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The sustainability of agriculture: a quantitative assessment of the main productions in the north of Lazio

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Contents

SHORT ABSTRACT

This PhD thesis deal with the topic of environmental sustainability of the production processes of some of the main crops in the province of Viterbo.

The study starts from the consideration that to address an analysis on the sustainability of production processes it is necessary to explicit the definition of sustainability to be adopted. In fact, from an economic perspective, it is not possible to ignore the substantial difference between the concepts of weak sustainability and strong sustainability. This difference is not only a mere ideological concept because the choice of one of the two definition has direct implications on the assessment methodology, on the indicators choice and on the interpretation of the results of empirical analyses.

In this thesis, for each one of the four analyzed cultivations (vine, olive, hazelnut, potatoes), the sustainability of production processes was calculated following the two different perspectives. To evaluate the condition of strong sustainability the indicator Ecological Balance (EB), obtained through the difference between the Biocapacity (BC) and the Ecological Footprint (EF), was chosen; while the weak sustainability assessment is based on the comparison between the value of natural capital loss and the increase of economic capital.

Results show that some production processes are sustainable in a strong sense (reporting a positive value of EB), while others are not. In these last cases the economic value of ecological deficit (measured by the negative value of EB) was compared with the process gross margin, thus verifying the existence of a weak sustainability condition. In particular, the olive and vine cultivations (at least referring to the representative techniques adopted in Viterbo province) are strongly sustainable, the potatoes cultivation is not weakly sustainable, the hazelnut cultivation is strongly sustainable when an extensive technique is adopted and weakly sustainable in the other cases.

These results allow to conclude that for an agricultural production process the existence of an environmental sustainability condition is primarily determined by the adopted definition of sustainability.

INTRODUCTION

The relationship between agricultural activity, ecosystem and economy is a central theme in the debate on environmental sustainability, since the first global emergencies of the 1960s. This debate involves both politicians and scientists, also raising considerable public interest.

It is a shared opinion that the human activities, and the consequent exploitation of natural resources, carried out without taking into account how the ecosystems are affected by such activities, have contributed to a strong environment impact, participating in the strengthening of the climate change and increasing its effects and consequences.

For this reason, both locally and globally, over the years the issue of sustainability has become increasingly important and the need to frame and quantify the topic has also grown.

This long-lasting and complex debate has originated in different interpretation on the concept of sustainability. Looking from an economic perspective, two main definitions have been established: strong sustainability and weak sustainability.

The weak sustainability approach, inscribed into the neoclassical paradigm, presupposes that natural capital and "*man-made*" capital are replaceable and that there are no substantial differences between the kinds of well-being generate (Neumayer, 2013). The only condition for sustainability is that the total value of the aggregate capital stock should be maintained or increased for the sake of the future generations (Solow, 2006). According to this vision "*…it does not matter whether the current generation uses up non-renewable resources or dumps CO_2 in the atmosphere as long as enough machineries, roads and ports are built in compensation..".*(Neumayer, 2003).

The definition of strong sustainability, on the other hand, starts form the idea, embedded in the ecological economics paradigm, that natural capital cannot be seen as a mere stock of resources. It is a complex system consisting of continuously evolving biotic and abiotic elements that interact by determine the capacity of ecosystems to provide human society, directly or indirectly, with a wide range of functions and services (Noël and O'connor, 1998; De Groot *et al.*, 2003; Ekins *et al.*, 2003). For this reasons a condition of (strong) sustainability imposes that the quantity and quality of natural capital should be maintained or improved, independently form the variation of economic capital.

In the agricultural sector, with its structural borderline position between environmental and economic dimensions, different approaches to assess the environmental impact of the production activities have been proposed (Gerdessen and Pascucci, 2013).

Some methods recommended for calculating the environmental impact, and therefore the sustainability, of the agricultural processes are based on purely naturalistic/biological approaches, other are borrowed from the industrial sector (such as Life Cycle Assessment - LCA). In the first case the economic component finds a marginal space, while in the second the close relationship between the activities performed and the ecosystems affected by them is forgotten. At the contrary, unlike all the other economic activities, agriculture intervenes directly in the biological cycles of plant and animals and alters them for its productive purposes.

An interesting possibility for measuring the environmental impact of agriculture is offered by the Ecological Footprint (Wackernagel and Rees, 1996a) and, in particular, by recent upgrading of the standard methodology specifically tuned on the peculiar characteristics of farming systems.

Starting from these evidences, the first aim of this thesis is to *apply the Ecological Footprint (EF) methodology to evaluate the environmental impact of a crop production system at farm level* (strong sustainability) *and discuss the relationship with its economic performance* (weak sustainability). To this purposes, a method will be proposed, and implemented in a calculation model, to verify the occurrence of the condition of strong and weak sustainability in some agricultural production processes.

Being a main prerogative for the Ecological Footprint to identify a well-defined geographical area of analysis, the province of Viterbo was chosen as territory where to investigate the sustainability of the main cultivations. Moving from these consideration, the second research question is *to assess the (strong and weak) sustainability of the main cultivations in the province of Viterbo.* To do this, the first step it was to identify the more representative crops in the province; these were identified in vineyard, olive, hazelnut and potato. For each crop it was identified the area of the province where it plays a relevant role and the representative cultivation techniques, then the model base on ecological footprint was applied to evaluate the condition of sustainability. As far as the cultivation of the vineyards, an analysis was carried out beyond the cultivation stage, to evaluate the sustainability of the final product, represented by a wine bottle, including the distribution phase.

To answer to the two mentioned research questions, this thesis is organized in four parts. In the first part, developed in the two initial chapters, the general issues related to the concept of sustainability are discussed. The first chapter explains how this concept has developed over the time, considering, in particular, its economic meaning and the relative implications. The second chapter focuses on the definition of sustainability, looking at its relationship with the different economic paradigms that are at the origin of the theoretical difference between the concepts of strong and weak sustainability.

The second part, developed in the third chapter, concerns a general overview of the agricultural sector of the province of Viterbo. The data obtained are utilized to select the main cultivations of the province to be analyzed and then to bound the areas where such cultivations assume a relevant role in productive, economic and social terms.

The third part describes the methodological approach proposed to assess the sustainability of the selected cultivations. The four chapter, where these issue is faced, is divided in three sections. The first one concerns the identification of the representative production techniques for each crop. In the second section the methodology of the ecological footprint, together with its calculation improvement for agricultural activities, is described; always in this section the calculation of the ecological balance as indicator to evaluate the strong sustainability condition, is presented. The third section explains the approach to assess the weak sustainability of the production processes and, in particular, how it can be evaluated the monetary value of the natural capital loss and the increase of economic capital. The findings of this part of the thesis represent the possible answer to the first research question.

The fourth part of the thesis is devoted to present and discuss the main results of the empirical analysis. The chapter 5, where this part is developed, is structured in some section, one for each cultivation analyzed, vineyard, hazelnut, olive and potatoes respectively. For each one of them, according to the methodology, it is evaluated the representative technique, the ecological balance, the economic budget and, on the base of these two last values, the condition of strong and weak sustainability. This chapter ends with a discussion based on a comparative framework among the evidences provided by the results obtained for the four cultivation analyzed, evidences that can represent the answer to the second research question.

The thesis ends with some final considerations about the established research path, its limitations and future developments and its possible implications to drive the agricultural sector to a better trade-off between economic performances and environmental impacts.

CHAPTER 1

THE SUSTAINABILITY CONCEPT IN AN ECONOMIC PERSPECTIVE

With the increase in public awareness and the major concerns for environmental and social issues (Robinson, 2004; Du Pisani, 2006), the concept of sustainability has become a crucial aspect, enjoying great attention in many areas of contemporary society and subject to heterogeneous and variable interpretations.

Over time, different disciplines and perspectives were born (ecology, sociology, etc.) that focus only on certain aspects of the concept (Mebratu, 1998) and in many cases they lose the holistic approach.

Adding to increase this ideological entropy, the terms "*sustainable development*", "*sustainability*" and "*sustainable*" are sometimes overly exploited and often misused by the various stakeholders (Lozano, 2008; Quental, Lourenço and Da Silva, 2011; Christen and Schmidt, 2012).

However, adopting a "scientific" approach and taking an economic perspective, the definition of sustainability tends to reduce its intrinsic vagueness and become a dimension that can characterize a specific object through the "sustainable" attribute.

In this chapter a review of the definitions of the concept of sustainability is proposed, going to identify the historical periods fundamental for the characterization of the concept and highlighting the merits and limits.

The proposed approaches to the definition of sustainability dimensions will be examined, introducing the bioeconomic approach, which is the basis of the construction of the PhD thesis. Finally, the concept of strong and weak sustainability is explored, proposing the Ecological Footprint as an indicator of measurement of strong sustainability.

1.1 The history of the concept of sustainability

The adjective sustainable derives from the Latin "*sustinere*", formed by "*sus-*", variant of "*sub*", and "*tinere*" which means to defend, maintain, assume, endure, etc (Castiglioni and Mariotti, 2012). Later the term would have emigrated into the English language as "sustainable", becoming a noun "sustainability" (Amari, 2012).

Semantically, sustainability refers to the relationship and balance, between a (sustainable) artifact and the environment that hosts and supports it, which interact without mutual damaging effects (Faber, Jorna and Van Engelen, 2005).

The concept of sustainability has a long history and is quite vague and is not characterized by a univocal definition. Already in the 18th century, the principle of sustainability was accepted in forestry (Wiersum, 1995), when Carlowitz, in his work *Sylvicultura oeconomica* (Carlowitz, 1732), coined the German concept of *"Nachhaltigkeit"* (sustainability). Carlowitz asserted that in a condition of expected wood shortage, a balance had to be struck between deforestation and restoration of forests, in such a way that the use of timber could be continuous over time, without affecting the ecosystem and generating positive economic and social impacts (Bolis, Morioka and Sznelwar, 2014).

