecoinvent Centre, the Swiss Centre for Life Cycle Inventories.

To calculate NH_3 volatilisation from mineral fertilisers emission factors developed by ECETOC[5] have been chosen. For the N_2O emissions, the following function Bouwman (1995) in Brentrup et al. (2001) was used:

N_2O emission (Kg N_2O-N ha^{-1}) = 0.0125×N application (Kg N ha^{-1})

Current data on NO emissions are calculate in a similar way of N_2O emission (Ntziachristos et al. 2014):

NO_X emission (Kg NO-N ha^{-1}) = 0.3% X N application (Kg N ha^{-1}).

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[5] http://www.ecetoc.org/

Table 7 Life cycle inventory for the case study of Padua (IT) data were collected referred to 1 m^2 of cultivated land, than normalized to the FU of 1Kg of product obtained.

		Element	Material	Process	Quantity	Unit	Life span (years)	Transport (Km) & type	N emissions
Cultivation system and crop inputs	Irrigation system	Irrigation tubes	PE (Polyethilene)	Extrusion plastic film	0.141	Kg	10	20, Lorry	
		Water	Tap water		7	L			
		Fertilizers	Ammonium nitrate	Fertilizer field application	25	g		28, Lorry	x
			NPK (6-12-24)	Fertilizer field application	75	g		28, Lorry	x
			Compost	Composting facility	1	Kg		28, Lorry	x
	Tunnel*	Film	Nonwoven-fabric	Extrusion plastic film	0.15	Kg	10	20, Lorry	
		Rods	Galvanized iron	Metal working	4	Kg	30	20, Lorry	
	Plant protection	Copper oxychloride	Unspecified pesticide		3.5	g L^{-1}		6, Lorry	
		Water	Well water		1	L			

*Only for lettuce and chard protected production.

c) *Life cycle impacts assessment*

In this phase of LCA, the objective is the classification and characterization of the LCI. ISO rules impose to follow two steps (EPA 2006):

- Selection of impact categories, category indicators, and characterization models;
- Assignment of LCI results to selected impact categories (classification).

In this case, we used Simapro 8.0.3.14 software (PRé Consultants, 2014)[6], a tool that could be employed for the LCIA phase. The impact categories illustrated in Fig. 29, could be detected by two different models (Bare et al. 2000):

- *Midpoint:* defined as a parameter in a cause-effect chain or network (environmental mechanism) for a particular impact category that is on the inventory data and the category endpoints.
- *Endpoint:* it reflects differences between stressors at an endpoint in a cause-effect chain and may be of direct relevance to society's understanding of the final effect, such as measures of biodiversity change.

This study investigates the impact category of global warming potential (GWP), thought midpoint methods, the IPCC 2013 100a (PRé 2016). It contains the climate change factors of IPCC in a time-frame of 100 years; it is expressed in Kg CO_2 eq.[7] This last unit comes from the characterization of elementary flows. For example, 3.5 Kg CO_2 is multiplied by the characterization factor (CF=1) and the unit of the result is 3.5 Kg CO_2 equivalents.
IPCC characterization factors for the direct (excluding CH_4) global warming potential of air emissions are:

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[6] At the forefront of sustainability for more than 25 years; focused on Life Cycle Thinking. The company has built itself a worldwide reputation as a leader on impact assessments. With state-of-the-art methodology and tools, PRé puts the metrics behind sustainability to create business value (www.pre-sustainability.com).

[7] A metric measure used to compare the emissions from various greenhouse gases based upon their global warming potential (GWP). Carbon dioxide equivalents are commonly expressed as "million metric tons of carbon dioxide equivalents ($MMTCO_2Eq$)". The carbon dioxide equivalent for a gas is derived by multiplying the tons of the gas by the associated GWP.

$$MMTCO_2Eq = (\text{million metric tons of a gas}) \times (\text{GWP of the gas})$$

- not including the indirect formation of dinitrogen monoxide from nitrogen emissions;
- not accounting for radiative forcing due to emissions of NOx, water, sulfate, etc. in the lower stratosphere and upper troposphere;
- not considering the range of indirect effects given by IPCC;
- not including CO_2 formation from CO emissions (PRé 2016).

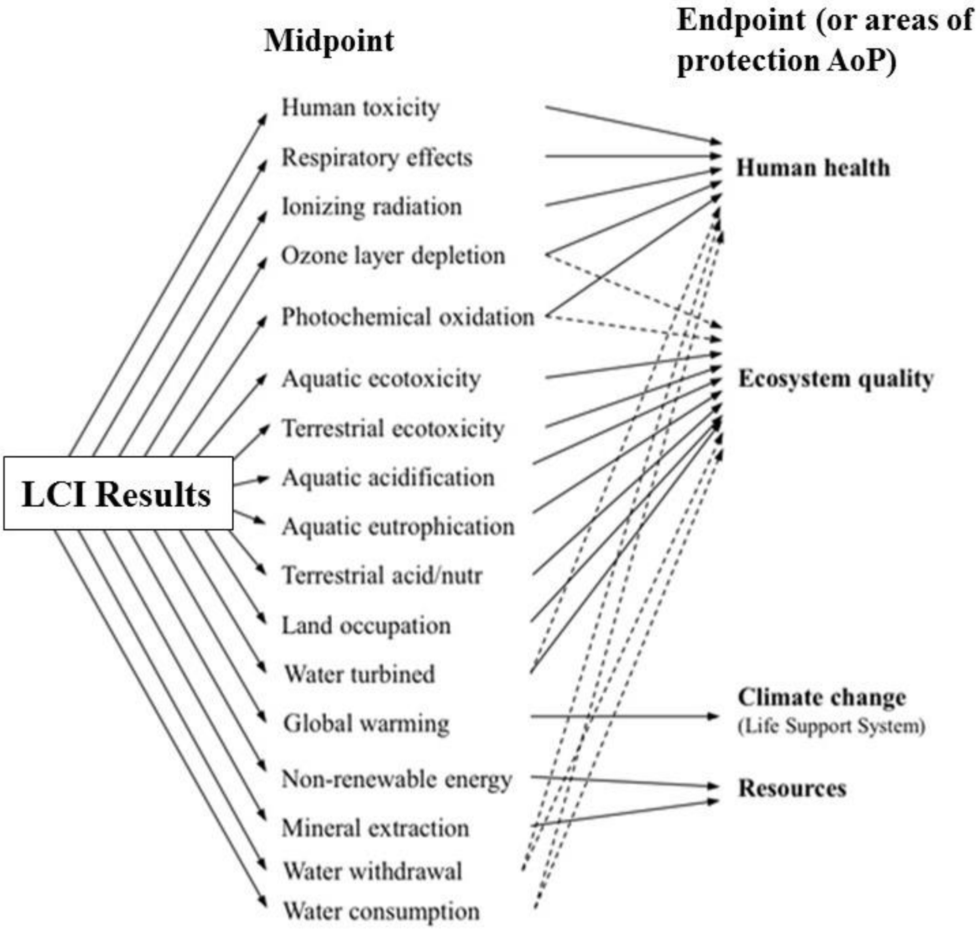

Figure 29 Scheme of the impact categories dealt with in ILCD Handbook on Life Cycle Impact Assessment at midpoint and at endpoint.

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3.2 Results

First, results relating to the total GWP and single vegetable crops are shown using the IPCC 2013 GWP 100a V1.00 methods (Fig. 30). Then, single raw data were not shown, but reported in table impacts according to different input classes (i.e. nitrogen emission, fertilizers, etc.).

Second, there is a comparison with literature, in particular with Sanyé-Mengual et al. (2015), which assessed the environmental profile of rooftop garden in Bologna (soil and soilless system cultivations).

We selected only the species present in both case studies. The case study of Bologna refers to cultivation data collected in two years (2012-2013) (Orsini et al. 2014), later elaborated in Sanyé-Mengual et al. (2015).

Total global warming potential (GWP)

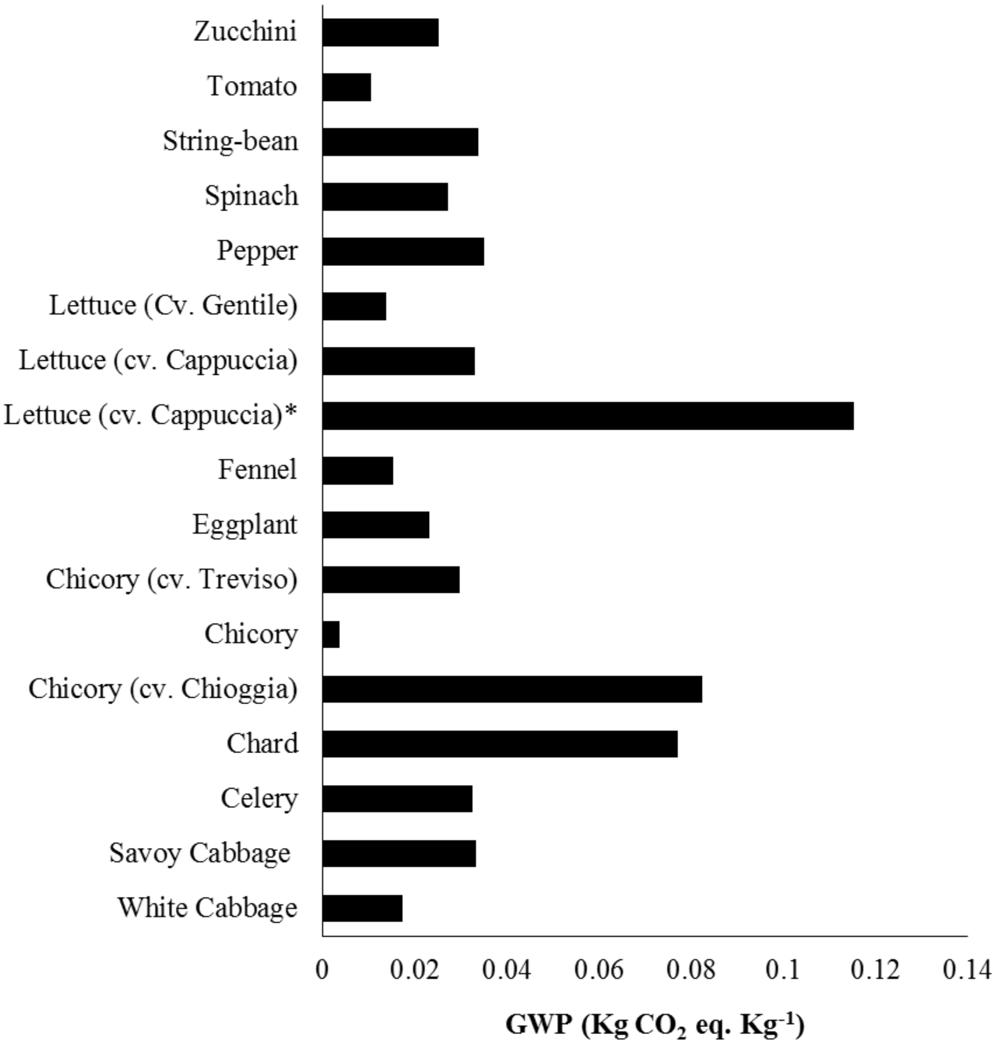

Figure 30 GWP of crop productions in a home garden (Padua).

Summing the environmental impact of each kg of cultivated vegetables, the total GWP 0.6 Kg of CO_2 eq. The average GWP is 0.03 Kg CO_2 eq. emitted per Kg of product. If we consider the total production, the GWP of the home garden (25 m^2) is 0.87 Kg of CO_2 eq. Kg^{-1}.

The choice of FU is very important, and the impact could change. In Figure 31 is shown a comparison between two FUs: 1 Kg of produced crops (in black), and 1 m^2 of occupied land (in white) to produce food. It is possible to observe that the most impacting factor for GWP of 1 m^2 of cultivated land is the use of fertilizers and the transport; outputs are correlated with the yield crops.

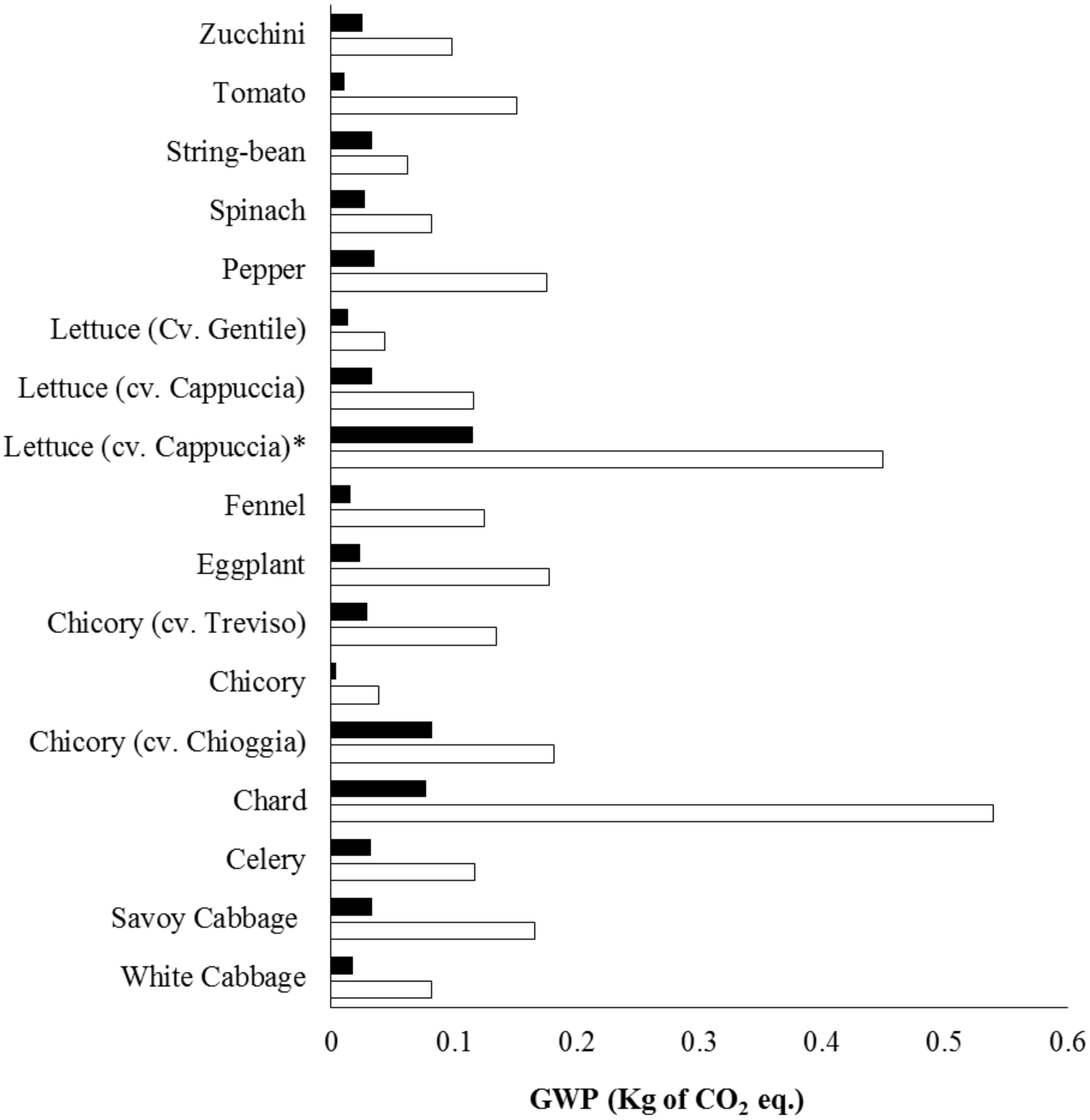

Figure 31 Comparison between two different FUs: 1Kg of produced crops and, 1 m^2 of cultivated land to produce crops.