Since the end of the Second World War, the most important economic growth in the history of capitalism took place and it was claimed that the infinite resources of the planet could allow economic growth without ends (Weinstein, Eugene Turner and Ibáñez, 2013). This vision of post-war optimistic enthusiasm was expressed for the first time during the Bretton Woods Conference (1944), from the Secretary of the Treasury of the United States of America, Henry Morgenthau, who foresaw: "[..] *a dynamic world economy in which the peoples of every nation will be able to realize their potentialities in peace…and enjoy, increasingly the fruits of material progress on an earth infinitely blessed with natural riches* [..]" (Daly & Farley, 2004). Economic policy thus became the key to resolving problems worldwide and 5 years later in the inauguration address of the second term of the US President Henry Truman, of 20 January 1949, the concept was emphasized: " [..] *Greater production is the key to prosperity and peace… More than half the people of the world are living in conditions approaching misery. Their food is inadequate. They are victims of disease. Their economic life is primitive and stagnant.*

Their poverty is a handicap and a threat both to them and to more prosperous areas…For the first time in history, humanity possesses the knowledge and the skill to relieve the suffering of these people…I believe that we should make available to peace-loving peoples the benefits of our store of technical knowledge in order to help them realize their aspirations for a better life [..]". Economic policies saw the occurrence of an unprecedented income growth phase in history by duration and intensity (Pollard, 1990).

In the 1960s, concerns about the unsustainability of economic models that led to over-utilization of natural resources began to arise. In 1962, in the book "*Silent Spring*" by Rachel Carson, for the first time are criticized the technologies applied in the various sectors that had the aim to improve the productivity and the efficiency of the processes. It is claimed that the negative consequences generated on the environment involve the alteration of ecosystems. This innovative position, outside to the classic analysis schemes of this period, is the catalyst of birth of the first environmental movements of the 1960s.

In conjunction with the increased sensitivity worldwide for environmental issues, and with the movements that believed in more respectful development models, the creation of the Club of Rome in 1968 and the publication of the report The Limits of Growth in 1972, was a decisive warning about the possible unintended consequences of economic growth.

In April 1968, an international group of 105 scientists, politicians, representatives of industry and civil society gathered in Rome to discuss the changes that were affecting the planet due to human actions. Its aims were to foster the understanding of the various but interdependent components - economic, political, natural and social - which constitute the global system; to bring this new understanding to the attention of policy makers and the public worldwide; and in this way promote new initiatives and political actions (Meadows *et al.*, 1972). For the first time we thought about the long-term consequences and it was commissioned at the Massachusetts Institute of Technology what, four years later, would be the report *The limits of growth*, or even called Meadows Report, by its lead author Donella Meadows. The report stated that if the current rate of population growth, industrialization, pollution, food production and exploitation of resources were unchanged, the limits of development on the planet would have been reached at an unspecified moment, in a period of one hundred years.

The publication of this report coincided in 1972, with the celebration in Stockholm, of the *UN Conference on Human Environment*, having as an imperative goal "[..] *To defend and improve the human environment for present and future generations* [..]" (United Nations, 1972). It was the first world summit to consider the human impacts on the environment and the first important attempt to reconcile economic development with environmental integrity, previously considered incompatible (Caldwell, 1984).

The debate that followed was incorporated into the work of the World Commission on Environment and Development (WCED) in 1983, which it aimed to develop a global agenda for change. The commission chaired by the Norwegian Gro Harlem Bruntland, four years later (1987), presented the Our Common Future Report, better known as the Bruntland Report. With this report the theory of sustainable development is introduced. In fact, the report emphasizes how "[..] *Environment and development are not separate challenges; they are inexorably linked. Development cannot subsist upon a deteriorating environmental resource base; the environment cannot be protected when growth leaves out of account the costs of environmental destruction…Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs* [..]" (World Commission on Environment and Development, 1987).

The Bruntland commission is widely recognized as the one who has popularized the concept of sustainable development by including it in international political debate (Clinton, 1977; Mebratu, 1998; Purvis, Mao and Robinson, 2018). This new approach means that the concept of sustainable development has as its foundation two fundamental aspects, the conservation of natural resources and human development, understood as the aspiration to a better life and aided by constant economic growth.

Although after the release of the Report some as Brown and his colleagues (Brown *et al.*, 1987) and Daly (Daly, 1990) linked the concept of sustainable development to a limitation of economic growth, the institutionalization of the Report continued in 1992 with the Earth Summit in Rio de Janeiro.

In June 1992, the Conference on Environment and Development, better known as the Second Earth Summit, was held in Rio de Janeiro and was attended by 178 governments and about 2,400 non-governmental organizations and institutions. It sought to establish a new development model based on the Brundtland Report's approaches, but seeking to establish binding agreements and create control organs and mechanisms. The result of this conference was *Agenda 21*, which establishes a set of rules for social, economic and environmentally sustainable development; and the *Rio Declaration*.

The "Rio Declaration" included 27 principles[1], many of which deepened the concept of "sustainable development" and with the "Agenda 21" has identified the plan by which to implement these principles (Jordan and Voisey, 1998). The Conference was generally considered a success (Quental, Lourenço and Da Silva, 2011) and from this moment on the concept of sustainable development has spread and rooted in sectors where until then it was an outsider. Sustainable development has therefore become a unifying word for governments and for all the different stakeholders involved (UN, 2010).

After the 1992 Rio Summit, the UN formed the Commission on Sustainable Development (CSD) to guide and monitor the progress achieved with the implementation of Agenda 21 and the Rio Declaration.

In the following years, in several workshops the reasoning on how to measure these three main aspects of sustainability continued, first treating them as isolated aspects and then explaining the need to integrate them and emphasizing a holistic and balanced approach (UN, 2002).

Ten years after the Rio Summit, in the 2002, a new international meeting took place in Johannesburg under the name of the World Summit on Sustainable Development (WSSD). It was organized by the United Nations, to discuss the status of decision making as a Rio. Also for this the Johannesburg Conference is also referred to as "Rio + 10". At this summit new commitments were reached, as the 180 participating governments ratified the Rio agreements and signed the Johannesburg Declaration, which set more precise objectives and incorporated new topics such as globalization and corporate responsibility.

[1] **Principle 1** - Human beings are at the centre of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature.
Principle 4 - In order to achieve sustainable development, environmental protection shall constitute an integral part of the development process and cannot be considered in isolation from it (United Nations, 1992)

Ten years after Johannesburg and twenty years after the 1992 Summit, the United Nations Conference on Sustainable Development (RIO +20) was held in Rio de Janeiro in June 2012. The agenda focused mainly on two topics: how to build an ecological economy to achieve sustainable development and lift people out of poverty and how to improve international coordination for sustainable development.

At this summit (UN, 2012), the need for a holistic approach was revealed, which was also reiterated in 2015 at the Summit in Paris (UN, 2015), where sustainable development cannot be considered if the economic, social and environmental dimensions are considered individually.

1.2 The models of sustainability

In many fields of action and also in everyday life, models are used as simplifications of complex reality, to make decisions and to act on this. It is obvious that even in the area of sustainability and development, there has always been a need to develop appropriate models that would replace the obsolete unsustainable models that saw economic growth as the only measure of development (Lozano, 2008; Waas *et al.*, 2011).

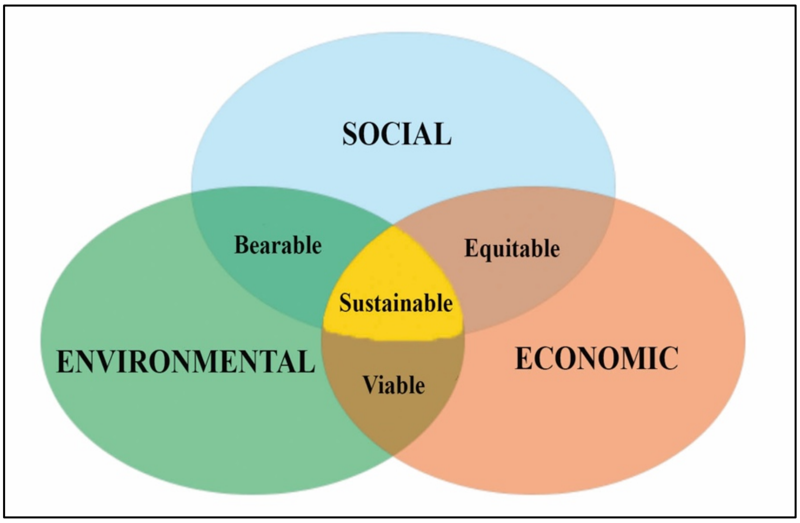
In the literature there are various model proposals (Giddings, Hopwood and O'Brien, 2002; Lozano, 2008) and two of the most used models are the *Triple Bottom Line* (or TBL) and the bioeconomic representation of the TBL model.

The three-dimensional TBL sustainability model (social, environment and economic) is usually represented by three intersecting circles of equal size (Figure 1).

The TBL approach was coined in the '90s by business consultant John Elkington in his book "*Cannibals with Forks: the Triple Bottom Line of 21st Century Business*", to describe the economic, environmental and social value of investments that could mature outside the company's economic result (Elkington, 2013).

In 2002, in Johannesburg, during the world summit for sustainable development, the key approach to the interpretation of global sustainability was identified in the TBL, through the slogan "*Planet, People, Prosperity*" (European Union (EU), 2002). Therefore, a political value was assigned to the TBL and was started the debate in the scientific world on the meaning of the three dimensions and their interaction.

Figure 1 The classic representation of the TBL model

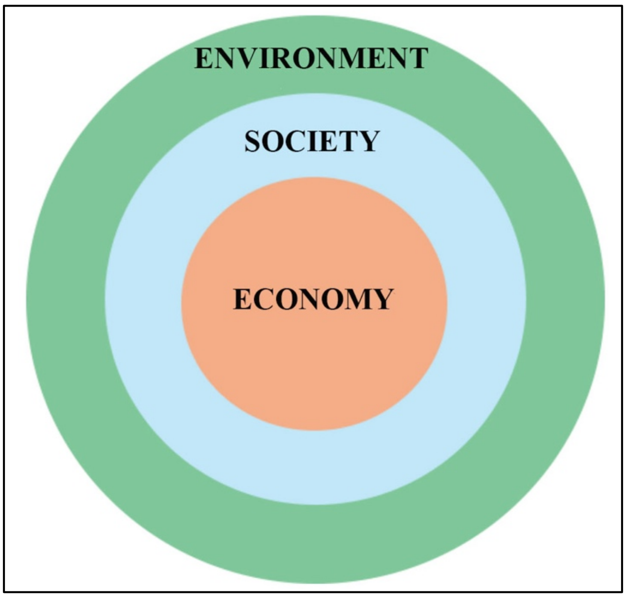


The criticism of this approach has been different and Lehtonen (2004) summarizes it in four types. The first of a political nature is moved towards the assumption of this model by governments, which could accept unsustainable behavior of companies and lobbies and making them accepted by public opinion. The second criticism is moved to the centrality of the economic dimension that remains divided by the social dimension. According to Lehtonen, this model reinforces the idea that the economy plays a central role and completely detached from the social one, to which all anthropic activities should be reported. The third criticism regards the relationship between the dimensions of sustainability. Each dimension has logics and characteristics that can contrast those of the other two dimensions. For example, a type of contrast that may arise, as claimed by Harribey (1998), concern the conservation of natural resources that can be considered in contrast to the growth of the well-being of the populations. Fourth and last critical aspect always concerns the relationship between the dimensions of sustainability, since the classical representation of the TBL model confers the same importance to the three dimensions, inasmuch are represented with three spheres of equal size intersecting each other.

This model refers to a *Weak Sustainability*, which has as its fundamental assumption the possibility of making natural capital interchangeable (which therefore must have a monetary valuation) and artificial capital whose sum must remain constant over time (Ekins *et al.*, 2003; Neumayer, 2012, 2013). Is therefore implied that with the progress of the human civilization and the consequent use of natural resources, it is conceivable a loss of percentage weight of natural capital over time in favor of the artificial one.

The second TBL approach is bioeconomic (Passet, 1996; Maréchal, 2000), represented by three concentric circles (Figure 2), where the environmental sphere circumscribes the social dimension, which in turn circumscribes the economic sphere.

Figure 2 The bioeconomic representation of TBL model



This model reveals a structure in which economic activities should be at the service of society and not guide it, with the main aim of respecting the limits of the physical and ecological system in which the community lives (Passet, 1996; Maréchal, 2000).

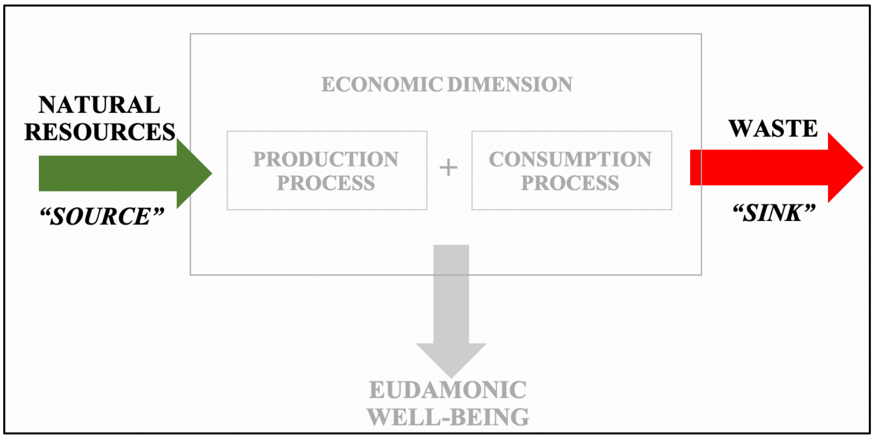
The Bioeconomic TBL approach just described refers to a *Strong Sustainability* (Ekins *et al.*, 2003; Neumayer, 2013), because it does not consider replacing natural capital (which may not have a monetary valuation) with stocks of artificial capital, and lays the assumption that natural capital must be constant over time without the possibility of compensation.

1.3 The Environmental, Economic and Social Dimension

1.3.1 The Environmental dimension

The main theorist of environmental sustainability was Robert Goodland that in 1995 in the article "*The concept of environmental sustainability*" has outlined the main aspects of this dimension. Goodland identifies two categories of environmental services with which the environment is able to support human activities. The "*Source*" function of renewable and non-renewable raw materials and the "*Sink*" function regarding the adsorption, by the ecosystem, of waste produced by human activities (figure 3).

Figure 3 Scheme of the environmental dimension



With regard to the "*Source*" function of the system, the use of renewable raw materials should not exceed their ability to regenerate, while the use of non-renewable raw materials should take place at such a rate as to allow the emergence of technologies capable of replacing them (Goodland, 1995). It is therefore important that the consumption of resources, made available by the ecosystem, takes into account the biophysical limits of the same, preserving its integrity and its resilience. Resilience means the ability of the system to respond to the perturbations that act on it, to adapt to change, and to return to the state before the perturbation.

The maintenance of the "*Sink"* function, instead, is linked to the absorption and assimilation capacity of the ecosystem, of waste and pollutants generated by the process in progress. This absorption capacity should not be exceeded, to allow the ecosystem to work in the future.

1.3.2 The Economic dimension

The definition of economic dimension is quite complex because over time there has been a debate, still open, between the different schools that see the economic system in totally opposite way and therefore come to completely different definitions of sustainability.

The clear contrast between the currents occurred in the 80s. There was a marked difference between who saw continued growth as a fundamental element of economic sustainability and those who considered the achievement of steady state essential (Brown *et al.*, 1987).

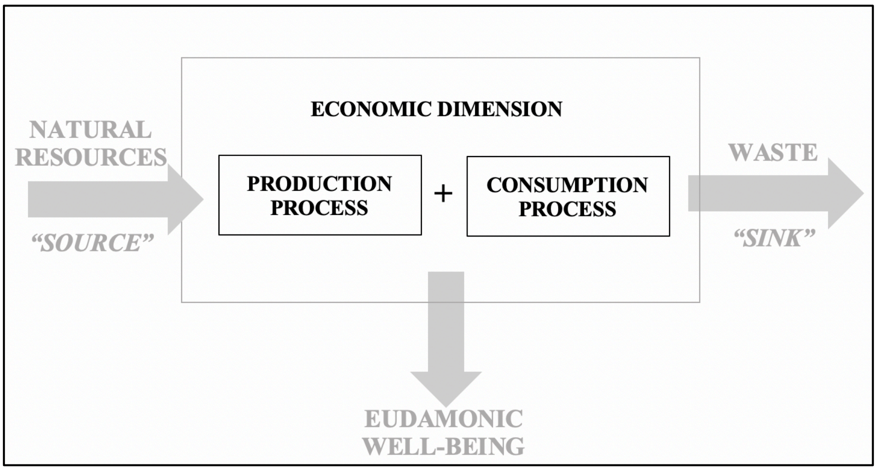
The first, relating of the neoclassical approach of the economy, believe that economic growth is the inevitable result of population growth, acquisitive nature of people, and technological innovation (Brown *et al.*, 1987). Furthermore, believe that market forces and scientific-technological progress can remove any limitation on long-term development, leading the economic system towards infinite and unlimited growth.

A vision opposed to that of neoclassical economists, is that of Georgescu-Roegen (1971), that starting from the physical principles and the concept of Entropy, sees in the second law of thermodynamics the main theoretical obstacle to a continuous economic growth (Brown *et al.*, 1987).

According to this theory, the economic process is divided into two distinct stages, the production and the consumption processes (figure 4), which through their joint action are responsible for the transformation of natural resources into waste and the generation of durable well-being of the population (Bonaiuti, 2008).

The production processes operate a transformation that attributes to the matter/energy output (products) a higher value of the incoming material/energy (natural resources). The outgoing flows from the production process are made up of products, which become the input flows of consumption processes, to which are added the waste generated by the production processes themselves (Avolio *et al.*, 2016). The consumption process transform matter and energy with highly utility, incorporated in the goods leaving the sphere of production, in matter and energy with low utility (waste) in order to satisfy the needs of the community (Franco and Blasi, 2013).

Figure 4 Scheme of the economic dimension



1.3.3 The Social dimension

The social sphere is characterized by three aspects that make difficult its definition:

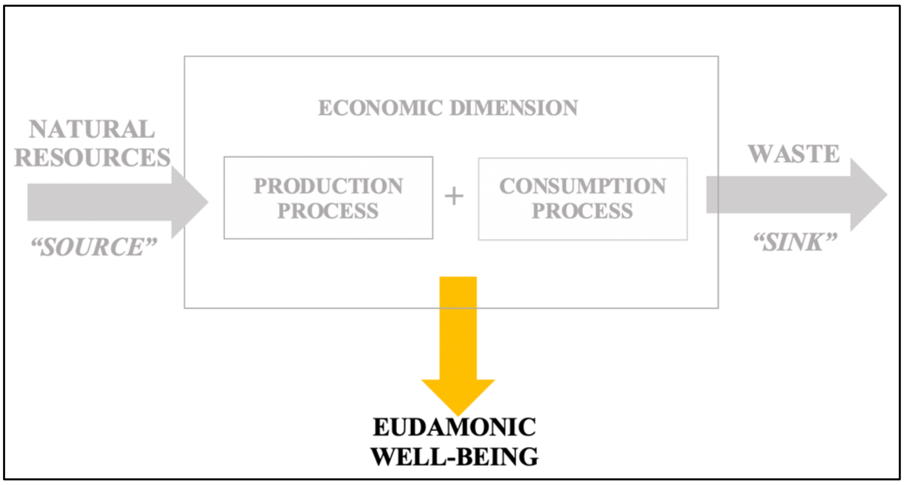
- Bipolarity: the social sphere concerns at the same time the individual and the community. So an individual who wants define it incurs the paradox of having define himself.
- Reflectivity: the perception of the social condition of the individual influences the behavior of the community which, in turns, modifies the individual perception in a vicious circle that is difficult to solve.
- Immaterial: social phenomena are immaterial and difficult to define and therefore measure.

Despite this difficulty and the obvious differences of view, in recent years studies on the quality of life and perception of well-being have increased, giving rise to two different theoretical approaches.

The first attributable to the hedonic perspective, analyzes the dimension of pleasure understood as personal well-being (Kahneman, Diener and Schwarz, 1999), with a main reference to the emotional dimension and to the satisfaction of life.

The second approach defined *eudaimonic* (Ryan and Deci, 2000) includes beyond individual satisfaction, also a path of development towards the integration of the community, freeing itself from the purely individualistic approach (Blasi, 2011).

Figure 5 Scheme of the social dimension



The approach followed in the bioeconomy is the eudaimonic one, because it places as fundamental the relationship of the individuals and the development of the community. It frees itself from the purely individualistic approach that very often has characterized the contributions coming from the economic sciences.