Single crops GWP

Following, crops' results will be shown. Different output classes are illustrated as follow:

■ Transports ▨ Pesticides ■ Fertilizers ■ Tap water ☐ Auxiliary equipment

- Cabbage

The GWP for White cabbage is 0.02 Kg CO_2 eq. Kg^{-1}, while for the Savoy cabbage is 0.03 Kg CO_2 eq. For both cultivations, the most impacting factors are the use of fertilizers and the transport of materials. Particularly, for the first crops the impact of fertilizers (light grey) caused by their use and nitrogen emissions in the air is 67% of the total, while in the case of Savoy cabbage is around 50%. The most impacting input is the ammonium nitrate, which accounts for 75% of the total impacts for fertilizers. Second, the global impact of transports (dark grey) is around 25% for White cabbage and 43% for Savoy cabbage (Fig. 32).

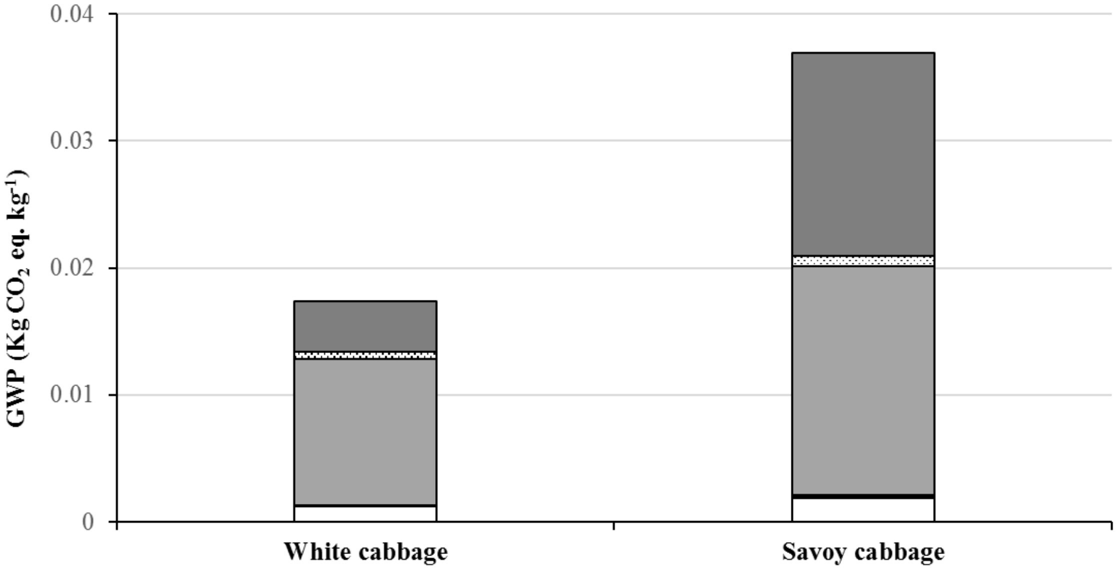

Figure 32 GWP for White and Savoy cabbages according to input categories, namely: auxiliary equipment (☐), tap water (■), fertilizers (■), pesticides (▨), transport (■).

- Celery

The total yield for celery is 3.6 Kg m^{-2} and the total impact referred to the FU is 0.033 Kg CO_2 eq. Most impacting factors are fertilizers (68%) (light grey) and the transport of materials (21%) (dark grey) on the global impact (Fig. 33).

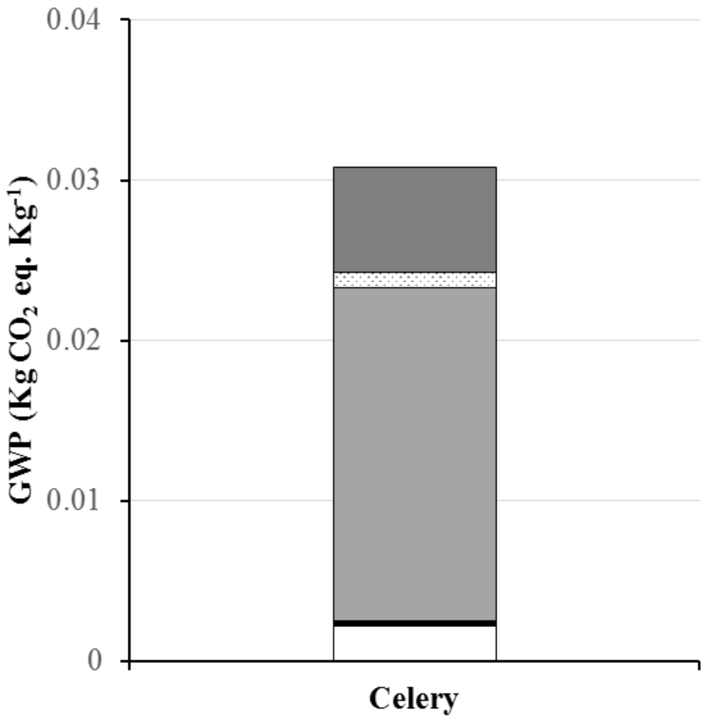

Figure 33 GWP of celery cultivation according to input categories, namely: auxiliary equipment (☐), tap water (■), fertilizers (▨), pesticides (▒), transport (▩).

- Chard

The total yield for chard (protected cultivation) is 7 Kg m^{-2} and the total impact is 0.08 Kg CO_2 eq. Kg^{-1}. Here, in the auxiliary equipment (white), is considered the impact of tunnel (nonwoven-fabric) and iron bars. Therefore, the most impacting factor is the cast iron’s metalworking, which accounts for 98% of the total impact of auxiliary equipment (0.42 Kg CO_2 eq. Kg^{-1}). The impact of the use of pesticides and tap water is less than 0.004 (Fig. 34).

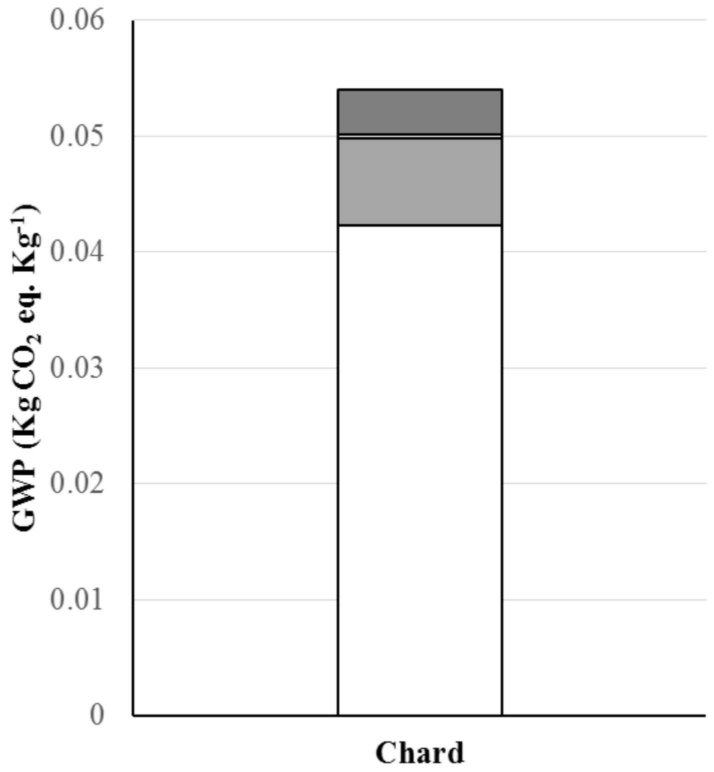

Figure 34 GWP of chard (protected crop) according to input categories, namely: auxiliary equipment (□), tap water (■), fertilizers (▨), pesticides (░), transport (▩).

- Chicory

Here are grouped results for chicory cultivations. The GWP for chicory is 0.004 Kg CO_2 eq. Kg^{-1} (10.6 Kg) (Fig. 35). When fertilizers are not used, the 90% (i.e. chicory cultivation) of impacts is allocated to the transport (dark grey).

For chicory (cv. Chioggia) is 0.082 Kg CO_2 eq. Kg^{-1} (yield 2.2 Kg), while for chicory (cv. Treviso) the results are 0.030 Kg CO_2 eq. Kg^{-1} (4.5 Kg m^{-2}) (Fig. 36). The most impacting factors are the use of fertilizers and the transport of materials (light and dark grey).

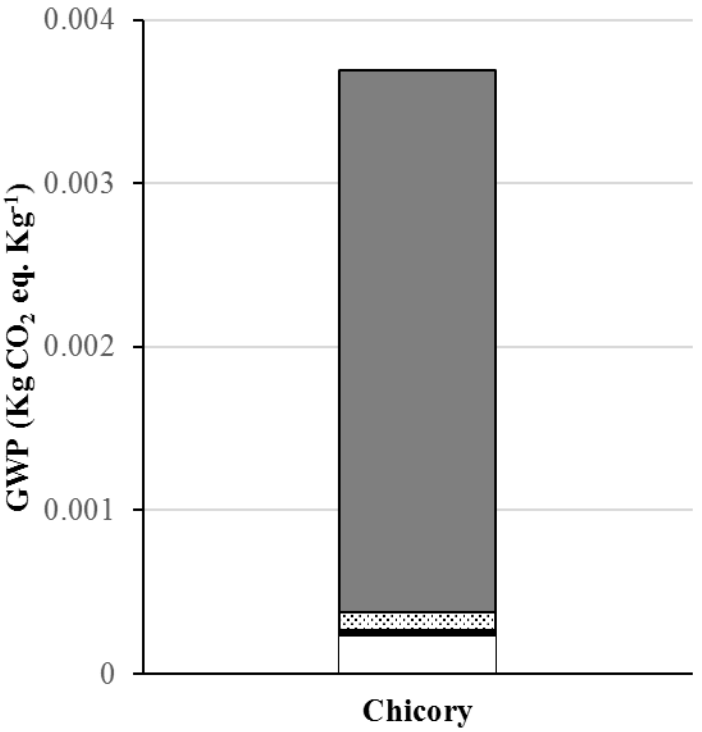

Figure 35 GWP of chicory production according to input categories, namely: auxiliary equipment (□), tap water (■), fertilizers (▩), pesticides (░), transport (▦).

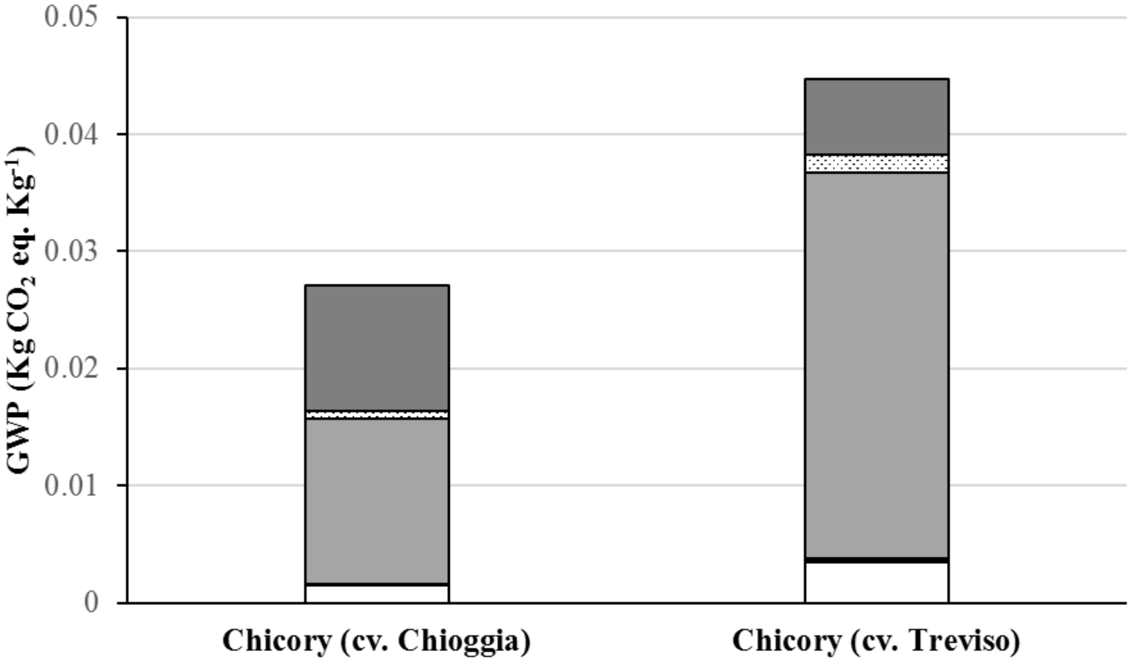

Figure 36 GWP for chicory crop. Comparison between cv. Chioggia and cv. Treviso according to input categories, namely: auxiliary equipment (□), tap water (■), fertilizers (▩), pesticides (░), transport (▦).

- Eggplant

The total yield is 7.7 Kg m^{-2} and the environmental impact 0.023 Kg CO_2 eq. Kg^{-1}. Fertilizers accounts for 79% of the total GWP (light grey) (Fig. 37).

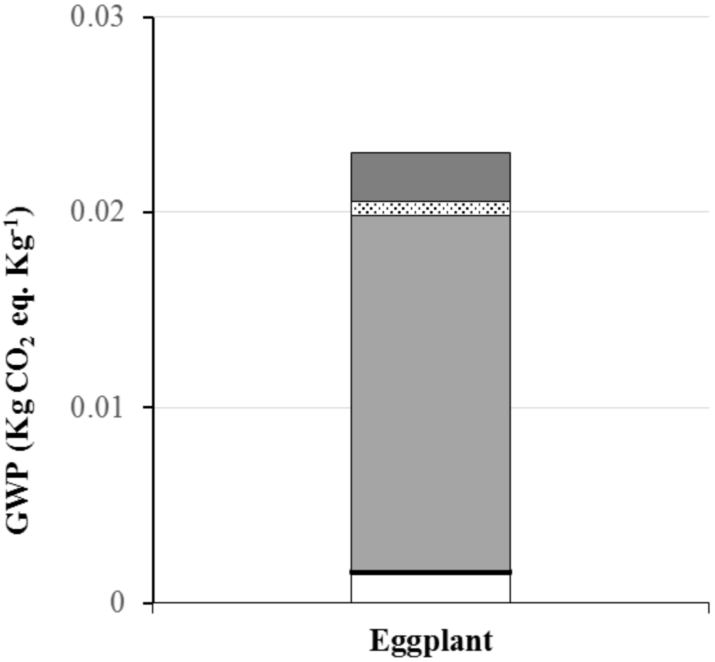

Figure 37 GWO of eggplant production according to input categories, namely: auxiliary equipment (□), tap water (■), fertilizers (▒), pesticides (▨), transport (▓).