1.3.4 How to measure the three dimensions

Since the publication of the Brundtland report (World Commission on Environment and Development, 1987), the concepts of sustainable development and sustainability have become one of the main objectives of the policy makers and scientific researchers (Krajnc and Glavič, 2005).

Sustainability is now the most popular word in political agendas and not only. As a result there is a strong desire, on the part of politics and world science, to evaluate changes in the economic, environmental and social spheres at different territorial levels. This need of evaluation is due to the fact that a problem that can not be measured will be difficult improve an unmeasurable problem (Böhringer and Jochem, 2007).

Sustainability is a multidimensional concept, where economic, environmental and social aspects must be considered simultaneously. However, implementing sustainable production schemes is a complex process linked to the interdependencies determined by all the components of the system. It is therefore important define on which type of sustainability, weak or strong, one wants target the analysis (Boggia and Cortina, 2008).Briefly in the economic approach to the concept of sustainability, the key point is whether natural capital, that is to say the range of functions provided by the natural environment (Ekins *et al.*, 2003), must be maintained or replaced by the capital produced. This is basically the difference between the concepts of strong and weak sustainability (Dietz and Neumayer, 2007).

Defined the type of sustainability to be measured, the indicators translate the issues of the individual sustainability dimensions into quantifiable measures, with the aim of addressing the main sustainability issues (Azapagic, 2003). Specifically, an indicator can provide a clue to a question of greater significance or make perceptible a tendency or a phenomenon not immediately detectable (Hammond *et al.*, 1995). The tool for a multidimensional representation is characterized by an appropriate set of indicators, integrated in an evaluation methodology, useful for measuring the sustainability of a system (Moffatt, Hanley and Wilson, 2001; Lawn, 2006).

In the specific case of this PhD project, in the following paragraphs will be clarified the theoretical aspects and the indicators, and a specific indicator will be chosen and described the characteristics and the possibilities of application in the empirical cases.

CHAPTER 2
SUSTAINABILITY: DEFINITIONS AND ASSESSMENT

2.1 The definitions of sustainability

Throughout history, economists have studied the relationship between nature and human well-being (Common and Stagl, 2005).

In 1798, the classical economist Thomas Malthus in his *An Essay on the Principle of Population* asserted that economic growth could not be infinite in the presence of natural constraints (Malthus, 1798). Malthus states that while population growth is geometric, that of livelihood is only arithmetic. This remarkable difference would lead to an imbalance between available resources, especially food ones, and the ability to satisfy an ever increasing population growth. For these reasons the production of resources cannot support population growth. A constant increase in the presence of human beings will produce, proportionately, an ever decreasing availability of sufficient resources to feed them. For this reason the final number of living persons would be reduced to a steady state level (Ang and Van Passel, 2012).

With the Industrial Revolution and with the improvement of the living standards of the populations, neoclassical economic theories replace the Malthusian pessimism. Neoclassical economists do not consider the scarcity of resources as an absolute problem and believe that nature cannot set limits to the improvement of well-being.

As reported in the first chapter, it is only in the 70s that the environment begins to have an effective role in economic analysis. Therefore, two sub-disciplines are born, the environmental economics and natural resource economics, both still conceptually in line with neoclassical theories (Common and Stagl, 2005). The first one deals with economic insertions in the environment and pollution problems, while the second one deals with problems associated with the use of natural resources.

Neoclassical economists have long tended to assume–basically that every technology can be improved upon and every barrier can be surmounted or broken (Ayres, 2007).

While these two sub-disciplines perceive substantially the economy and the environment as two distinct entities, in the same period a branch of the economy has developed, the Ecological Economics, which considers the links between ecosystems and economic systems as the focus of its theory (Munda, 1997).

Starting from the Brundtland report, these two branches have established a heated debate regarding the sustainability of production processes and the relationship between Natural and Manufactured Capital; a debate that has expanded enormously, affecting all the various actors in society. So the formulation of the concept of sustainability has conquered an unprecedented socio-linguistic space and there are few expressions that in such a limited time since their birth, have been so successful (Boada and Toledo, 2003).

Sustainability can be understood at the global level as the maintenance or improvement of the "quality conditions" of the system of interrelations between "Natural Capital" and "Manufactured Capital" (Ayres, van der Bergh and Gowdy, 2001). The scientific community is divided, and the economic discipline (Environmental economic and Ecological economic) introduce and keeps arguing about two possible interpretation of sustainability (Davies, 2013), "*Weak*" and "*Strong*" sustainability.

Table 1 Weak versus Strong Sustainability (Barbier and Burgess, 2017)

Weak Sustainability	Strong Sustainability
• Natural, human and reproducible capital can be substituted for each other. • Natural human and reproducible capital are an aggregate , homogeneous stock.	• Cannot always substitute for natural capital with reproducible or human capital. • Cannot view natural, reproducible and human capital as a homogeneous stock.
• Natural capital should be used efficiently over time • As long as depleted natural capital is replaced with even more valuable reproducible and human capital, then the value of the aggregate stock will increase.	• Certain environmental sinks, processes and services are unique and essential, subject to irreversible loss, and there is uncertainty over their future value and importance.
• Maintaining and enhancing the value of this aggregate capital stock is sufficient for sustainability.	• Maintaining and enhancing the value of the value of the aggregate capital stock is necessary but not sufficient. • Sustainability also requires preserving unique and essential natural capital.

2.1.1 Weak Sustainability

In the weak sustainability perspective, natural resources are considered as factors of production (Solow, 1974; Hartwick, 1977).

Solow states that current generations can extract non-renewable resources in an optimal way, as long as they add optimally to the stock of reproducible capital (Solow, 1974).

Three years later Hartwick perfected and improved Solow's assumption, proposing what would later be remembered as the "Hartwick Rule" (Hartwick, 1977). According to this rule, that is the statement of weak sustainability, the rents (difference between the price at which one can sell the concerned resources and all associated costs) derived from the use of exhaustible resources should be reinvested in produced capital to achieve non-declining consumption (Ang and Van Passel, 2012).

The Hartwick-Solow model imputed renewable and non-renewable natural resources in a Cobb-Douglas production function[2], which is characterized by a constant and unitary elasticity of substitution between factors of production. This entailed the assumption that natural capital was similar to produced capital and could easily be substituted for it (Dietz and Neumayer, 2007). So weak sustainability allows the mutual substitutability between natural capital and product capital. And the system is considered sustainable as long as its total capital increases or remains constant (Wu, 2013).

If there is a decrease in the natural capital, the problem is irrelevant if this decrease can be offset by an equivalent amount of capital produced. With this substitutability of capitals (Natural capital and Man-made capital) a certain amount of capital is transferred to future generations, without affecting their well-being.

2.1.2 Strong Sustainability

Natural ecosystems, including those with strong anthropization, are a well-defined systemic groups, made up of multiple biotic communities (animals and plants) interacting

[2] The Cobb-Douglas functional form of production function is widely used to represent the relationship of an output to inputs. It was proposed by Knut Wicksell (1851-1926), and tested against statistical evidence by Charles Cobb and Paul Douglas in 1928 (Bao-Hong, 2008)

with each other and with the environment that surrounds them. Ecological systems play a fundamental role in sustaining life on the planet and allowing its continuation.

Disregarding the balance of ecological systems affects their ability to exist over time and therefore the possibility of developing any economic activity.

Considering this statement, it is obvious that in a long-term perspective, an economic activity can exist and sustain itself only if it is in symbiosis with the environment that hosts it and only if permanent and irreversible damage is not created.

The relentless pursuit of production and the maximization of monetary well-being has led to a conceptual alienation of man who does not consider the environmental reactions generated by his actions. The environmental and economic dimensions are therefore extremely interdependent and isolating them, forgetting their close relationship, has led to misrepresentations and bad environmental management (Costanza *et al.*, 2014).

Strong sustainability assume a complementary relationship between man-made capital and natural capital, generally defined as a heterogeneous stock of renewable and non-renewable resources, including the provision of ecosystem services and life support functions (MacDonald, Hanley and Moffatt, 1999; De Groot et al., 2003; Daly, H. & Farley, 2004)

Strong sustainability is based on the premise that it is impossible to replace many of the environmental functions and services. The paradigm that moves the evidence that natural capital performs different categories of functions (W. Pearce and Turner, 1991; Ekins et al., 2003):

- It provides the raw materials for production and consumption (food, timber, fossil fuel);
- It assimilates the waste products generated by production and consumption processes;
- It provides amenity services;
- It provides the basic life-support functions on which human life, as well as the first three categories of natural capital functions, depends.

There may be considerable substitution possibilities between the first category of natural capital functions and produced capital. It may also possible to substitute some natural waste assimilative capacity and some natural amenity services. However basic life support systems are impossible to substitute and it is "a 'glue value' that holds everything together" (Turner and Pearce, 1994). All this implies that the environmental and ecological systems that provide the basic functions of food, water, breathable air and a stable climate should be subject to a strong sustainability rule (Dietz and Neumayer, 2007).

Natural capital provides very basic and fundamental life-support functions that no other form of capital can provide (Neumayer, 1998) and there are other reason for its non-substitutability (Turner and Pearce, 1993). Turner and Pearce state this because, the detrimental consequences of depleting natural capital are largely unknown and uncertain and the loss of natural capital is often irreversible.

In dealing with the concept of strong sustainability, two main point of view should be considered (Neumayer, 2013).

The first approach requires the maintenance of the total value of natural capital. In the case of use of non-renewable resources in the economic processes, the extraction must be offset by an investment in renewable replacement resources, in order to keep the aggregate value of the total natural resources stock constant. This concept of strong sustainability implies an unlimited substitutability between different forms of natural capital and presupposes the possibility of assigning a monetary value to each of them. The difference between weak and strong sustainability is strictly linked to the concept of ecosystem services (Martins, 2016). This notion is instrumental in presenting nature as a reserve of capital that can provide a certain number of services (Costanza and Daly, 1992; Norgaard, 2010).

The adoption of the neoclassical value theory limits the ability to adequately address ecosystem services and strong sustainability. The use of a subjective mental parameter in neoclassical economics leads to the evaluation of ecosystem services in terms of subjective preferences that may change, and may not reflect biophysical constraints. Moreover, the use of homogeneous aggregate capital in neoclassical economics, while supposing that there is a high degree of sustainability between natural capital and productive capital, leads to neglecting the specific problems posed by natural resources and towards an interest only with weak sustainability (Martins, 2016). Therefore the adoption of neoclassical theory value constrains the possibility to consider ecosystem services in a strong sustainability perspective that is to say that monetization of natural capital implicitly assumes the adoption of a weak perspective.

The second strong sustainability approach requires that a subset of total natural capital be stored in physical terms so that its functions remain intact over time (Dietz and Neumayer, 2007). This so-called *Critical Natural Capital* (Ekins *et al.*, 2003) it should be preserved through two rules (Daly, 1992):

1. Use renewable resources as their stock is not subject to deterioration;
2. Use the sinking capacity of the environment for the natural absorption of pollution, taking into account that this peculiarity does not deteriorate over time.

The second point is more coherent with the basic idea and the concept of strong sustainability, implies that any empirical analysis aimed to assess the condition of sustainability or unsustainability, should be based on the measurement of the physical dimension of natural capital.

The latter being the approach followed for the elaboration of this thesis, the following section describes the Ecological Footprint, which is the indicator that allows the best measurement of natural capital (using land as the unit accounting), in the spirit of strong sustainability.

2.2 Measuring the condition of strong sustainability with the Ecological Footprint

"Acknowledging that nature has a finite capacity is not pessimistic, just realistic, it makes room of wise decision. To ignore these basic constraints would jeopardize future well-being. Ecological Footprint analysis starts from the premise that humanity must live within global carrying capacity. It also maintains that if we choose wisely it might even be possible to increase our quality of life. Our concern is that the way we now live on the planet is self-destructive. The Footprint is a tool that facilitates learning about ecological constraints and developing a sustainable lifestyle" (Wackernagel and Rees, 1996a).

In this thesis the strong sustainability was assessed at the local level, represented by the territory (municipality) of the Province of Viterbo, basing on the Ecological Footprint (EF) approach (Wackernagel and Rees, 1996a). This choice is supported by a general agreement among scholars about the fact that Ecological Footprint is an indicator able to perform a strong sustainability measurement (Dietz and Neumayer, 2007).

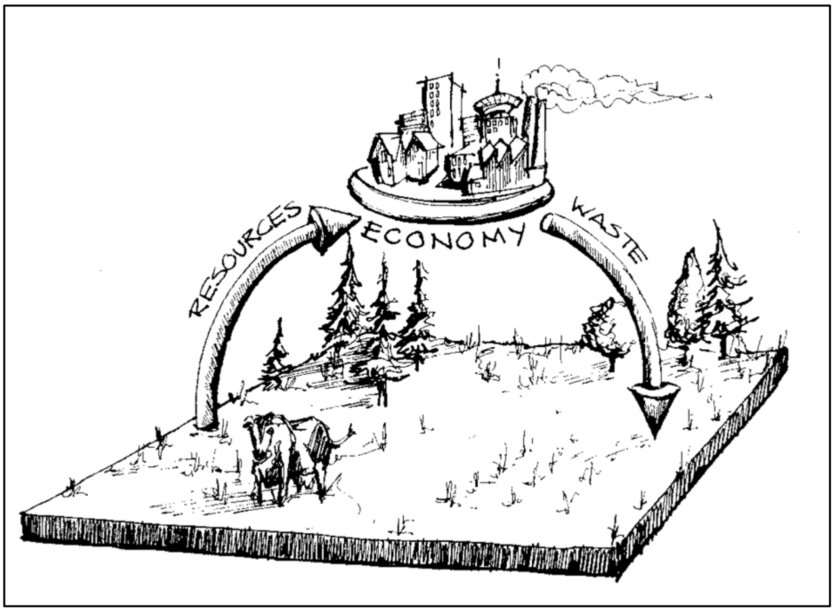
The Ecological Footprint represents the critical natural capital requirements of a defined economy or population in terms of the corresponding biologically productive areas (Wackernagel and Rees, 1997; Wackernagel *et al.*, 1999, 2002; Monfreda, Wackernagel and Deumling, 2004; Mancini *et al.*, 2017). In other word as asserted by Lin *et al.* (2018), is an account-based system of indicators which are based on the principle that the Earth has a limited amount of biological production, and that through it supports all life (Wackernagel *et al.*, 2018a, 2018b). The Ecological Footprint provides an integrated and multi-scale approach to monitor excessive use of natural resources and the resulting impacts on ecosystems (Mancini *et al*., 2018) and biodiversity (Galli *et al*., 2014).

The first academic publication about the Ecological Footprint was by William Rees at the University of British Columbia of Vancouver (Rees, 1992). Mathias Wackernagel, under the supervision of Rees, over the next two years has further implemented the concept of Ecological Footprint and the calculation method in his PhD dissertation (Wackernagel, 1994). In the beginning Wackernagel and Rees had assigned the concept the name *Appropriate carrying capacity*, but to make the idea more usable, Rees coined the term Ecological Footprint.

The ecological footprint theory bases its analysis on recognizing that everyone (from any individual to an entire city or country) has an impact on the planet, because they consume the products and services of nature. Likewise, recognizes that, in order for human beings to live in a sustainable manner, it must be understood that it is not possible to use the essential products and processes of nature at a faster rate than they renew, nor to dump waste in the environment a speed higher than they assimilate.

However, the increase in the production of goods and services for the satisfaction of human needs by economic activity, which today uses a large amount of natural resources (natural capital), is leading to its deterioration, including its own regeneration capacity (Wackernagel and Rees, 1996a). So the ecological footprint determines the amount of productive land that the economy needs (figure 6).

Figure 6 Resources, Economy and waste (Wackernagel *et al.*, 1999)



The Ecological Footprint monitors the combined impact of anthropogenic pressures, which are typically assessed independently (CO_2 emissions, fish consumption, land use change, etc.) and which facilitate the comprehension of the pressures that human beings place on the biosphere and its ecosystems. The Ecological Footprint can be applied on different scales that can vary from individual products, to cities and regions, to countries and to the entire planet as a whole (Ewing, Moore, *et al.*, 2010).
The classic formulation of the Ecological Footprint (EF) divides the use of ecologically productive territory into six main categories[3].

1. *Built-up land*: Ecologically unproductive land, is the area of land covered by human infrastructure such as transportation, housing, industrial structures;
2. *Energy Land*: area needed to produce, using sustainable methods (i.e. biomass), the amount of energy used. In reality Wackernagel and Rees (1996) apply a different definition, which is based on the area of forest necessary to adsorb the CO_2 emitted

[3] The consideration of such different types of territory has posed the problem of their different productivity. To make the uses of different types of soils comparable, the classic formulation of the Ecological Footprint introduces a normalization operation, which allows to consider the areas of the different types of land, based on their average world productivity. For these surfaces the hectare, which refers to real surfaces, is not used as a unit of measurement, but rather a more generic "area unit", indicated with the term "equivalent hectare".

by the production of energy from fossil fuels. The two areas have the same order of magnitude, but this second method makes it possible to concentrate the calculation of the energy component of the Ecological Footprint on the problem of the concentration of CO_2 in the atmosphere and the consequent climate alteration. In this way it also becomes possible, starting from the data regarding the different CO_2 emissions, to distinguish the impacts caused by the use of different fossil fuels (solid, liquid, gaseous) to produce energy.

3. *Crop Land*: arable land (fields, vegetable gardens, etc.) used for the production of foodstuffs and other non-food products of agricultural origin (cotton, tobacco, etc.);
4. *Grazing Areas*: area of grassland used, in addition to crop feeds, to raise livestock for meat, diary, hide and wool products. It comprises all grasslands used to provide feed for animals, including cultivated pastures and wild grasslands and prairies;
5. *Forest*: area of forest required to support the annual harvest of fuel wood, pulp and timber products
6. *Water*: area of marine and inland waters necessary to generate the annual primary production required to support catches of aquatic species (fish and seafood) and from aquaculture.

The consideration of such different types of territory has posed the problem of their different productivity, for this reason the classic Ecological Footprint formulation introduces a normalization operation. This allows to weigh the areas, of different soil types, based on their average world productivity derived from studies conducted by FAO for the identification of Global Agroecological Zones (GAEZ). The quantification of surface types is done through the standard unit of equivalent hectares (gha).

Since it is not possible calculate the area of land necessary for the supply, maintenance and disposal of each of the tens of thousands of consumer goods, the count must be limited to a few main categories[4].

Most of the data is extracted from national statistics on their production and consumption of energy, food or forest products. For many categories of goods, national statistics

[4] For the estimation of the EF, the average per capita consumption of some particular goods is calculated starting from the aggregated regional or national data or dividing the total consumption for the population..

provide data on both production and trade, from which it is possible distinguish domestic production, imports and exports, making possible the measure of net consumption.

NET CONSUMPTION = PRODUCTION + IMPORT – EXPORT

For each good belonging to the different consumption categories[5], the EF components is calculated for the six types of ecologically productive land previously listed, expressed in "equivalent hectares"[6]. In this way, a real surface (expressed in ha) is transformed into an equivalent area (expressed in gha), which counts the extension that would be obtained if was considered a land with a productivity equal to the world average. Starting from the consumption of a given territory, the Ecological Footprint of each inhabitant is obtained dividing the total consumption by the number of inhabitants

The BioCapacity indicator (BC) describes the productive component of ecosystems. Measures the supply of bio-productivity and tracks the ecological assets available in a region and their capacity to produce renewable resources and ecological services (Galli *et al.*, 2014; Mancini *et al.*, 2017) provided by the different types of soil previously identified. This indicator is also expressed in global hectares (gha), which are evaluate taking into account the bioproductivity of the different categories of land in relation to "equivalent factors" and "performance factors" update annually by GFN[7] (Pulselli *et al.*, 2011).

Ecological Footprint and Biocapacity accounting take into account the sustainability principles identify by Daly in is work "*Towards some operational principles of sustainable development*[8]" (Daly, 1990). Their values are used to measure one key aspect

[5] Consumption is divided into the following categories: consumption of food, non-food goods and services; energy consumption, divided into sub-categories such as fuels for private transport, electricity, heating and others; land use; water; waste.