- Fennel

The total yield for fennel production is 8.2 Kg m^{-2} and the total impact referred to the FU is 0.015 Kg CO_2 eq. Transport (light grey) affects for 80% the GWP (Fig. 38).

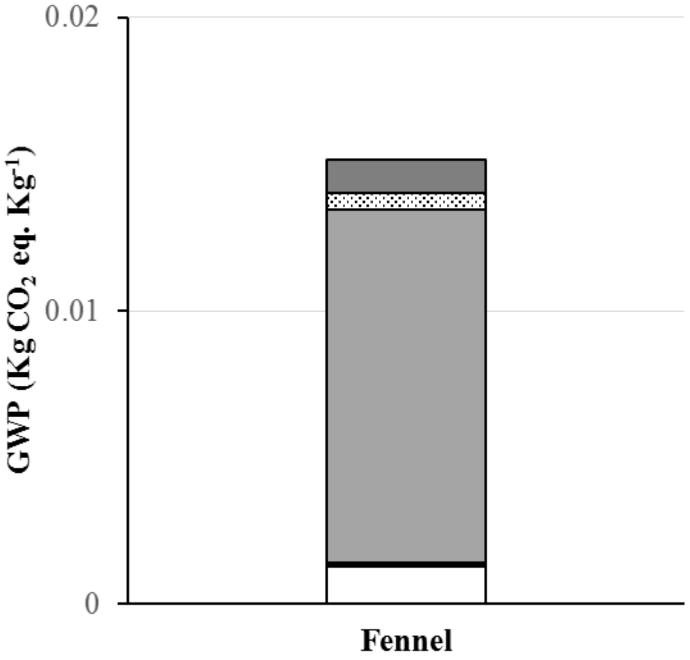

Figure 38 GWP of fennel cultivation according to input categories, namely: auxiliary equipment (□), tap water (■), fertilizers (◼), pesticides (▨), transport (◼).

- Lettuce

The total yield of protected lettuce cv. Cappuccia* is 3.9 Kg m^{-2}; 3.5 Kg m^{-2} for lettuce Cappuccia without no-woven fabric tunnel, and 3.2 Kg m^{-2} for lettuce cv. Gentile. Referring to the GWP of 1 m^{2} the most impacting cultivation is lettuce cv. Gentile. Nevertheless, if we consider the FU (1 kg of produce), the cultivation of lettuce cv. Cappuccia* (with tunnel protection) emits 0.12 Kg CO$_2$ eq. Kg^{-1} against 0.036 CO$_2$ eq. Kg^{-1} of lettuce cv. Gentile. In addition, these results are interesting because three different scenarios are presented:

	Tunnel	Fertilization	NO Fertilization
Scenario 1	X	X	
Scenario 2			X
Scenario 3		X	

In the *Scenario 1* the most impacting input is the auxiliary equipment (white) in particular the working of raw materials (77%). In the *Scenario 2* (most sustainable) for lettuce cv. Cappuccia (cultivation without material of protection and without use of fertilizers), the most impacting factor is the transports of materials (80%) (dark grey). In *Scenario 3* the most impacting factor is the use of fertilizers (59%) (light grey) (Fig. 39).

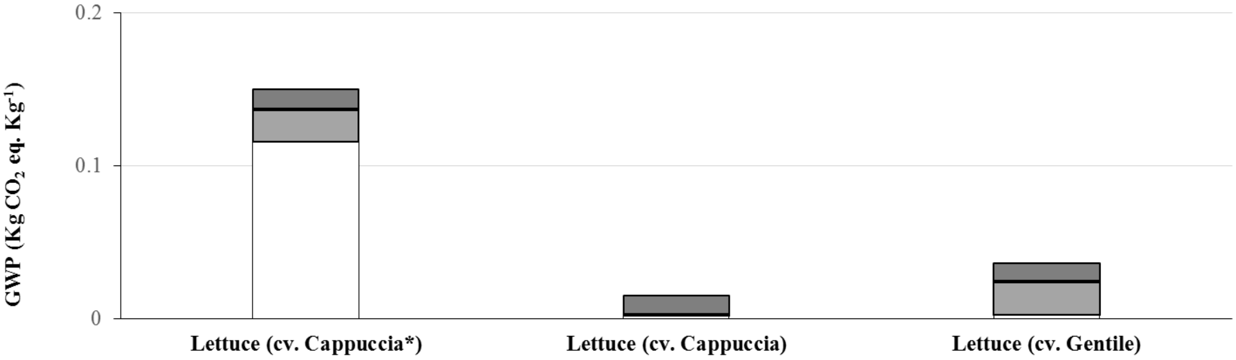

Figure 39 Environmental profile of lettuce crops according to input categories, namely: auxiliary equipment (□), tap water (■), fertilizers (▒), pesticides (░), transport (▓). Three different scenarios.

- Pepper

Pepper yield production is 5 Kg m^{-2} and the environmental impact is 0.035 Kg CO_2 eq. Kg^{-1} emitted into the air. The use of fertilizers (light grey) is the most important factor on GWP; affecting it for 73% (Fig. 40).

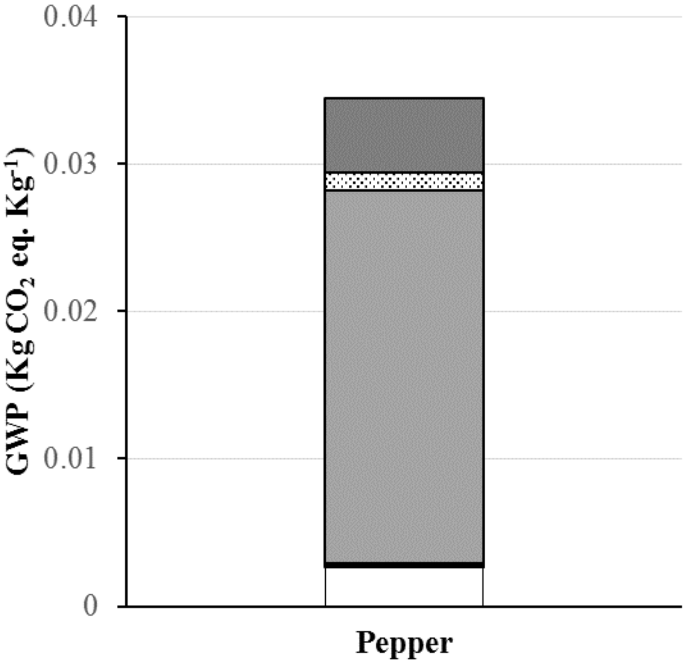

Figure 40 GWP of pepper cultivation according to input categories, namely: auxiliary equipment (□), tap water (■), fertilizers (▒), pesticides (░), transport (▓).

- Spinach

The total yield production is 3 Kg m^{-2} and the GWP is 0.027 Kg CO_2 eq. Kg^{-1}. Here, the 50% of Kg CO_2 eq. Kg^{-1} is attributed to the transport of materials (dark grey); 39% to the use of fertilizers (light grey), 9% to the auxiliary equipment (irrigation systems) (white) and 1% to the use of tap water and pesticides (black and dotted white) (Fig. 41).

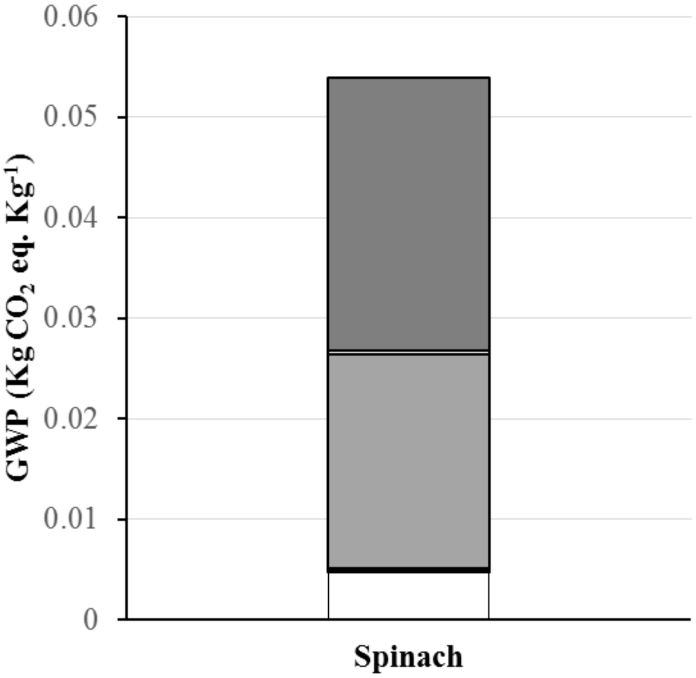

Figure 41 GWP of spinach cultivation according to input categories, namely: auxiliary equipment (☐), tap water (■), fertilizers (■), pesticides (▨), transport (■).

- String-bean

The total yield production is 1.85 Kg m^{-2} and environmental impact is 0.027 Kg CO_2 eq. Kg^{-1}. In the cultivation of string bean the GWP expressed in Kg CO_2 eq. Kg^{-1} is 0.027. The most impacting factors are the use of fertilizers (67%) (light grey) and the auxiliary equipment (22%) (white). The transport accounts only for 7% (dark grey) (Fig. 42).

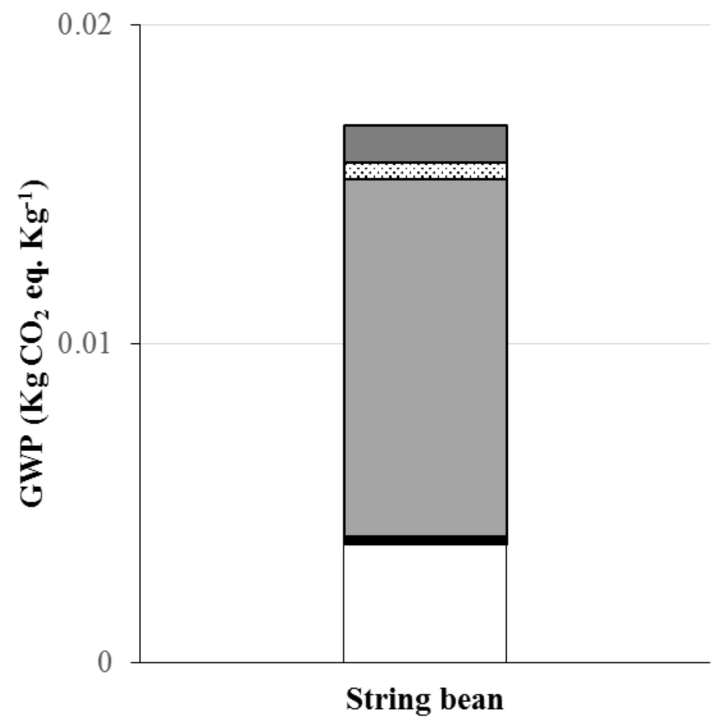

Figure 42 GWP of string bean according to input categories, namely: auxiliary equipment (□), tap water (■), fertilizers (▒), pesticides (░), transport (▓).

- Tomato

The total yield of tomato production is 14.5 Kg m^{-2} and the total impact referred to the FU is 0.010 Kg CO_2 eq. The environmental profile of tomato cultivation show that most impacting factors are the use of fertilizers (63%) (light grey), the auxiliary equipment (14%) (white) and the transport (19%) (dark grey) (Fig. 43).

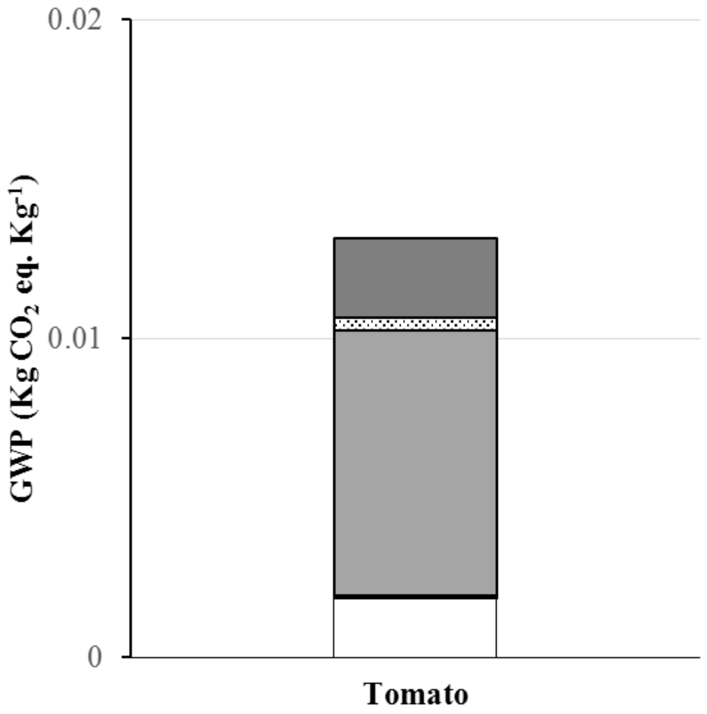

Figure 43 The environmental profile of tomato cultivation according to input categories, namely: auxiliary equipment (☐), tap water (■), fertilizers (▒), pesticides (░), transport (▓).

- Zucchini

Zucchini production is 3.9 Kg m^{-2} and the environmental impact (GWP) is 0.025 Kg CO_2 eq. Kg^{-1}. Most impacting factors are fertilizers (64%) and transport (25%) (light and dark grey) (Fig. 44).

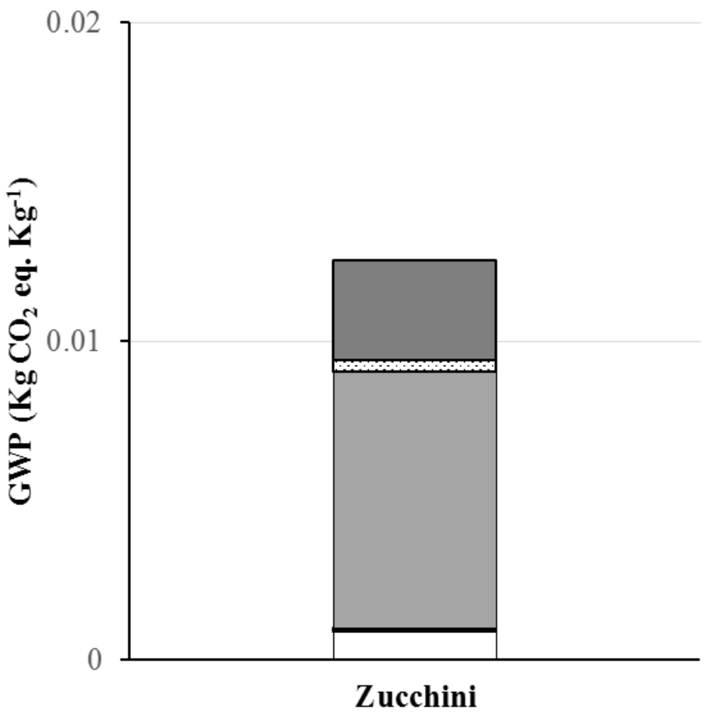

Figure 44 GWP of zucchini crop according to input categories, namely: auxiliary equipment (□), tap water (■), fertilizers (■), pesticides (▒), transport (■).

Global results

These crops had a global warming impact ranging from 0.0037 to 0.015 Kg of CO_2 eq. Kg^{-1}. The less impacting culture is the chicory, while the most affecting is the protected cultivation of lettuce. Indeed, the difference is due to the material used to cover the plant, but in particular, it is caused by the metal working of cast irons to support the nonwoven-fabric.

If we consider the open-air cultivation without protection, the production of chicory (cv. Chioggia) rises 0.082 Kg of CO_2 eq. Kg^{-1} emitted. These values are strongly influenced by the length of the crop cycle and the yield (Kg m^{-2}). For that reason, fruit and steam vegetables have less environmental impact.

The life cycle stage that contributed the most to the environmental indicators turned out to be (in average) the use of fertilizers (≈ 50%), and the transport of raw materials (≈ 30%). Due to the volatilization and lixiviation, nitrogen fertilizers affect the systems. Indeed, the ammonium nitrate is responsible for the 75% of the environmental impact of fertilizers. The auxiliary equipment does not affect the GWP, because since the irrigation system was manual, it does not consume electricity. That is not true in the case of protected cultivation of chard and lettuce (cv. Cappuccia). Otherwise, with the LCA approach and Simapro 8.0.3.14 software, we were able to create new scenarios, substituting some elements of auxiliary equipment. In Figure 45 a new scenario is shown (in white). PE bars substitute iron ones, and, taking into account their lifespan, respectively 15 and 20 years, it is possible to note a reduction of environmental impact around 30%.

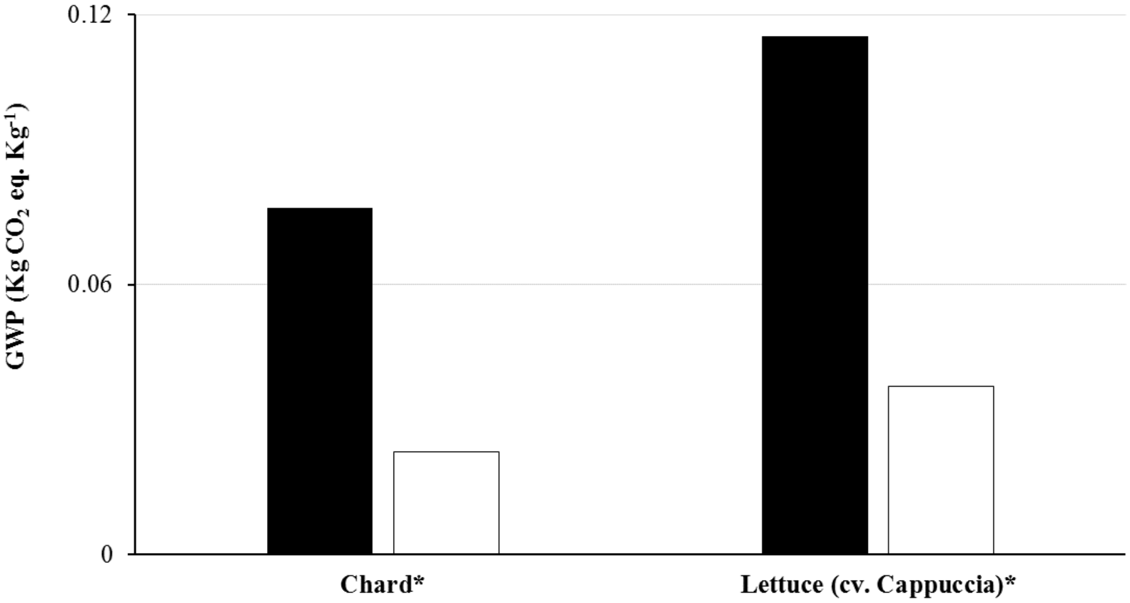

Figure 45 GWP of chard and lettuce cultivation, changing auxiliary equipment: experimental data (■) and simulated scenario (☐).

Home garden production could improve the management and overcome some garden problems such as the impact due to packaging or to the use of an industrial compost.

Limitation of the study

One of the limitation of this kind of study is the data source and the high subjectivity of who leads the study.

3.3 Discussion

Using the data obtained in this study, it has been possible to do a comparison between another case study developed in a home garden, or more correctly, in a community garden in Bologna (Sanyé-Mengual et al. 2015). Hypothesising the same distance between cultivation and consumption, it is possible to highlight the different impact due to the cultivation of the same species in two different growing systems. The case study of

Bologna represents a soilless system cultivation on a rooftop garden. Figure 46 illustrates the comparison between vegetables cultivated in a soil-based home garden (Padua, white) and a soilless system where plants are grown on a wooden box filled with commercial substrate (Bologna, black). The range in GWP goes between the lowest value of 0.01 Kg CO_2 eq. Kg^{-1} (for tomato cultivation on soil) to the highest one, 0.32 Kg CO_2 eq. Kg^{-1} (lettuce cultivation on a soilless system).

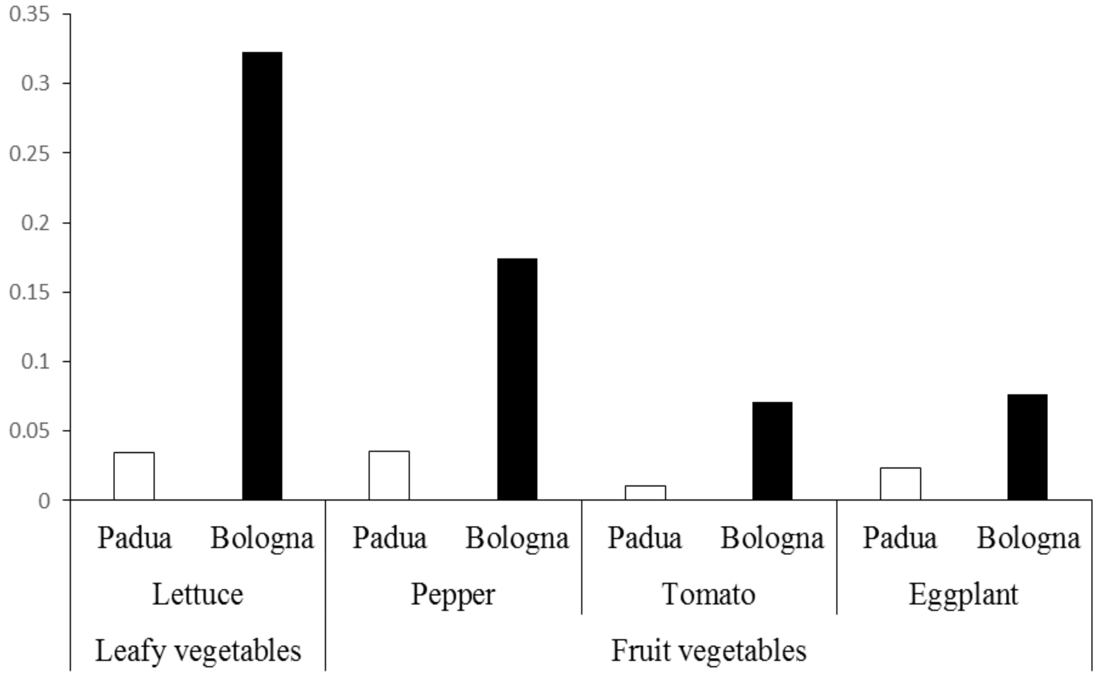

Figure 46 Comparison between different cultivation systems.

It is possible to see a different trend between the growing of leafy and fruit vegetables. Since in Padua a traditional open-air system was used, while in Bologna a soilless system was used, the difference between values is to be associated with both the elevate amount of irrigation water provided (which was about two times more in the soilless system compared to the soil one, due to mismanagement in the former) and the lower yields in the soilless system (1.5 vs 3.0 kg m^{-2} in soilless and soil-based gardens, respectively) (Sanyé-Mengual et al., 2015). In Sanyé-Mengual et al. (2015), the irrigation was the most contributing element of GWP impact (75%) and the use of rainwater harvesting systems was suggested in order to reduce the environmental impact. On the other hand, when a floating system was used in the rooftop experimental garden, water use efficiency was increased, resulting in values much greater than those observed on soil (25 g FW l^{-1} H_2O vs 9 g FW l^{-1} H_2O in floating vs soil, respectively), also due to the greater observed yield

(2.5 kg m^{-2}) and the shorter crop cycle (21 vs 65 days from transplanting to harvest in floating vs soil-based garden, respectively).

3.4 Conclusion

This study accounted for the environmental impact, only for GWP, of crop production in a home garden located in Padua, thereby contributing to the sustainability assessment of urban agriculture from a quantitative approach.

The global warming potential, expressed in Kg of CO_2 eq. emitted in the atmosphere strongly depended on cultivation method, crop yield and cycle, as well as on periodicity. Soil production of tomatoes had the highest crop yield, and consequently the best environmental performance. For leafy vegetables, chicory had the best performance.

The crop's biodiversity contributed to supply the food owner demand, and could contribute in obtaining cheap and environmentally friendly products. Potential benefits of open-air farming and the crop planning are crucial points to optimize the environmental profile of home gardens. The urban "foodprint" represents an important area to improve urban environmental performance (Goldstein et al. 2014). Further research may focus on integrating the economic dimension in sustainability studies of home gardening. LCA methodology is confirmed to be a good tool to assess the environmental profile of crop production, and in the decision-making processes. Indeed, as illustrated, it was useful to apply some changes in life cycle stages and to suggest new cultivation materials.

Chapter IV

Large-scale production and ‘food miles’

This chapter evaluates the environmental impact of a large-scale crop cultivation. The focus of the study is the final part of the production chain, i.e. the distribution phase. The selected crop is fennel (*Foeniculum vulgare*), produced off-season in Italy and Spain, both production will be compared to analyze the agri-food trade. This work was realized with the collaboration of Ivan Domeniconi, a graduate student of the University of Bologna, and Esther Sanyé-Mengual, a researcher at ResCUE-AB; and with Pere Muñoz Odina, professor at IRTA (research institute owned by the Government of Catalonia ascribed to the Department of Agriculture) in Cabrils, Barcelona (ES).

4. How many kilometres separate the producer from the consumer of vegetables? Analysis of production and distribution chains.

‘Food miles’ and of the international trade have both undoubtedly increased dramatically in recent years. When discussing the impacts of food production, the most impacting factors are the consumption of energy (Jungbluth et al. 2000) and the transport of the product. This is caused by the need to meet consumers’ demand, so it is necessary to import some of the product or cultivate it in artificial conditions, such as heated greenhouses (Webb et al. 2013). An interesting review about LCA on food underlines the main steps to carry out the assessment (Roy et al. 2009). These type of studies are important to assess the different potential sources of foods to determine if there are systems or locations of production which offer significant reductions in energy and other resource use over others. Also, they could help in decision-making processes or trade-off situations. Payen et al. (2015) show an example of fresh tomato production (which requires a large quantity of water) and its consumption in France. Off-season tomatoes are either produced locally in heated greenhouses or imported from Morocco and Spain. Through this study, possible scenarios or environmental profiles were analysed, suggesting some environmentally friendly food choices. Causapé et al. (2004) indicated that increased production of field-grown salads and vegetables in the Mediterranean area might damage water supplies, increase soil salinization and decrease water quality due to eutrophication and pesticide contamination. Foster et al. (2006) reviewed the evidence on life cycle impacts of a range of commonly purchased fresh and processed foods in a ‘shopping basket’ and assessed the additional sustainability disadvantages of food miles. Other studies focused on UK agro-food importations, e.g. Canals et al. (2008). They identified the environmental hotspots in the life cycle of some vegetables (i.e. broccoli, salad and green bean) as well as the comparative environmental impacts of different supply options. The study specifically addressed the seasonality of fresh vegetables and compares produce that may be on the market shelves at the same time of the year. Furthermore, it explores the variation of environmental impacts associated with the same or similar products through the year. The agriculture is the primary field affecting global emissions (Bentsen et al. 2014). A report from FAO shows that GHG from agriculture and animal husbandry increased from 4.7 billion tons of CO_2 eq. in 2001 to over 5.3 billion tons in 2011, a 14% increase, which occurred mainly in developing countries following the increase of the total agricultural production. The main causes, as stressed before, are the impact generated by the distribution of products, and by the enteric fermentation of cattle that releases methane, and the use of fertilizers (Tubiello et al. 2014).

This study will contribute to integrate researches of LCA on large-scale vegetable productions, and to suggest some useful supply-chain comparisons. That, in order to improve the sustainability of vegetables' production and consumption.

Agri-food trade in Italy and Spain

In Italy, more than 15 million hectares are cultivated, 3.7% of which are used for field-grown vegetables (De Haan et al. 2001). The agri-food industry is the central element of the first economic sector of the country. It buys and processes 72% of the national agricultural raw materials. Spain is the first EU fruit and vegetable exporter and the 38% of the total 921,000 cultivated ha was destined to vegetable cultivation, potato excluded (in 2008 – 2010, as reported by MAGRAMA[8]) (ITA 2014). Italy and Spain are the only EU countries, which have an agri-food structure distribution that based on traditional retails (Traverso 2010).

- *Exports to France*

Italian exports to France (for a total of 38 billion euro) increased compared to 2014 (+2.8%). Italy, with its 7.4% share of French imports, according to the French Customs Office data, passes from the 4th to 3rd place compared to 2014 among the major exporting countries to France. In 2015, Italy exported vegetable and fruit crops for a value of 638 million euro[9].

In general, France is Spain's most important partner, in fact, exportation have increased steadily (except in 2010) from 5,178,027.58 t (in 2008) to 6,395,599.59 in 2013, 24% of which was sent to France (Martínez Aguirre 2014).

Goals and motivation of the research

This study aims to analyze fennel productions, which cause point pollution problems to ensure the year-round presence of the products. The environmental impact of

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[8] *www.mapama.gob.es/*

[9] http://www.infomercatiesteri.it

imported/exported fresh agricultural products, such as (but not limited to) off-season vegetables transported over long distances, is under growing scrutiny. We hypothesised that LCA ranking between local and exported vegetables might change depending on the impact category considered (i.e. GWP, Kg CO_2 eq. t^{-1}). This raises questions regarding the comparative life-cycle burdens of different food supply chains and the extent to which some types of chains may be exporting environmental burdens to other countries.

In this study, the selected crop was the fennel (*Foeniculum vulgare*), because its considerable nutritional virtues, could determine a potential growth of its presence on markets.

The production is analysed in three Case Studies (CS, Fig. 47):

1) Abruzzo, IT (CS-Abruzzo)
2) Emilia-Romagna (CS-EmiliaRomagna)
3) Comunitat Valenciana (CS-ComValenciana)

Figure 47 Fennel production, map of case studies: 1) CS-Abruzzo; 2) CS-EmiliaRomagna and 3) ComValenciana.

After the evaluation of these three food production chains, two scenarios were analysed, a national scenario and an international one.