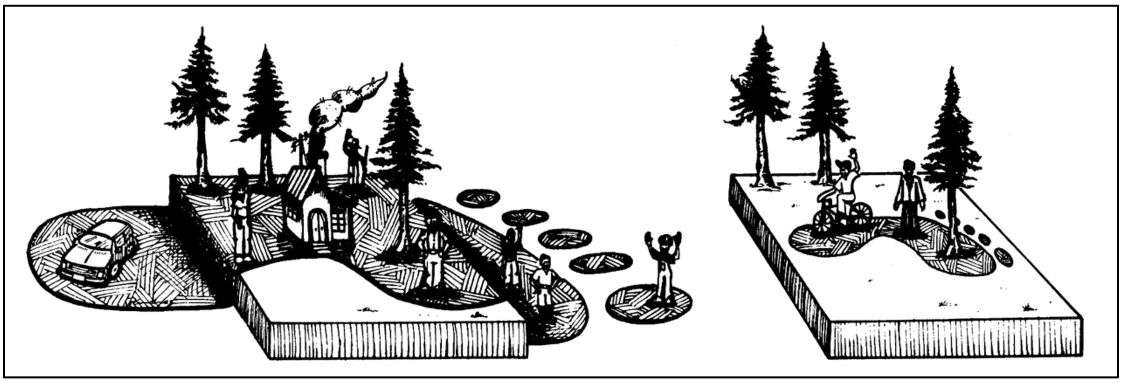
[6] The different types of productive land are weighed by their specific equivalence factors, which take into account their average bio-productivity.

[7] The Global Footprint Network (GFN) is the private research body, which aims to standardize the calculation criteria of the Ecological Footprint worldwide (https://www.footprintnetwork.org/). The calculation of the EF proposed by the GFN considers about 700 main consumer goods (food, clothing, machinery, etc.)

[8] [*… there are two obvious principles of sustainable development. First that harvest rates should equal regeneration rates (sustained yield). Second that waste emission rates should equal the natural assimilative capacities of the ecosystems into which the wastes are emitted. Regenerative and assimilative capacities must be treated as natural capital, and failure to maintain these capacities must be treated as capital consumption, and therefore not sustainable…*](Daly, 1990)

of sustainability: the human appropriation of the Earth's regenerative capacity (Galli *et al.*, 2012).
BioCapacity, compared with the Ecological Footprint, allows defining a real environmental balance by subtracting from the offer of ecological surface (BioCapacity) the demand for surface area required by the local population (Ecological Footprint).
So the difference between Biocapacity (BC) and Ecological Footprint (EF) defines the so-called Ecological Balance (EB) which makes it possible to translate in quantitative terms the environmental surplus/deficit situation of a region, and hence verify its strong sustainability condition (figure 7).

Figure 7 Picture of the ecological Deficit (Wackernagel *et al.*, 1999)



If EB is lower than zero, the carrying capacity of the region is exceeded and an ecological deficit occurs; and in such situation the region is judge to be unsustainable, under a strong sustainability approach (Neumayer, 2013). The Ecological Balance therefore expresses the notion of carrying capacity, translating the local economic activity necessary to produce the resources consumed and to assimilate the waste generated by a given region.

CHAPTER 3

AGRICULTURAL PRODUCTION IN NORTHERN LAZIO

In the previous sections, an effort was made to clarify and classify the concept of sustainability focusing in particular on the concept of the Strong Sustainability. In this chapter is discussed the setting of the sustainability assessment of some agri-food chains, with reference to the province of Viterbo. In practice, this is the construction of a model based on the evidence that emerged in the review of the literature on sustainability and on the characteristic of the supply chains that will be identified.

The choice of the Province of Viterbo is dictated by the need of the bioeconomic approach to identify a defined territorial area of analysis.

The analysis carried out at the municipal level will allow the identification of the production districts of the main agricultural production; referring to these districts the Ecological Balance will be used to verify the strong environmental sustainability of some agricultural production.

3.1 The main features of Tuscia agricultural system

The territorial scale of analysis relates to the province of Viterbo. The province, located in central Italy, has a total area of 3.615 km^2 divided into 60 municipalities, with a population of 318.205 inhabitants (Istat, 2019a). It borders to the north with the province of Grosseto and Siena, to the east with the province of Rieti and Terni, to the south with the province of Rome and to the west with the Tyrrhenian Sea (figure 8).

According to the 2010 Agricultural Census (Bellini *et al.*, 2013) the province of Viterbo is the seventeenth province in Italy for the value of agricultural production, the first in

Central Italy[9] and the 4th in Central-Southern Italy. As reported in the 19th Report on the Economy of Tuscia Viterbese (Chamber of Commerce Viterbo, 2018), the added value of agriculture is about 330 million euros, equal to 5,1% of the added value of total assets (Table 2).

Figure 8 The Province of Viterbo

Table 2 Value added by economic activity in the provinces of Lazio expressed in millions of euro (Source: Chamber of Commerce of Viterbo, 2018)

Province	Agriculture, forestry and fishing	Industry	Services	Total
Viterbo	299.1	879.0	4,690.3	5,868.4
Rieti	90.3	410.0	2,158.3	2,658.5
Roma	549.6	17,509.3	124,974.1	143,032.9
Latina	680.0	2,811.8	8,153.3	11,654.1
Frosinone	169.7	2,959.7	6,811.5	9,941.0
Lazio	**1,788.7**	**24,569.7**	**146,787.5**	**173,145.9**

[9] The geographical distribution of Italian provinces within the different regions according to Istituto Nazionale di Statistica (ISTAT) is: **North (**Piedmont, Valle d'Aosta, Liguria, Lombardy, Trentino-Alto Adige, Veneto, Friuli Venezia Giulia, Emilia Romagna); **Center** (Tuscany, Umbria, Marche, Lazio); **South** (Abruzzo, Molise, Campania, Puglia, Basilicata, Calabria); **Islands**: Sicily. Sardinia

In the province of Viterbo there are about 20,700 farms, 45,6% less than those in the 2,000 census data (Istat, 2000). Even the UAA (Utilized Agricultural Area), in this time frame, has shown a significant reduction (about -7%), albeit more limited than the decline in the numbers of farms (Table 3).

Table 3 Variation (2000-2010) of farms and UAA (ha) in the provinces of the Lazio region (Source: Istat, 2000, 2010)

Province	Farms 2000	Farms 2010	Absolute variation	Relative variation
Viterbo	38,144	20,736	-17,408	-45.6%
Rieti	21,168	9,228	-11,940	-56.4%
Roma	59,950	21,631	-38,319	-63.9%
Latina	35,853	20,583	-15,270	-42.6%
Frosinone	59,551	26,038	-33,513	-56.3%
Lazio	**214,666**	**98,216**	**-116,450**	**-54.2%**
Province	**UAA 2000**	**UAA 2010**	**Absolute variation**	**Relative variation**
Viterbo	209,966	195,155	-14,801	-7.1%
Rieti	105,172	88,475	-16,696	-15,9%
Roma	193,092	175,977	-17.114	-8,9%
Latina	92,936	88,390	-4,546	-4,9%
Frosinone	123,584	90,601	-32,982	-26,7%
Lazio	**724.751**	**638,601**	**-86,149**	**-11,9%**

Table 4 Number of farms by Class of UAA in the province of Viterbo (2000-2010) (Source: Istat, 2000, 2010)

UAA	2000	2010	Var. %
< 5 ha	29,932	13,918	-53.5
5 – 10 ha	3,645	2,809	-22.9
10 – 20 ha	2,235	1,831	-18.0
20 – 50 ha	1,457	1,463	+ 0.4
50 – 100 ha	513	441	-14.0
> 100 ha	365	274	-24.9
Total	38,144	20,736	-45.6

The largest farms contraction (Table 4) in the inter-census interval is concentrated in the smaller classes of UAA. In fact, the percentages of greatest contraction (-53.5%) concern farms less than 5 ha. The contractions tend to remain negative in all classes, except for those that include farms of 20 - 50 ha, where the increase is almost 0.5%.

Looking at the UAA productive destination (Table 5), about 12% of the provincial agricultural area is dedicated to permanent meadows and pastures and 34% to forage crops. Considering these two areas, it can be said that about half of the total agricultural land of the province is devoted to livestock feeding. Of the remaining agricultural area, about half (47%) is occupied by cereals, the 40% by tree crops and the 7% by potatoes and vegetables. Regarding the area occupied by tree crops, hazelnut cultivation stands out, with an extension of about 18,000 ha (48% of the tree crops area), followed by the olive cultivation (about 14,000 ha) and vineyards that occupy the 8% of the land devoted to tree crops.

Table 5 Utilizations of the UAA (ha) in the Viterbo province
(Source: Istat, 2000, 2010)

	UAA (ha)	**% of the total**
Cereals	45,893.8	23.5
Legumes	2,190.0	1.1
Potatoes and vegetables	6,499.4	3.3
Industrial crops	3,344.0	1.7
Forage crops	68,187.2	34.9
Set-aside	6,407.2	3.3
Tree crops	38,931.2	19.9
Permanent meadows and pastures	22,100.2	11.3
Others	1,602.3	0.8
Total	**195,155.4**	**100**

3.2 Selection of the main agricultural productions in Viterbo province

The peculiarities of the agricultural system of the Viterbo province is the variety of productions and, in this context, there are situations of excellence at national and international level. Among the most important crops there are the hazelnut, vineyard, olive and potato. With reference to hazelnut, in particular, in the province there are around 91% of the total farms at the regional level and around the 96% of the dedicated UAA. The hazelnut plants, according to Istat estimates (Istat, 2010 - 2017) affect about 22,000 ha in 2018, with a production of around 560,000 quintals, equal to about 40% of the entire Italian production.