- *National trade*

Italy is leading the fennel production worldwide, with a cultivated area of over 20,000 hectares and an average yield of around 470 thousand tons. Fennel is available all year round in Italy in all distribution channels, and its consumption is mainly national. In Italy, around 10 million products (almost 70% of the total production) pass through 150 markets. One of the most important and strategic is the agri-food center of Bologna (CAAB). Other countries continue to request it, weighing just about 10% of production. France and Germany confer 1/3 of total fennel exports grown in Italy (Italiafruit News 2015).

- *International trade*

The worldwide cultivation of fennel is mainly spread in Italy, France and Spain (Fundacion Cajamar Valencia 2014), Turkey, Syria, Egypt, Morocco and Iran (Siviero et al. 2005), and Hungary (Cserni et al. 2011). However, since France is the second fennel producer in Europe, but it consumes more than it produces, a portion of the fennel consumed is imported from Spain and Italy (Fundacion Cajamar Valencia 2014).

Accordingly, the present study analysed the following scenarios (Fig. 48):

a) *National trade*: fennel produced in CS-Abruzzo and in CS-Romagna, transported to the agri-food centre of Bologna (CAAB).
b) *International trade*: fennel produced in CS-Abruzzo and in CS-ComValenciana, exported to Saint-Charles International Market (SCIM), French distribution hub for fruits and vegetables.

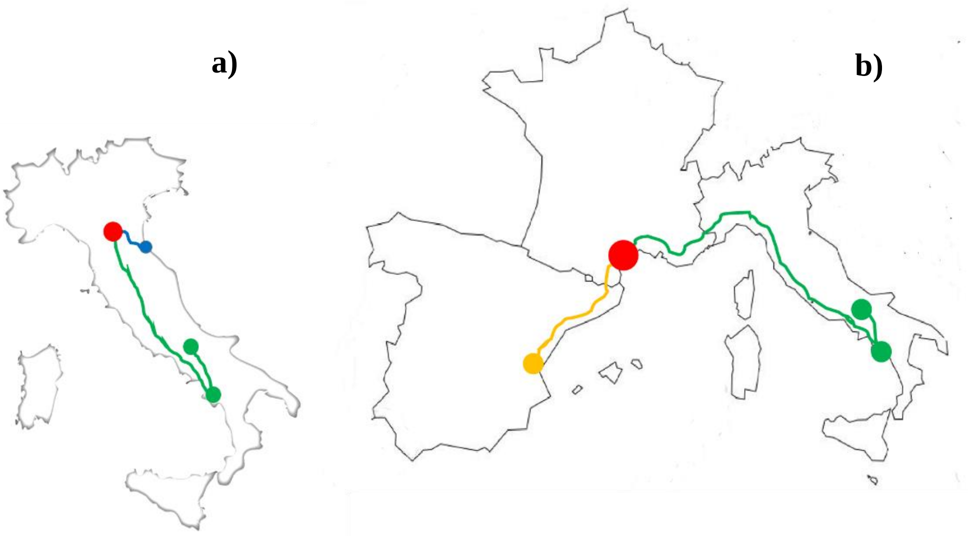

Figure 48 Scenarios: a) Italian fennel production (CS-Abruzzo ● and CS-EmiliaRomagna ●) conferred to CAAB (🟥); b) Italian (CS-Abruzzo ●) and Spanish (CS-ComValenciana ●) fennel production exported to France (🟥).

Food miles for distribution phase by road, in the above two scenarios, are:

a) From CS-EmiliaRomagna to CAAB: 100 Km (blue), while between CS-Abruzzo and CAAB, 600 Km (green). In the latter, the product is processed in a warehouse near Salerno before being transported to Bologna.
b) From CS-Abruzzo to Saint-Charles International Market (France) the distance is around 1500 Km, while from CS-ComValenciana is around 600 Km.

4.1 Materials and methods

4.1.1 Fennel cultivation

Fennel (*Foeniculum vulgare* Mill.) (Fig. 49) is a hardy, perennial, umbrelliferous (Apiaceae) herb considered native of the Mediterranean areas and it has become widely naturalized elsewhere; it may be found as a wild species in many parts of the world (Barros et al. 2010).

The crop requires soil harrowing. Fennel is rather sensitive to nitrogen fertilization, and it can accumulate nitrates in the edible parts, in the order of 1000-2500 mg Kg^{-1} of fresh weight (Santamaria et al. 2002). Nitrogen will be administered twice in the overall amount of 25-30 grams m^{-2} of ammonium nitrate.

Figure 49 Fennel

- *Fennel cultivation in Italy*

Italy is the major producer (about 19,000 ha in 2015[10]) and consumer; it produces about 85% of fennel bulb in the world. The regions most involved in its production are Puglia (30%), Campania (18%), Lazio (11%), Sicily and Marche (9%), Abruzzo (5%), Calabria and Emilia Romagna (4.5 and 4%, respectively). Seasonal fennel cultivation stretches from June-August (seedling) or July-August to September-November (harvesting). The soil which will host the fennel crop must be prepared with the utmost care up to a depth of about 25-30 centimeters (e.g. grooving and milling). Usually the planting framework is 0.5-0.7 m x 0.2-0.25 m with a density comprised between 80,000 and 120,000 plants ha^{-1}. In this case, the commercial yield is higher than 40 t ha^{-1}. The crop management includes a drip irrigation system, mineral fertilizations and some pest and diseases treatments (i.e. ciprodinil + fludioxonil). Fennel's most damaging disease is caused by the fungi *Sclerotinia sclerotiorum*, which irreparably damages the heart (grumolo) of the plant (Cipriani & Pollini 2008). In the southern regions of Italy, especially in coastal areas, production is typical during winter

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[10] agri.istat.it

stretching until the spring. Abruzzo, where the Fucino Plain is cultivated, stands out for summer production that becomes complementary to that of other regions to cover an almost year-round availability on the market (Gonnella et al. 2013).

- *Fennel cultivation in Spain*

Spain is one of the most important fennel producer in Europe and specializes in export. In Spain, fennel production is located in the South of the country, especially in the Valencia, Alicante, and Murcia productive areas (Escalona et al. 2004). The fennel calendar cultivation stretches from August-November (seedling) until November-May (harvesting). Usually the planting framework is 0.66 x 0.30 m, with a density of 100,000 plants ha^{-1}. The average commercial yield is 46 t ha^{-1}. The duration of the crop cycle is, in average, 145 days. Crop management includes primary tillage (grooving, milling, and seeding), a drip irrigation system, mineral fertilizations and some pest and diseases treatments (i.e. *Bacillus thuringiensis* and cupric sulfur).

4.1.2 Case studies

- *CS-Abruzzo*

The Fucino Plain has an extension over 200 Km^2, and once hosted the eponymous Lake (also known as Celano Lake), which was drained, and the area started to be cultivated in the early 1800s. The disappearance of the lake caused substantial social changes due to the transition of the local economy from fisheries to farming but also because of important environmental impacts caused by the disappearance of a balanced biological ecosystem (Frank et al. 2008). Vegetable crops are field grown, thanks to favorable circumstances, including the possibility of repeating two to three growing cycles in the same area. The Plain is located in Central Italy, over the Lazio-Abruzzo Apennines (Petitta et al. 2004). The fractured carbonate aquifers surrounding the Plain feed high-discharge springs and streambed springs, which ensure steady discharges even during the dry season. The heterogeneous aquifer of the Plain, having a variable vertical permeability, is supplied by groundwater seepage and by direct infiltration from rainfall. The long-term water balance of the Plain can count on 700 mm y^{-1} of precipitation, 450 mm y^{-1} of evapotranspiration, and consequently 250 mm y^{-1} of water excess in the October-March period (Petitta & Mariño 2010). Concerning fennel in Fucino, unitary productions is hovering around 25 t ha^{-1}, corresponding to approximately 50,000 t for the whole area.

Experimental field

“La Serra” Cooperative is located in Celano (AQ), and the experimental fields are inside the Fucino Plain (Strada 11, Lat.42°4'53.50"N; Long.13°32'32.25"E) (Fig. 50). This is the most representative cooperative located in the Region. Overall, the cooperative covers an area of 15 ha, and the spring loop fennel takes up 6 ha, cultivar Tauro, sown on 12.03.2014. Usually, producers harvest raw fennel, and the subsequent phases of refining happen in a warehouse in Salerno (SA), about 250 Km away from the productive area. From there, the distribution supplies the national and international markets, including the CAAB.

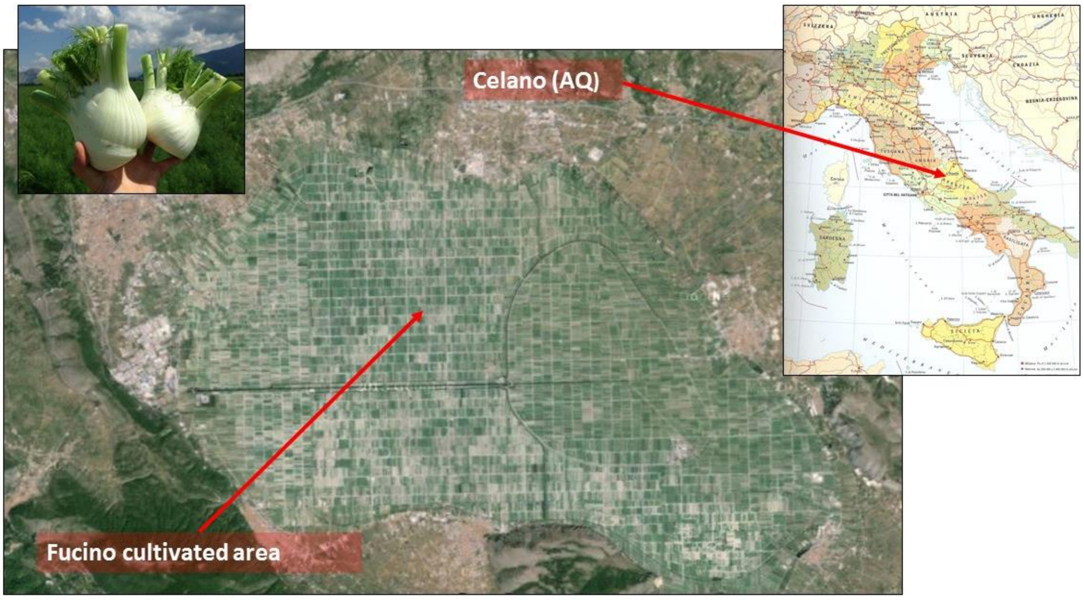

Figure 50 Fucino Plain, CS-Abruzzo.

Primary data

The following data were collected during a 40-minutes interview with the owner of the enterprise and some agronomists.

Regarding land preparation, some conventional tillage occurred, i.e. plowing, uprooting and harrowing, all carried out with a 170 HP tractor, respectively for 2 h ha^{-1}, 1 h ha$^{-1,}$ and 1.5 h ha^{-1}. The total fertilization plan foresaw the distribution of manure (40 t ha^{-1}, 170 HP tractor, Nitrophoska (1.1 t ha^{-1}, 60 HP tractor) and calcium nitrate (0.3 t ha^{-1}, 60 HP tractor). Both fertilizers were transported to the field with a truck (total distance travelled: 350 Km). The sowing occurred on 12/03/2014 using a 60 HP tractor (1 h ha^{-1}), while the irrigation system distributed 1400 m^3 of well water per ha (8 h), using galvanized aluminum pipes (350 m) and steel sprinklers (24 unit ha^{-1}). The auxiliary equipment was produced 270 Km away from the field, and transported there by truck. During the harvest, raw fennel was placed in polyethylene's bins (530 unit ha^{-1}). Then, it was brought to the warehouse (in Salerno, 230 km away) to be cleaned and packed (25 m^3 of tap water, 70 Kg of polyethylene for 1 t of product). Distribution to the final supply point was made by truck (620 Km).

Secondary data

Secondary data come from ECOINVENT database of Simapro 8.0.3.14 software, and data collected from CAAB on food management and disposal.

- *CS-EmiliaRomagna*

The Emilia-Romagna Region is located in the north-eastern area of Italy, with a total surface of 22,447 Km^2 and a population of 4,429,766 inhabitants[11]. The region ranks among the Italian regions with the largest share of irrigated and irrigable surface. Emilia-Romagna is also favoured by large fertile lowlands, proximity to international markets and a mild climate, providing a thriving and varied agricultural sector that accounts for 2.7% of regional gross value added (compared to the national average of 1.9%)[12]. In the region. There are different kind of farms, and, especially in the study area, they have specialised in vegetable production for the fresh market. These farms are small (2.5 to three hectare), specialized in four to five profitable crops; one of which is the fennel cultivation. Levels of mechanization are very low, and products are sold through cooperatives that supply directly supermarket chains, wholesale market or private traders.

Experimental field

The agricultural enterprise “Bianchi Secondo” is located in San Mauro Pascoli (Lat. 44°7'56.12"N.; Long. 12°25'18.27"E.), a township in the Forlì-Cesena (FC) province (Fig. 51). The area produces produce of excellent quality thanks to environmental factors, but also thanks to the farmer’s vast experience. The enterprise usually harvests and cleans the products in field, loads them in wooden boxes and brings them to the warehouse close the cultivated area. The final product distribution is limited to the local market or to the CAAB.

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[11] (2015)

[12]

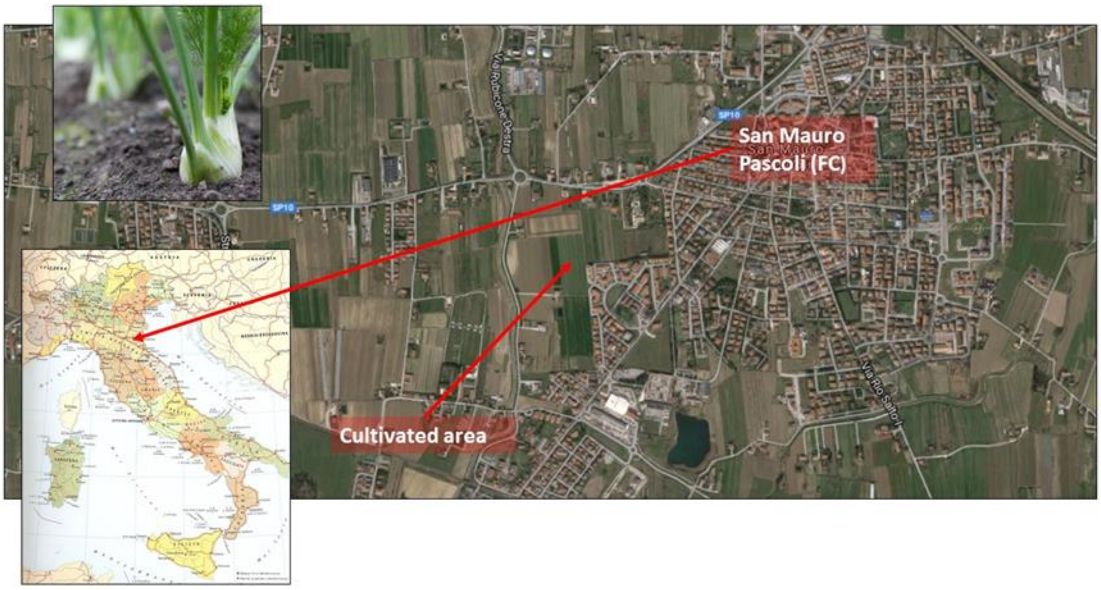

Figure 51 San Mauro Pascoli, CS-EmiliaRomagna.

Primary data

The following data were collected during a 40-minute interview with the owner of the enterprise and some agronomists.

In this area, we have a different land management process which begins with digging (tractor 80 HP 4.5 h ha^{-1}), then harrowing (tractor 80 HP 3 h ha^{-1}), milling (tractor 80 HP, 4 h ha^{-1}) and rolling (tractor 18 HP, 1.5 h ha^{-1}). Fertilizers, transported via lorry (8 Km), were distributed by a tractor 18 HP in the following doses: manure (2 t ha^{-1}, 2 h ha^{-1}), Nitrophoska (1.1 t ha^{-1}, 1 h ha^{-1}) and calcium nitrate (0.3 t ha^{-1}, 0.5 h ha^{-1}). Here, some pest and diseases managements were done using Karate (Lambda-cialotrina, 1 l ha^{-1}), Score (Difenoconazolo, 0.4 l ha^{-1}), Switch (Cypordinil, Fludioxonil, 0.5 Kg ha^{-1}), Most Micro (Pendimetalin, 2 l ha^{-1}) (9 Km via lorry). Crop residues are buried, while other wastes are disposed of or recycled at HERA, the main company in environmental services (waste collection and treatment), energy and water services in Emilia-Romagna. The other wastes created during the process are exhausted oil, fertilizer bags and containers for agrochemicals. The polyethylene used for packaging 1 t of the product weights 70 Kg, while the tap water used for cleaning the fennel amounts to 20 m^3. These steps occur in the warehouse close to the field (300 m, tractor 18 HP), while leaves are removed during the hand-picking phase. The distribution to CAAB Bologna (100 Km) is made by truck.

Secondary data

Secondary data come from ECOINVENT database of Simapro 8.0.3.14 software, and data collected from CAAB on food management and disposal.

- *CS-ComValenciana*

Valencia is an autonomous community of Spain, the fourth most populated after Andalusia, Catalonia and Madrid with more than 4.9 million inhabitants. The area is located along the Mediterranean coast in the south-east of the Iberian peninsula. The Comunitat Valenciana has an intensive agricultural base that includes citrus trees, fruit trees, and vegetables (Ramos et al. 2002). The industrial sector is active in the agricultural sector, but also in the mechanical, textile and shipbuilding sectors (port of Villanueva del Grao).

Experimental field

Experimental crops were cultivated in the "Centro de Experiencias de Cajamar" in Paiporta, Valencia (Spain) (Lat. 39°25.6884′ N; Long. 0°25.059′ W) (Fig. 52) which promotes the cooperativism, agri-food research and the transfer of knowledge with the aim of favoring the development of the agri-food sector and the growth of its socio-economic environment.

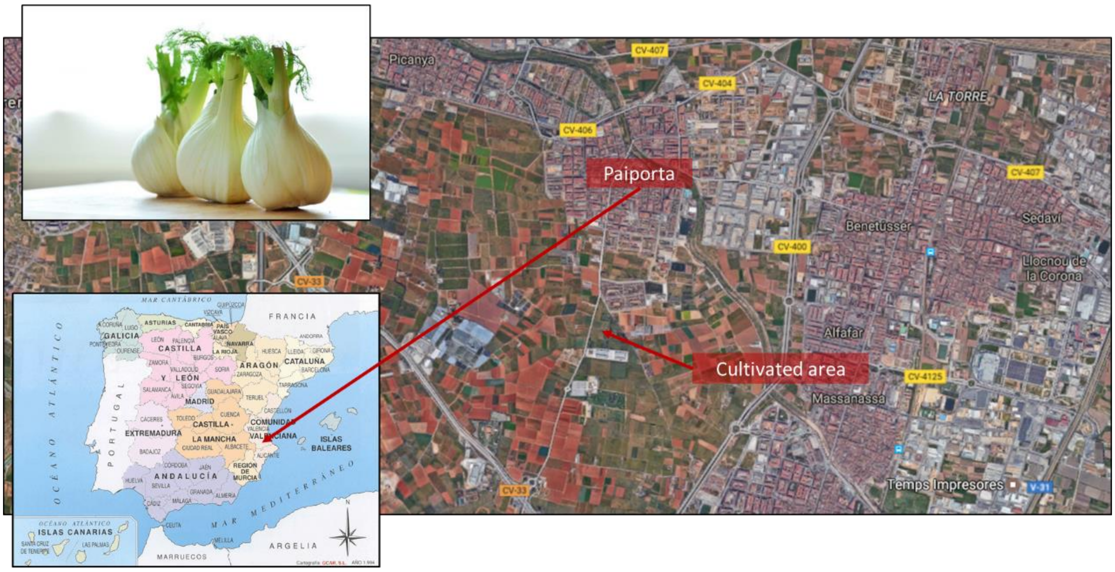

Figure 52 Paiporta, CS-ComValenciana.

Primary data

The following data were collected during a 40-minute interview with Carlos Bauxili, vice-president of the Spanish Society of Horticultural Sciences (SECH).

Secondary data

Secondary data come from ECOINVENT database of Simapro 8.0.3.14 software, and from literature.

4.1.3 Life cycle assessment

To evaluate the environmental impact of off-season fennel cultivations, the same LCA methodology applied in Chapter III will be used.

Two large-scale fennel productions will be compared, using cradle-to-consumer system boundary and FU=1 tons (t) of produced fennel. It is unusual to find in literature a complete life cycle assessment of the agricultural product; here it is possible to read some examples.

The investigated impact category is the GWP, as in the previous chapter, through the IPCC 2013 100a midpoint method. It contains the climate change factors of IPCC with a time-frame of 100 years and it is expressed in Kg CO_2 eq. This last unit comes from the characterization of elementary flows. In this case, 1 Kg CO_2 is multiplied by the characterization factor (CF=1) and the unit resulting is the Kg CO_2 equivalents. The system boundary, as previously shown, presumes that: a) both Italian enterprises are delivering to CAAB, while b) CS-Abruzzo and CS-ComValenciana export to Saint-Charles International Market, in France (Fig. 53).

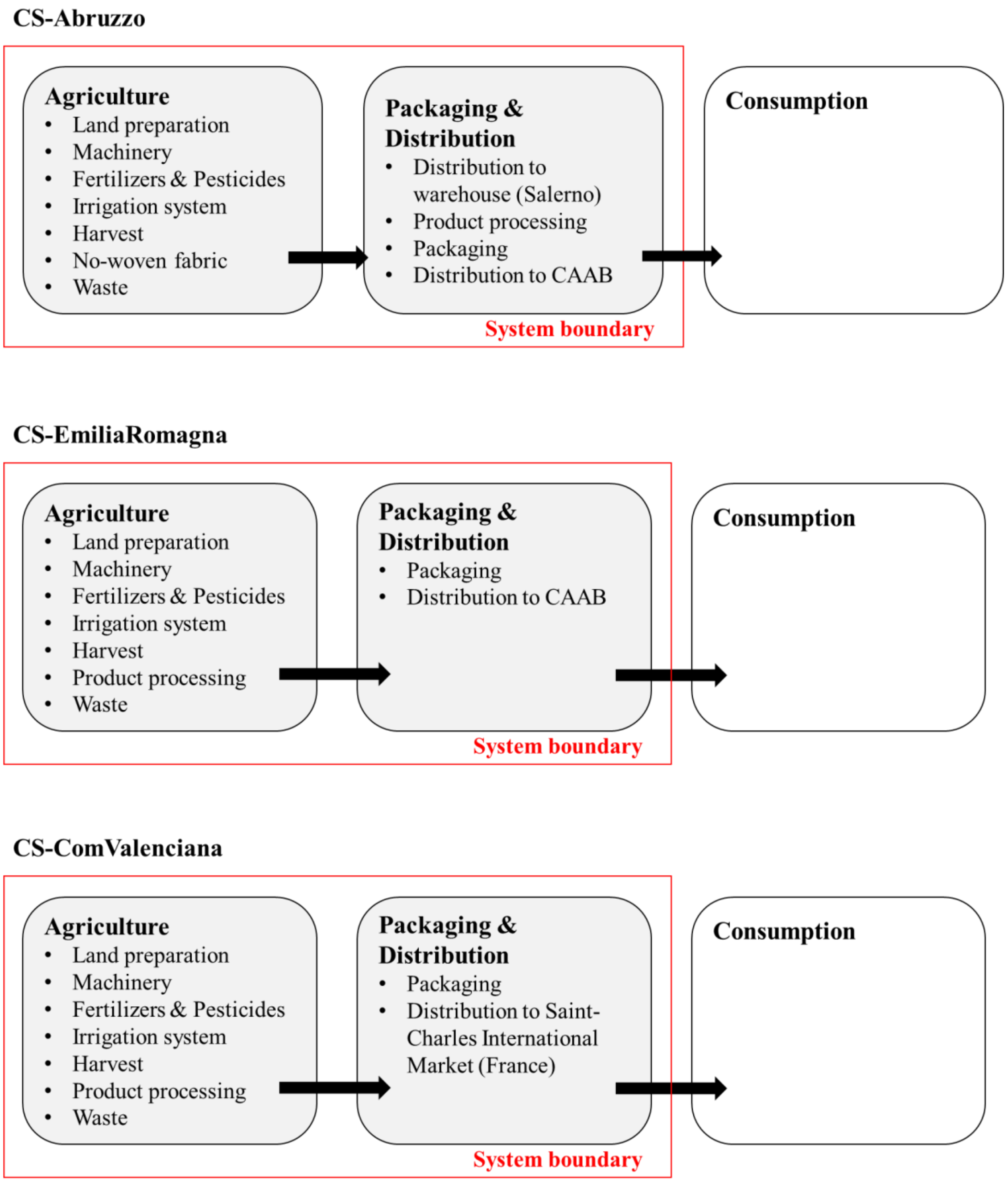

Figure 53 System boundary and principal inputs relating to different product phases in each case study.

4.2 Life Cycle Inventory (LCI)

Following interviews with farms' owners, a life cycle inventory was prepared. Primary data referred to 1 ha inputs, but were then normalized to the FU of 1 t of produced fennel, considering their lifespan[13].

- *CS-Abruzzo*

The variety Tauro was produced in Celano (AQ) in a 6 ha field. The crop cycle lasted 83 days. The planting density was 85,000 plants ha^{-1}, the raw yield was 48 t ha^{-1}, while the commercial one 27.5 t ha^{-1} (Table 8).

- *Land praparation*

The interview data collected were processed by calculating the amount of fuel consumed by the total hours of use of the machine multiplied by the hourly consumption of the same. Once obtained, the total liters of fuel have been multiplied by the density of the fuel (diesel standards, density at 15 °C between 820-845 Kg m^{-3} the product complies with European standard EN 590: 2010. Then, to obtain the value expressed in MJ, the Kg were multiplied by the calorific value of the diesel power (calorific value standard diesel 47.3 MJ/Kg; UNI 10389)[14]. Also, the impact of the nonwoven fabric to protect the crop was calculated.

- *Irrigation*

The irrigation system is composed of galvanized aluminum pipes with inserts every six meters: the total length is of 270 meters. The weight (in Kg) of the whole irrigation system was calculated. The sprinklers are 24 and made of steel; they were weighed as well. The energy used by the tractor to drive the pump and the Kg of well water utilized for the cultivation, and the transport of materials from the factory to the experimental field were all considered as well.

- *Fertilizers*

The quantity of nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) were obtained from their composition, and from knowing the amount of fertilizer used per hectare. The

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[13] The of for which a thing (http://dictionary.cambridge.org)

[14] https://www.eni.com

transport by the manufacturer and the energy consumed by the tractor for the distribution of elements was considered.

- *Agrochemicals*

For each product used, his quantity was calculated in Kg, knowing the total amount used in liters, multiplied by their density. The amount of water in Kg used for the phytosanitary treatment, the energy consumed by the tractor and the transport of products from the manufacturer were all taken into account.

- *Harvest*

The collection of raw fennel is done by hand, so it is considered to be zero impact. We counted the life cycle of the bins in which the fennel was placed and the transport of it to the processing center located in Salerno (SA).

- *Waste*

In this phase, the impact of waste produced was taken into account: the exhausted oil used by tractors, fertilizer bags and agrochemical containers, and boxes for final packaging were all considered. Each material was weighted. The crop residues were transported back on the field, and then buried.

- *Packaging*

In the warehouse, the fennel was washed and packed. The electricity consumed to illuminate the building, for the use of machinery and forklifts for loading and unloading pallets was taken into account. The water consumed for washing is drinking water, so in the process of data processing, it will have a greater weight on impact than water taken from the channel. The LCA of the boxes for the packaging of the product ready for market and transport from the producer factory was also taken into account.

- *Distribution*

For distribution, the transport of fennel from the processing and packaging center to the point of delivery was taken into account (CAAB).

Table 8 LCI of CS-Abruzzo.

		Element	Material	Process	Quantity	Unit	Lifespan (years)
Cultivation system	Land preparation	Tractor 170HP	Diesel		5373.28	MJ	15
		Tractor 60HP	Diesel		567.6	MJ	15
	Nonwoven-fabric	nonwoven-fabric	LDPE	Extrusion	6.8	Kg	5
		Tractor 60HP	Diesel		567.6	MJ	
		Transport	Truck (270 Km)		1840	KgKm	
	Irrigation	Pipes	Galvanized aluminium	Metalworking	13.6	Kg	15
		Sprinklers	Steel	Metal working	0.86	Kg	10
		Water	Groundwater		1400000	Kg	
		Pump	Steel	Extrusion	0.58	Kg	10
			Polyethylene	Injection moulding	0.025	Kg	10
		Tractor 60HP	Diesel		3784	MJ	
		Transport	Truck (350 Km)		7600	KgKm	
	Fertilizers	N		N emissions	165	Kg	
		P			112	Kg	
		K			148	Kg	
		Tractor 60HP	Diesel		1532	MJ	15
		Transport	Truck (350 Km)		146000	KgKm	
	Agrochemicals	Herbicide	Stomp (Pendimethalin)	Unspecified pesticides	2.28	Kg	
		Fungicide	Switch (cyprodinil. fludioxonil)	Unspecified pesticides	2.5	Kg	
			Score (Difenoconazolo)	Unspecified pesticides	2.15	Kg	
			copper oxychloride	Unspecified pesticides	12.5	Kg	
		Pesticides	Karate (Lambda-cialotrina)	Unspecified pesticides	5.28	Kg	
		Water	Tap water		4800	Kg	
		Tractor 60HP	Diesel		1135.2	MJ	
		Transport	Truck (350 Km)		8500	KgKm	
	Harvest	Bins	HDPE	Extrusion	399.9	KG	10
		Transport	Truck (350 Km)		78000	KgKm	
	Waste	Exhausted oil			14	Kg	
		Fertilizer's bags	LDPE	Extrusion	11.4	Kg	
		Agrochemical's containers	PVC	Extrusion	9.7	Kg	
		Transport	Truck (34 Km)		35.1		
		Packaging film	PVC	Extrusion	8.5	Kg	
Distribution	Packaging	Transport	Truck (230 Km)		1190	KgKm	
		Energy Consumption			374.4	Kw/h	
		Water	Tap water		30000	Kg	
		Packaging film	HDPE		76.8	Kg	10
	Distribution	Transport	Truck (620 Km)		31824	MJ	

- *CS-EmiliaRomagna*

The variety Solaris produced in San Mauro Pascoli (FC), where the field area is 2.5 ha. The crop cycle lasted 62 days. The planting density was 90,000 plants ha^{-1}, the raw yield 44 t ha^{-1}, while the commercial one 22.4 t ha^{-1} (Table 9).