Table 6 Percentage ratio for each crop, of the farms and UAA on the regional total (Source: Istat, 2010)

	Hazelnut		Potato		Vineyard		Olive	
	Farms (%)	**UAA (%)**	**Farms (%)**	**UAA (%)**	**Farms (%)**	**UAA (%)**	**Farms (%)**	**UAA (%)**
Viterbo	90,8	95,9	30,2	71,0	20,4	17,7	20,1	20,6
Rieti	1,1	0,3	19,6	8,0	9,3	4,5	9,5	15,9
Roma	6,6	3,5	18,6	15,0	24,9	42,8	22,9	24,7
Latina	0,4	0,1	3,6	2,7	11,8	23,8	17,0	14,2
Frosinone	1,1	0,2	28,1	3,3	33,6	11,2	30,4	24,6
Lazio	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

As for agricultural tree crops, there are 4,183 vineyard farms and 13,580 olive farms in the province, and both sectors can boast brands of geographical origins that enhance local productions. Potatoes also play an important role in the agricultural sector of the province, with 339 farms and a total area of about 1,200 ha. Surface that, analyzing the agricultural census estimates (Table 7), is practically constant over the period considered in the analysis.

Table 7 Area and production of the main crops of the Viterbo province[10] *(Source: Istat, 2010-2017)*

Year	Hazelnut		Vineyard		Olive		Potato	
	Area (ha)	**Production (q)**	**Area (ha)**	**Production (q)**	**Area (ha)**	**Production (q)**	**Area (ha)**	**Production (q)**
2010	17,708	280,800	5,167	379,025	21035	567,000	1,210	302,500
2011	17,700	491,960	5,120	411,421	13,671	258,780	1,190	368,900
2012	18,430	298,600	2,670	180,880	13,600	243,000	1,100	275,000
2013	18,432	385,000	3,100	357,600	13,620	258,600	1,110	310,800
2014	18,430	190,000	2,900	243,244	13,500	239,000	1,352	297,440
2015	18,390	441,360	2,200	220,000	13,500	340,000	1,340	268,000
2016	18,000	360,000	2,170	221,468	13,450	336,000	1,310	275,100
2017	22,000	560,000	2,460	141,650	15,000	118,000	1,210	302,016

[10] As reported on the website I.stat (http://dati.istat.it/), *"...the database from which the data come from, concerns surface estimates and production of agricultural crops, floriculture and whole pot plants. The data were collected following an estimative methodology. The estimates are made on the basis of assessments by local experts in the sector who are located throughout the territory. The experts' estimates may include the results of direct checks on the territory, as well as the indications coming from external sources (for example professional bodies and producer associations, administrative sources, auxiliary data sources correlated with the cultivation object of estimation)..."*

3.3 Methodology adopted to define the production districts

In order to proceed with the research analysis, according to the bioeconomic approach, it is important to identify the territorial limit of the study areas for each selected cultivation (hazelnut, vine, olive and potato), so as to evaluate their characteristics and connections with ecosystems and local communities.

A database was built at municipal level for each one of these productions, with data from the 2010 Agricultural Census (Istat, 2010), 2011 Population Census (Istat, 2011) and 2014-2015-2016-2017 Italian FADN[11] database (CREA, 2017a), whose elaboration allowed to obtain indexes useful to identifying the production districts of the main crops in the province (table 8).

Table 8 Data at municipal level, used for the construction of the Database

Data	Source
Total Agricultural Area Total Utilized Agricultural Area (UAA) Total Number of farms Number of farms for each crop UAA for each crop	ISTAT 2010 Agricultural Census
Resident population Occupied population	ISTAT 2011 Population Census
Cultivated area Man Hours (Crop) Gross Margin	FADN (2014,2015,2016,2017)

[11] The Farm Accountancy Data Network (FADN or RICA in Italian) is an annual sample survey established by the European Economic Commission in 1965, with EEC Regulation 79/65 and then updated with EC Regulation 1217/2009. The Italian FADN is based on a reasoned sample of about 11,000 farms, structured to represent the different types of production and size present on the national territory. Farms participating in the FADN are selected on the basis of a sampling plan drawn up for each region. The RICA sample allows an average national coverage of 95% of the UAA, 97% of the Standard Production value, 92% of Labor Units, and 91% of Livestock Units (Source: http://rica.crea.gov.it/)

For this purpose, three new variables have been defined to describe the productive (*LEV_PRO*), economic (*LEV_ECO*) and social (*LEV_EMP*) dimension of the selected crops.

$$LEV\_PRO = AAL\_CRP / AAL\_COM$$

$$LEV\_ECO = (GM\_CRP \times AAL\_CRP) / POP\_COM$$

$$LEV\_EMP = ((H\_CRP \times AAL\_CRP) / H\_EUN) / EMP\_COM)$$

In the previous equations *AAL_CRP* is the municipal area of the crop, *AAL_COM* the municipal agricultural land, *GM_CPR* the average unit gross margin of the crop in the period 2014-2015, *POP_COM* the resident population in the municipality, *H_CRP* the average labor per hectare of crop, *H_EUN* the number of annual work hours of an employed in agriculture and *EMP_COM* the total number of workers employed in the municipality.

These three variables were normalized, using the maximum and the minimum value recorder in the province, to create three new indicators (IND_PRO, IND_ECO, IND_EMP) ranging from 0 to 1. So, for example, the IND_PRO is evaluated as:

$$IND\_PRO = \frac{VAL\_PRO_i - VAL\_PRO_{min}}{VAL\_PRO_{max} - VAL\_PRO_{min}}$$

where VAL_PRO_i is the value of variable *VAL_PRO* in the municipality i (i=1…60).

As a final step, the three indictor where combined into a synthetic indicator (IND_CRP) which quantifies in the range from 0 to 1 the presence (in productive, economic and social terms) of the crop in each one of the municipality (i; i=1…60) in the province.

$$IND\_CRP = \sqrt{\frac{(IND\_PRO^2 + IND\_ECO^2 + IND\_EMP^2)}{3}}$$

Since each municipality is characterized by a specific IND_CRP value, for each single crop a threshold equal to 0.15 was set to include the municipalities with a higher value of the indicator in the district. Threshold was chosen empirically by checking the number of municipalities selected for the crops. In fact, it was also noticed on the basis of previous knowledge of local agriculture, that with higher thresholds, areas where production plays a significant role would have been excluded, while with lower, the production area would have expanded beyond outside of its real connotation. For all the crops examined it was observed that the value provided a fair discrimination between areas where the crops were present and not, in particular for crops with a greater territorial concentration (hazelnut and potato) as can see in tables 10 and 12.

3.4 The production districts of the selected crops

The methodology presented in the previous paragraph was applied to the four selected crop (vineyard, hazelnut, olive and potatoes) to determine the area of the province where the crop play a relevant role in productive, economic and social terms.

3.4.1 Vineyard district identification

In figures 9, 10 and 11 are reported the cartographic elaboration of the distribution of the three variables considered to describe the productive (*VAL_PRO*), economic (*VAL_ECO*) and social (*VAL_EMP*) dimensions of the vineyard cultivation in the Viterbo province.

Table 9 shows the variables and related normalized indicators used in the identification process of vineyard production district. The combination of these indicators has generated the *IND_CRP* indicator which quantifies the presence of vineyards in each municipalities.

Figure 9 Productive dimension of vineyard cultivation (VAL_PRO)

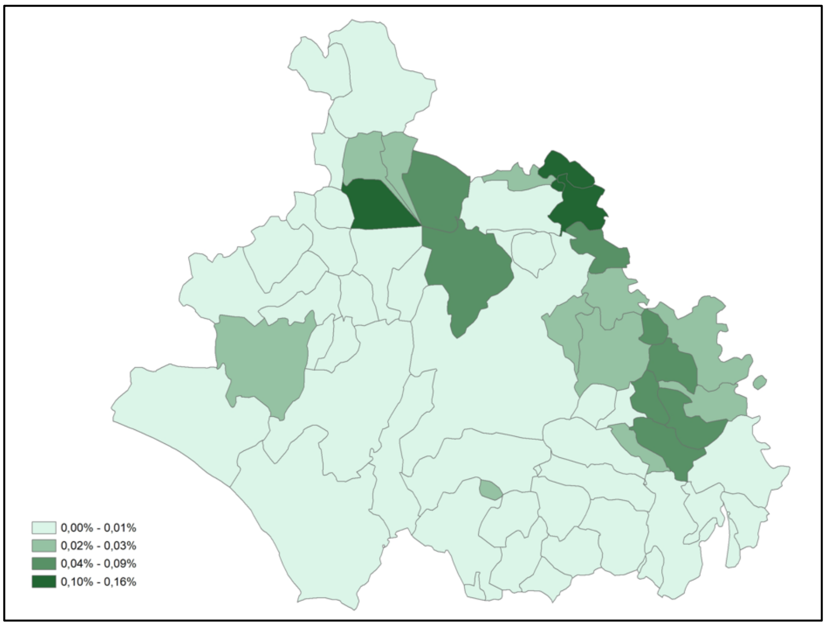


Figure 10 Economic dimension of vineyard cultivation (VAL_ECO)

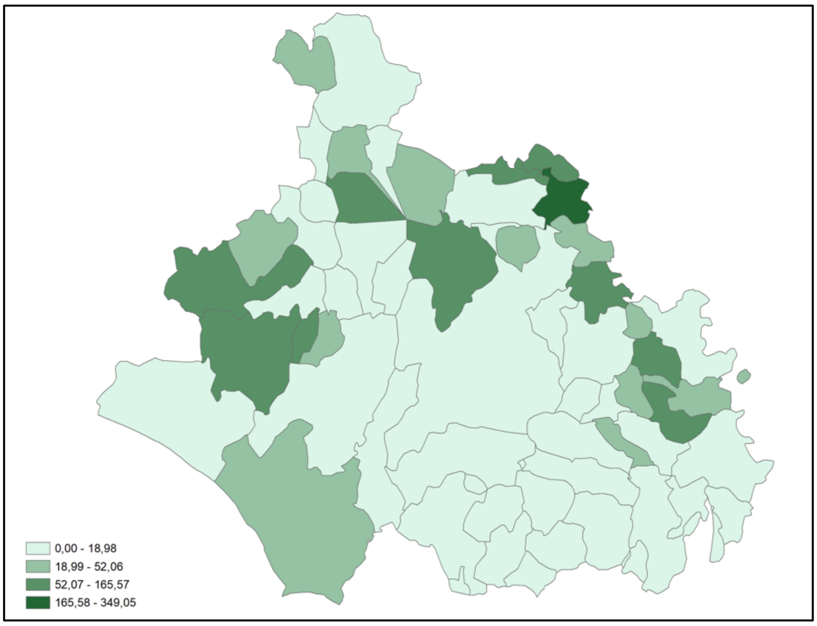


Figure 11 Social dimension of vineyard cultivation (VAL_EMP)