- *Land preparation*

As reported before, in Emilia-Romagna farms have smaller extensions than in the Fucino Plain. This is underlined by the use of a tractor with a lower horsepower (HP). Indeed, in the CS-EmiliaRomagna the farmer uses a caterpillar 80 HP and a rototiller 18 HP For these, total liters of diesel consumed for machining were calculated, and then were converted into kilograms, and energy (MJ).

- *Irrigation*

The irrigation system consists of galvanized aluminum pipes, steel sprinklers and a pump. To determine the incidence of the irrigation system we took into account the days of culture permanence in the field. The energy consumption of the electric motor that powers the pump extracting the water from the well was calculated in kWh. The final value was obtained by dividing the electric bill value and the average price of electricity in the province of Forlì-Cesena (0.16 €/kWh), taking into account the days of use of the electric motor. The volume of water is express in Kg, and the impact of the transport of irrigation (from the factory to the experimental field) system materials was taken into consideration.

- *Fertilizers*

The amount (in Kg) of nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) used for the crop fertilization were derived from the content of the fertilizer. We analyzed the energy consumed in their distribution and transport from the factory company.

- *Agrochemicals*

To calculate the impact of the different active principles utilized (in Kg), their density was multiply by used liters. The volume of water used for the treatment has been converted into Kg and the energy consumed for treatments and the transport of plant protection products was calculated.

- *Harvest*

Here, harvesting is manual, so its impact was not taken into account. Only the energy consumption to bring fennel to the warehouse was taken into account.

- *Packaging*

The fennel, once cut, is processed directly in the field. The plant residues are left on the ground, then buried. After placing it in the product boxes, the fennel is transported to the warehouse to be washed and placed on pallets ready to be loaded and transported to the CAAB. The energy consumed for washing product, and the drinking water consumed, as well as the kilograms of packaging used were calculated. After product processing, the crop lost approximately 55% of the total yield.

- *Waste*

The exhausted oil (in Kg) consumed by vehicles, fertilizer bags, containers of agrochemicals, and boxes' packaging were all considered. Finally, the impact of transport to HERA, where waste is either partially recycled or disposed of was also taken into account.

- *Distribution*

Data on the allocation were obtained by theorizing a common point of transfer for the two companies; the transport was performed with trucks, and the destination is the CAAB in Bologna.

Table 9 LCI of CS-EmiliaRomagna

		Element	Material	Process	Quantity	Unit	Lifespan (years)
Cultivation system	Land preparation	Tractor 80HP	Diesel	Energy	5221.9	MJ	15
		Tractor 18HP	Diesel	Energy	968.7	MJ	15
	Irrigation	Pipes	Galvanized aluminium	Impact extrusion Al	4.66	Kg	15
		Sprinklers	Steel	Impact extrusion steel	0.97	Kg	10
		Water	Groundwater		1900000	Kg	
		Pump	Steel	Impact extrusion steel	0.58	Kg	10
			Polyethylene	Injection moulding	0.025	Kg	10
		Pump	Energy	Electricity low voltage	3100	KW h^{-1}	
		Transport	Truck (245 Km)		1528.39	KgKm	
	Fertilizers	N		N emissions	172	Kg	
		P			192	Kg	
		K			227	Kg	
		Tractor 18HP	Diesel	Energy	662.7	MJ	15
		Transport	Truck (230 Km)		138000	KgKm	
	Agrochemicals	Herbicide	Most-micro (Pendimethalin)	Unspecified pesticides	2.28	Kg	
		Fungicide	Switch (cyprodinil. fludioxonil)	Unspecified pesticides	0.5	Kg	
			Score (Difenoconazolo)	Unspecified pesticides	0.43	Kg	
		Pesticides	Karate (Lambda-cialotrina)	Unspecified pesticides	1.057	Kg	
		Water	Tap water		2400	Kg	
	Harvest	Tractor 18HP	Diesel	Energy	283.8	MJ	
	Waste	Water	Tap water		24000	Kg	
		Packaging film	HDPE	Injection moulding	52.8	Kg	10
		Exhausted oil			10	Kg	
		Fertilizer's bags	LDPE	Extrusion	18.2	Kg	
		Agrochemical's containers	PVC	Extrusion	0.3	Kg	
Distribution	Packaging	Transport	Truck (230 Km)		0	KgKm	
		1	Diesel	Energy	94.6	MJ	
		Energy Consumption		Electricity low voltage	1742.4	Kw/h	
		Packaging film	PVC	Extrusion	8	Kg	
		Transport	Truck (18Km)		640	KgKm	
	Distribution	Transport	Truck (100 Km)		27500	KgKm	

- *CS-ComValenciana*

Various fennel cultivars were produced in Paiporta, where field has an extension of 7 ha. The crop cycle lasted 145 days. The planting density was 100,000 plants ha^{-1}, the raw yield 46 t ha^{-1} (Table 10).

- *Cultivation system and auxiliary equipment*

The primary data about land preparation come from the experimental field in Paiporta, where commonly used general agricultural machinery (60 HP, 44.74 KwH) for grooving (10 h ha^{-1}), milling (3.5 h ha^{-1}) is used and sowing is done predominantly by hand, so its impact is not calculated. The same occurs for the fertilizer spreaders and pest and diseases management. The irrigation occurs through a drip system. The data for the type and amount of materials are also obtained from Paiporta, while their life span comes from (Fuentes 2003). In CS-ComValenciana, harvesting was done by hand (and thus is not included in the impact assessment), using wooden boxes and plastic film to package the produce directly in the field.

- *Crop inputs*

The consumption of water is influenced by the period of the crop cycle. Here, we will use an average value of 25 m^3 ha^{-1} day^{-1}, while for phytosanitary treatments were used 1.6 m^3 ha^{-1} $cycle^{-1}$ of water. Fertilizers are supplied through the irrigation systems, in the following doses: ammonium nitrate NH_4NO_3 31 Kg ha^{-1}, potassium nitrate KNO_3 31 Kg $ha^{-}$and sulfuric acid H_3PO_4 8 L ha^{-1}. Against caterpillar, *Bacillus thuringiensis* (1 treatment for crop cycle, 0.5 Kg ha^{-1} $cycle^{-1}$) was used, whereas against powdery mildew two treatments of cupric sulfur (5 Kg ha^{-1} $cycle^{-1}$) were adopted.

Table 10 LCI of CS-ComValenciana.

		Element	Material/ Assembl.	Quantity	Unit	Life span (y)	Transport (Km & Type)
Cultivation system		Seeds					25, Lorry
	Milling	Tractor 60HP	Diesel	0,000191781	KwH	15	
	Grooving	Tractor 60HP	Diesel	6,71233E-05	KwH	15	
	Seedind	Tractor 60HP	Diesel	1,91781E-05	KwH	10	
		Drippers	PP (Polypropilene)	120	kg	10	40, Lorry
		Irrigation tubes	PE (Polyethylene)	2660	kg	10	40, Lorry
		Pump	Steel	3.5	kg	10	40, Lorry
			Polyvynilchloride	0.5	kg	10	40, Lorry
		Boxes (12kg)	wood	7700	kg		
		Food plastic film	PVC	9	kg	-	
Crop inputs		Water	Well water				
		Fertilizers	Ammonium nitrate				45. Lorry
			Potassium nitrate				5200
			Phosphoric acid				286. Van 3.5-5 t
	Spaying fertilizers	Fertiliser spreader	Diesel	10			
	Vs. caterpillar	Bacillus thuringiensis	Unspecified pesticide				
		Water	Tap water				
	Vs. powdery mildew	Cupric sulfur	Unspecified pesticide				
		Water	Tap water				
		Tractor 60HP	Diesel				
		Distribution	Refrigerated truck				550

4.3 Results

Global results

The results show the impact distribution of case studies (%): CS-Abruzzo, CS-EmiliaRomagna and CS-ComValenciana (Fig. 54). They will be analysed singularly below.

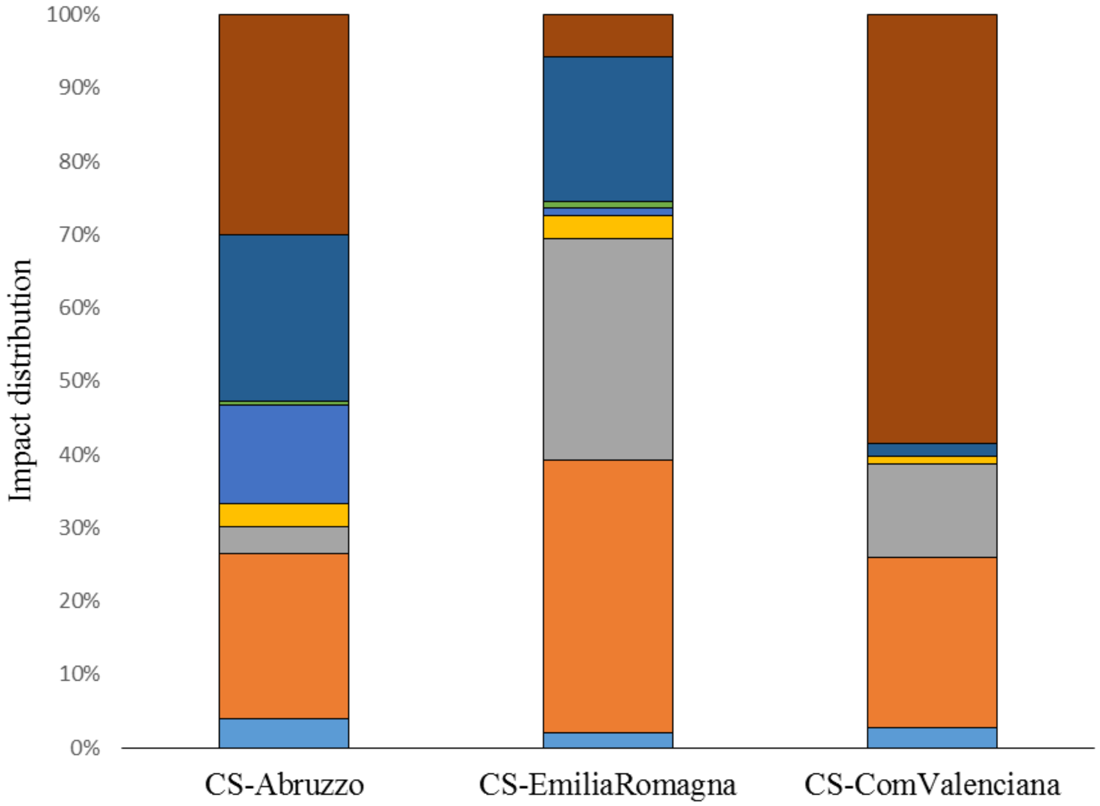

Figure 54 Impact distribution in case studies: agrochemicals or pesticides (■), fertilizers (□), irrigation (▨), land preparation (🟨), harvest (🟦), waste (🟩), packaging (🟦), distribution (🟫).

- *CS-Abruzzo*

In the case of spring fennel production in CS-Abruzzo, the total calculated impact is 204.24 Kg CO_2 eq. t^{-1}. The cultivation phase generates an impact of 96.58 Kg CO_2 eq. t^{-1}, while packaging and distribution phases generate an impact of 107.63 Kg CO_2 eq. t^{-1}. If we observe the singular inputs of each phase, the use of chemical fertilizers and the harvest are the most impacting factors, respectively 48% and 29%. The packaging accounted for 43% of the total environmental impact of the distribution phase. Cultivation phase is responsible for 47% of the total GWP.

- *CS-EmiliaRomagna*

In the case of the fennel production CS-EmiliaRomagna, the full impact obtained is 154.17 Kg CO_2 eq. t^{-1}. The production phase generates a total of 114.84 Kg CO_2 eq. t^{-1}, while packaging and distribution phases emitted ~ 40 Kg CO_2 eq. t^{-1}. If we observe the singular inputs of each phase, the use of chemical fertilizers and the irrigation system are the most impacting factors, respectively 50% and 41% of the first phase (cultivation phase), and 37% and 30% of the whole food production chain. In this case, in the distribution phase, the packaging accounted for 78% of GWP.

- *CS-ComValenciana*

Spanish fennel cultivation emits 47 Kg CO_2 eq. t^{-1}. The distribution phase is the most impactful (60%) of the whole food production chain. Of that percentage, only 2% is produced during the packaging phase, which includes the transport of raw fennel to the warehouse and the packing of the product. Analyzing the cultivation phase, the most impacting factor is the use of fertilizers and their emissions (59%), followed by the irrigation system (32%). For both cases, the impact is mainly due to the extraction and transportation of raw materials.

Scenario a)

In the *Scenario a),* where the distribution point was supposed to be in Bologna (at CAAB), the case study CS-EmiliaRomagna is less impactful than the CS-Abruzzo (Fig. 55). Main differences are in the use of irrigation and of fertilizers. Two different trends are highlighted:

- In CS-EmiliaRomagna the cultivation phase is more impacting than the distribution one (Fig. 56A). Since, the place to deliver is closer, the transport is less impacting.
- On contrary, in CS-Abruzzo, the distribution phase is the most impactful (Fig. 56B).

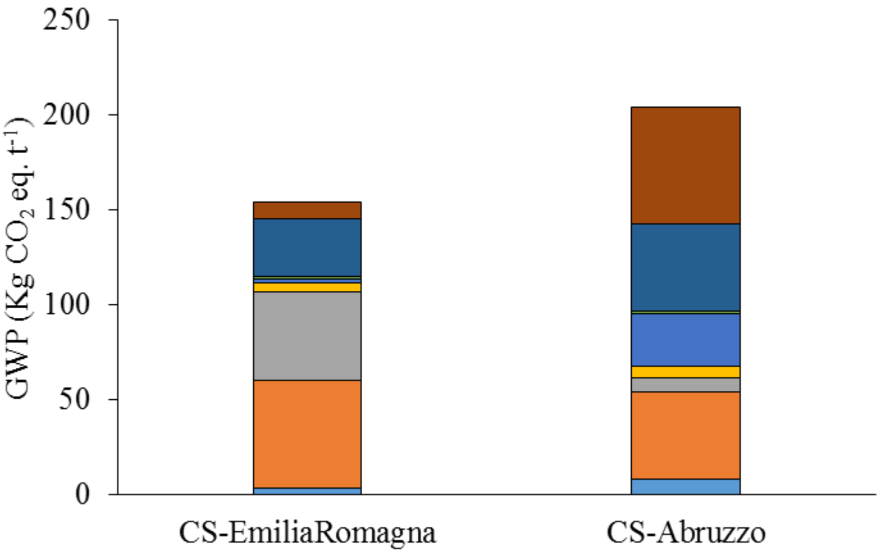

Figure 55 GWP of CS-EmiliaRomagna and CS-Abruzzo (Scenario a). Inputs are: agrochemicals or pesticides (■), fertilizers (□), irrigation (□), land preparation (🟨), harvest (🟦), waste (🟩), packaging (🟦), distribution (🟫)).

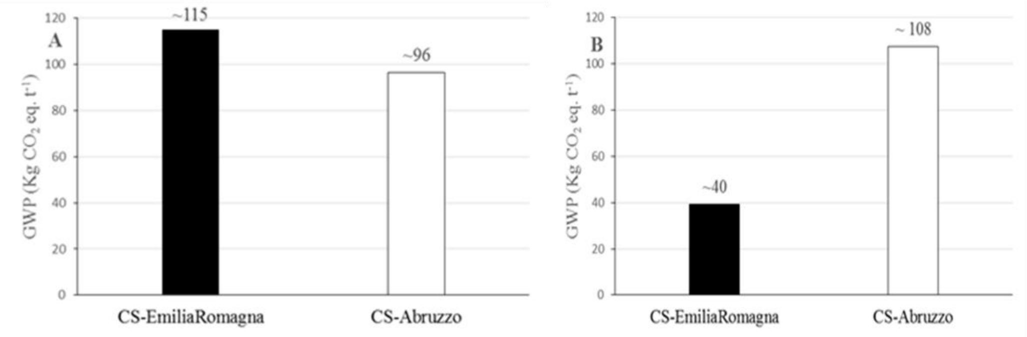

Figure 56 GWP of cultivation and distribution phases.

Scenario b)

In the *Scenario b),* where the distribution point was supposed to be in France (at Saint-Charles International Market), the case study CS-Abruzzo has a higher GWP than CS-ComValenciana, respectively 3,300 Kg CO_2 eq. t^{-1} and 47 Kg CO_2 eq. t^{-1} .The distribution phase in CS-Abruzzo is responsible for 97% of GWP, while 60% in CS-ComValenciana (Fig.57). If we compare only the cultivation phase, there are not a lot of differences. The most impacting factor is the use of fertilizers: respectively 59% total inputs of cultivation phase for Spain and 48% for Italy. About a third of the impact produced in this phase is to be attributed to the irrigation system in CS-ComValenciana, and to the harvest process in CS-Abruzzo.

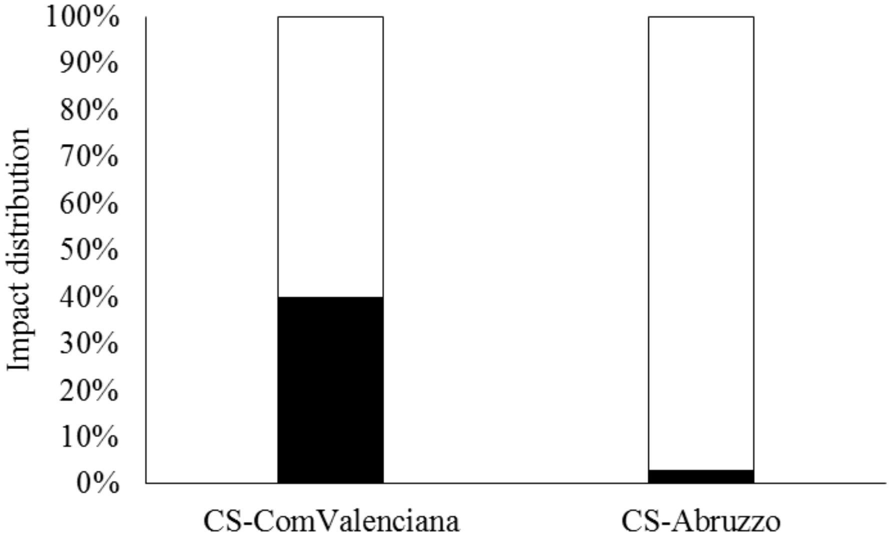

Figure 57 Impact distribution in CS-ComValenciana and CS-Abruzzo (Scenario b): cultivation (■) and distribution (☐) phases.

4.4 Discussions and Conclusion

Global results

Analysing the results, it is possible to affirm that the yield is similar in the three case studies (46 t ha^{-1}). In addition, the most impacting factors are the use of fertilizers, the auxiliary equipment (i.e. irrigation system) and the transport. The GWP of CS-ComValenciana is much lower than the other two. It is important to keep in mind that the subjectivity and the source of the data affect considerably the final result. In CS-ComValenciana it was not possible to obtain certain data (e.g. water and energy consumption to wash the fennel) or the data provided resulted to be very different compared to the other two case studies (i.e. quantity of fertilizers used).

- *Scenario a)*

Analysing CS-Abruzzo, the major impact is due to the transport of fennel, since it is refined, packaged and distributed 230 Km away from the field. If we focus only on the first phase (cultivation phase), we can note interesting data. Indeed, the major differences between CS-Emilia Romagna and CS-Abruzzo are in the use of irrigation and of fertilizers. This is due to the fact that in CS-Emilia Romagna the soil and climate conditions for off-season production are less favourable than in Abruzzo. Even if the cycle of cultivation is shorter in CS-EmiliaRomagna (62 days v. 83 days), more inputs are used. Otherwise, as reported before, the harvest method is more efficient because the fennel is processed in the field and distributed from a warehouse close to the production site.

- *Scenario b)*

A truthful comparison could not be done between CS-Abruzzo and CS-ComValenciana, since for the latter some data are missing. Otherwise, from an environmental point of view, it is more convenient for CS-Abruzzo to distribute the fennel in national markets. The product of CS-ComValenciana turned out to be more suitable to be exported in France as compared with that of CS-Abruzzo. However, other impact categories and socio-economic analysis are necessary to obtain a complete impact profile.

Summarizing, it is possible to conclude that fossil fuels are the greatest impact source. For these reasons, environmental loads could be reduced by creating manufacturing centers in Abruzzo and reinforcing local distribution chains (Edwards-Jones et al. 2008).

However, the off-season production of this crop is very dependent on soil and climatic conditions, making the distribution a necessary step.

Literature comparison

A CO_2 emissions accounting of food production is useful for acquainting policy makers with both the potentials and the challenges of greenhouse gases mitigation in agriculture. However, literature comparison presents some difficulties. Originally, the LCA methodology was used to trace the environmental profile of biofuel or oil-bearing crops (Nucci et al. 2014; Chiaramonti & Recchia 2010; Mattsson et al. 2000).

In these cases, the environmental profile of off- season productions is assessed, and the results may offer helpful insights into the discussion of dietary choices and may also provide some theoretical supports to decision makers to recognize and improve low-carbon food production, as discussed by Jianyi et al. (2015). Virtanen et al. (2011) shows that the climate change impact of production phase accounted for 62-75% in the whole life cycle of food from farm to tables. The carbon emissions of food production contain CO_2 produced by energy use, production of agricultural inputs or from feed production. The carbon footprint (CF) of vegetable food production ranged from 353.0 $MtCO_2$ eq.[15] to 648.8 $MtCO_2$ eq., accounting for 55-68% of the total CF (Jianyi et al. 2015). To reduce the environmental impact, a primary solution could be to consume local and seasonal food products with guaranteed source, and to reduce the number of intermediaries within the supply chain. A reduction of transport distances, food miles, and minimisation of disposable packaging are environmentally-friends choices as well. In the case of vegetables, these alternative practices are in particular contrast to the increasing and parallel trend towards large-scale retailing of ready-to-use products, which, in order to be sold, are industrially cut, washed and packed in sealed single-use packaging (Casati and Baldi, 2012; Rico et al., 2007 *in* Tasca et al. 2017*)*.

Limitations of the study

LCA is a good tool to assess the environmental impact and to make comparison between different cultivation methods and ways to deliver food. The limitation of the LCA methodology are generally associated with data source, the subjectivity of LCA-analyser

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[15] 1 Mt (megatons) = 10^6 t (tons)

and the common absence of a statistical analysis. However, improvement of statistical information accuracy is to an increasing extent being integrated into methods, databases and software, and is increasingly being applied in case studies (e.g. Monte Carlo analysis) (Heijungs & Huijbregts 2004). The distribution phase needs to be investigated more in depth. Not enough literature exists for a comparison, as this is a new topic related to agriculture. Different results in terms of avoided emissions are one of the challenges often met when elaborating correct input figures, as remarked by the European Commission as well.

Future research needed

Future researches need to focus on the environmental impact of large–scale agriculture production. In particular, it is important to study the difference between seasonal and off-seasonal food productions. In this study, the most impacting factors are fertilizers and transport of food during the distribution phase. To improve the self-production, it is important to underline the weight of packaging impact in food production chain, which could be easily reduced.

Chapter V

Discussion & Conclusion, Future perspectives

5. Discussion & Conclusion, Future perspectives

Discussion

This chapter outlines the key findings and contributions of this dissertation. Examining the results, it is possible to affirm that 'food miles' have an important role in environmental issues. It is not always possible to cultivate in the city, and some food cannot be produced in particular climate conditions (e.g. too high temperatures). Otherwise, these studies show some alternative ways to overcome the problem of the absence of soil. Hydroponic systems, or more correctly, soilless system cultivations (rooftops, terraces, pots, etc.) may be a solution. Local productions, in general, need less input to grow vegetables compared with the large-scale production. Besides, the kilometres that separate the consumer from the producer become minimal, in some cases less than 50 Km, in the case of urban and home gardens.

The reduction of food miles, as well as improving access to food and safeguard of the development of local economies has a significant influence on CO_2 emissions in the atmosphere. The latter, especially, are linked to the stage of packaging and distribution of products. If it is possible to grow local, these phases are almost irrelevant, even for large-scale cultivation, as we saw in the case fennel cultivation (CS-EmiliaRomagna). Subsequently, short answers were given to research questions:

- *RQ1: Could allotments or home gardens mitigate the urban climate conditions? Have they any effect on human well-being?*

Home gardens have some positive effect on the urban microclimate. The most important result is that the presence of a 'green' area (i.e. allotment or garden) could reduce the air temperature (during the day-time) by around 0.5 °C and give some benefit to the human well-being. However, during night-time the mitigation is not so marked.

- *RQ2: Which is the environmental profile of urban gardens? Are cultivation systems influencing factors?*

The environmental profile of urban garden, in terms of GWP, is less than 0.3 Kg CO_2 eq. Kg^{-1} emitted. It is not so high, and the value could be improved by recycling materials and using fewer fertilizers, adopting for example biological solutions. Indeed, cultivation management and cultivation system could affect the final GWP.

- *RQ3: Which are the environmental profiles of a large-scale and an off-seasonal production?*

Large-scale and off-seasonal productions are, obviously, more impacting than urban production, since they use more inputs for production. In order to define some import/export trades, similar studies could help to make the more sustainable decision. The transport is the most affecting factor, so for some production chain is better to choose a national trade rather than an international exportation.

Methodology

For what concerns the methodology that we used in this dissertation, it is possible to affirm that the LCA could be a useful tool to investigate environmental impacts. It must be improved and made more understandable to users. Nevertheless, it is a good tool for decision making; that is evident when we compared the two case studies of fennel production. Indeed, the high impact of CS-Abruzzo production is due to its processing and distribution phases. If it could improve at least the packaging phase, for example by processing the fennel directly in the field, the reduction could be substantial. The same goes for CS-ComValenciana. On the other hand, when comparing only the cultivation phase it is evident that the production to obtain fennel off-season requires more inputs in an area that is not optimal. To confirm that, in the future, some comparison with seasonal production could be carried out. In the supposed comparison of the total emissions of fennel produced in a home garden (using FU of 1 Kg) with one cultivated in large-scale, the impact of the first is in average 2,300 Kg CO_2 eq. This difference could be attributed to the distribution phase.

Regarding the use of ENVI-met to assess some microclimate change, the results on the presence or absence of garden in an urban context are surprising. Usually, this type of studies include trees, and it is interesting to see some climate improvement due to urban gardens. The instrument used is not calibrated for vegetable species, so a possible improvement of the model is to include these type of species. In that way, results could be more accurate.

Limitation of study

The LCA methodology, despite its many applications and its ability to identify the environmental impact on the vegetable crop production, has limitations that mainly concern the data source and accuracy. Uncertainty relates to a lack of knowledge: no data is available, or the available data is wrong or ambiguous. Variability, in contrast, is a quality of data that is essentially of a heterogeneous nature (Heijungs & Huijbregts 2004). The complexity of the study requires considerable resources, in terms of costs and time. They face difficulties especially when analyzing new products, because the necessary data must be necessarily hypothesized but most of these obstacles can be overcome for example by carrying out logical assumptions and using data from a database deemed reliable. The nature of the choices and the assumptions (i.e. to establish the boundaries of a system or choose the categories of impact) is very important, but too subjective. The models used for the analysis of inventory or the assessment of the impacts are not suitable for that single application and are not able to adequately describe any environmental impact. The availability and quality of data may limit the reliability of the results. Therefore, there is a need to work with a consistent and documented set of data. The LCA is also more applicable to indicate general impacts on a global scale (i.e. climate change), rather than on local effects such as smog, where the temporal and spatial factors of emissions have more relevance. Finally, unlike other assessment methods, the LCA does not include economic and social impacts of a product system. These, for example, are the subject of study of environmental impact assessments.

ENVI-met is a good tool to predict the thermal profile and microclimatic variability of some experiments (Salata et al. 2016). Otherwise, some limitations are present because the software could not be "forced" to insert some data.

Conclusion

The study has achieved its goal, as the environmental impacts of different food supply chains have been quantified. From a comparison between small or large-scale production, it is possible to understand that a self-production, where possible, could contribute to the reduction of food miles, cultivation inputs, and thus of environmental impact (GWP, Kg CO_2 eq. emitted in the air).

Mainly, the reduction of food supply chain CO_2 emissions concern:

Reduction of transport: urban food production activities reduce the transport phase of goods, resulting in a net decrease of vehicles' emissions. The distance between producer and consumer is reduced or eliminated.

Re-use of packaging: reuse or elimination of packaging (i.e. in the case of home garden production), make food production more sustainable.

Reduction of waste: when reducing food miles, the freshness of the product is improved, and food waste is reduced. Most of the products are lost during the transport phase (from a qualitative and quantitative point of view).

Agricultural activities could generate other benefits linked to food security, to human well-being (i.e. improving thermal comfort); to biodiversity and to the city itself (i.e. building integrated agriculture). They could guide urban areas to become strategic cities environmentally sustainable and environmentally friendly. Sustainable consumption and production aim is to promote the use of goods and services with reduced environmental impacts across their life cycles.

Dissertation contribution and future research needed

To reach the sustainable development goals, it is necessary to search a new way to safeguard natural resources such biodiversity, soil, water and, generate ecosystem services. Urban agriculture could be a good way to improve this, but new indicators need to be developed. In this dissertation, the LCA and the PMV are shown, which could assess the environmental and social sustainability. However, further research needs to investigate more the economic and social dimensions. The first step is for policy-makers to embrace a unified environmental and social framework for the sustainable development goals (e.g. climate change) (Griggs et al. 2013).

Chapter VII

Literature

6. Literature

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