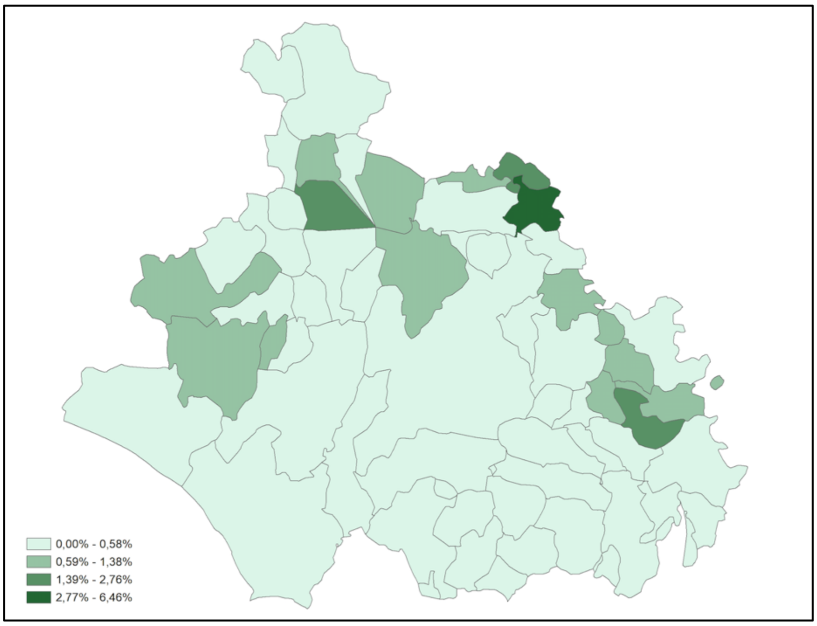
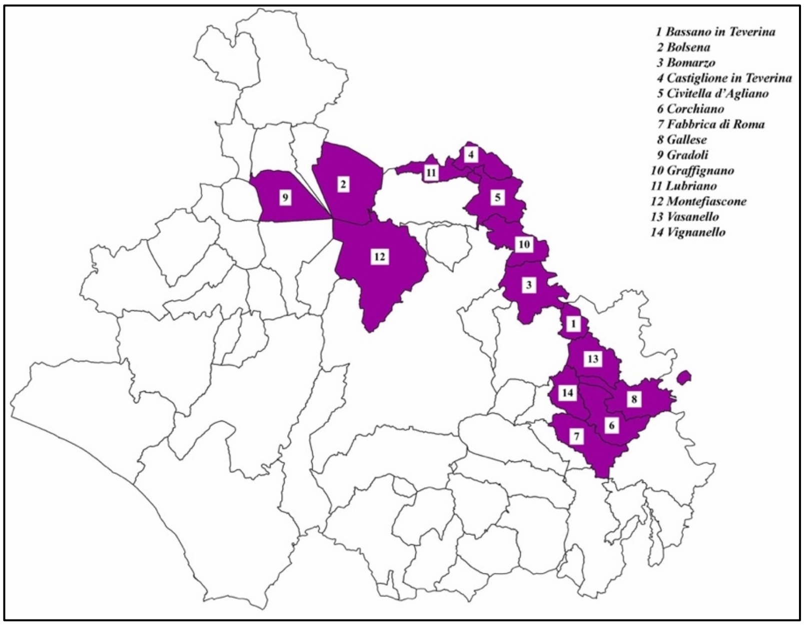


Table 9 Values of variables, indicators and IND_CRP to identify vineyard district

Municipality	VAL_PRO	VAL_ECO	VAL_EMP	IND_PRO	IND_ECO	IND_EMP	IND_CRP
Acquapendente	1.1%	19.0	0.31%	0.072	0.054	0.048	0.059
Arlena di Castro	0.6%	21.4	0.37%	0.039	0.061	0.058	0.054
Bagnoregio	0.5%	12.4	0.21%	0.034	0.036	0.033	0.034
Barbarano Romano	0.4%	13.1	0.23%	0.027	0.038	0.035	0.034
Bassano Romano	0.0%	0.0	0.00%	0.001	0.000	0.000	0.000
Bassano in Teverina	4.0%	34.7	0.63%	0.254	0.099	0.098	0.167
Blera	0.4%	13.5	0.26%	0.027	0.039	0.040	0.036
Bolsena	4.2%	52.1	0.87%	0.263	0.149	0.135	0.191
Bomarzo	3.1%	60.1	1.08%	0.196	0.172	0.167	0.179
Calcata	0.6%	2.5	0.05%	0.035	0.007	0.007	0.021
Canepina	1.2%	8.7	0.15%	0.079	0.025	0.024	0.050
Canino	1.5%	59.2	1.06%	0.095	0.170	0.164	0.147
Capodimonte	0.4%	10.8	0.19%	0.022	0.031	0.029	0.028
Capranica	0.5%	2.9	0.05%	0.029	0.008	0.007	0.018
Caprarola	0.1%	2.3	0.04%	0.009	0.006	0.006	0.007
Carbognano	1.5%	20.7	0.35%	0.093	0.059	0.054	0.071
Castel Sant'Elia	0.2%	1.4	0.03%	0.015	0.004	0.004	0.009
Castiglione in Tev.	14.8%	165.6	2.76%	0.933	0.474	0.428	0.653
Celleno	0.8%	22.0	0.36%	0.049	0.063	0.056	0.056
Cellere	0.2%	7.3	0.14%	0.011	0.021	0.021	0.018
Civita Castellana	0.2%	1.3	0.03%	0.012	0.004	0.004	0.008
Civitella d'Agliano	15.8%	349.0	6.46%	1.000	1.000	1.000	1.000
Corchiano	6.7%	101.7	1.86%	0.421	0.291	0.288	0.339
Fabrica di Roma	4.4%	16.7	0.30%	0.278	0.048	0.047	0.165
Faleria	0.6%	4.4	0.08%	0.038	0.012	0.012	0.024
Farnese	0.7%	23.3	0.42%	0.041	0.067	0.064	0.059
Gallese	3.4%	44.0	0.77%	0.217	0.126	0.119	0.160
Gradoli	11.5%	120.0	2.06%	0.728	0.344	0.319	0.500
Graffignano	4.5%	30.9	0.58%	0.281	0.089	0.089	0.178
Grotte di Castro	2.5%	39.3	0.66%	0.158	0.113	0.102	0.127
Ischia di Castro	1.1%	60.4	1.11%	0.070	0.173	0.172	0.147
Latera	0.5%	16.0	0.27%	0.032	0.046	0.042	0.040
Lubriano	3.0%	70.3	1.18%	0.191	0.202	0.183	0.192
Marta	1.1%	16.6	0.30%	0.072	0.048	0.047	0.057
Montalto di Castro	0.2%	8.1	0.14%	0.014	0.023	0.021	0.020
Montefiascone	5.9%	73.9	1.24%	0.375	0.212	0.192	0.272
Monte Romano	0.0%	1.8	0.03%	0.001	0.005	0.005	0.004
Monterosi	0.0%	0.0	0.00%	0.000	0.000	0.000	0.000
Nepi	0.5%	4.5	0.08%	0.031	0.013	0.012	0.021
Onano	0.8%	19.0	0.38%	0.048	0.054	0.059	0.054
Oriolo Romano	0.6%	1.2	0.02%	0.040	0.003	0.003	0.023
Orte	1.7%	9.3	0.16%	0.109	0.027	0.024	0.066
Piansano	0.2%	3.9	0.07%	0.010	0.011	0.010	0.011
Proceno	0.3%	27.2	0.39%	0.018	0.078	0.060	0.058
Ronciglione	0.2%	2.0	0.04%	0.014	0.006	0.005	0.009
Villa S. Giov. in T.	1.8%	12.7	0.24%	0.115	0.036	0.037	0.073
San Lorenzo Nuovo	2.0%	18.3	0.31%	0.123	0.052	0.048	0.082
Soriano nel Cimino	1.8%	14.9	0.27%	0.113	0.043	0.041	0.074
Sutri	0.2%	1.5	0.03%	0.011	0.004	0.004	0.007
Tarquinia	0.9%	24.1	0.41%	0.060	0.069	0.063	0.064
Tessennano	1.1%	76.9	1.38%	0.072	0.220	0.213	0.182
Tuscania	0.5%	17.0	0.31%	0.029	0.049	0.047	0.043
Valentano	0.3%	7.1	0.12%	0.017	0.020	0.018	0.018
Vallerano	1.1%	10.1	0.18%	0.070	0.029	0.027	0.047
Vasanello	8.9%	68.4	1.18%	0.559	0.196	0.183	0.358
Vejano	0.0%	0.1	0.00%	0.001	0.000	0.000	0.001
Vetralla	1.3%	11.5	0.21%	0.084	0.033	0.032	0.055
Vignanello	6.7%	49.5	0.91%	0.424	0.142	0.141	0.271
Viterbo	1.2%	9.1	0.16%	0.077	0.026	0.025	0.049
Vitorchiano	3.3%	17.9	0.28%	0.209	0.051	0.044	0.127

To identify the productive district, all the municipalities with an IND_CRP greater than 0.15 were taken into consideration, thus identifying two quite distinct areas (Figure 12); the first is located around the Lake of Bolsena and the second covers the Tiber River Valley on the border with Umbria region. These areas represent the two selected wine production districts considered in the next steps of the research.

Figure 12 Identified vineyard districts



3.4.2 Hazelnut district identification

In figures 13, 14 and 15 are reported the distributions of the three variables considered to describe the productive (*VAL_PRO*), economic (*VAL_ECO*) and social (*VAL_EMP*) dimensions of the hazelnut cultivation in the Viterbo province.

Table 10 shows variables and indicators related to hazelnut cultivation, which were combined to generate the *IND_CRP* indicator (reported in the last column of table 10) utilized to assess the presence of hazelnut cultivation in the Viterbo province.

To define the production district of hazelnut (Figure 16) an IND_CRP value greater than 0.16 has been set. From the map it is evident, as it was easy to broadcast, that this district is located in the area of the Monti Cimini, where the hazelnut cultivation is largely dominant.

Figure 13 Productive dimension of hazelnut cultivation (VAL_PRO)

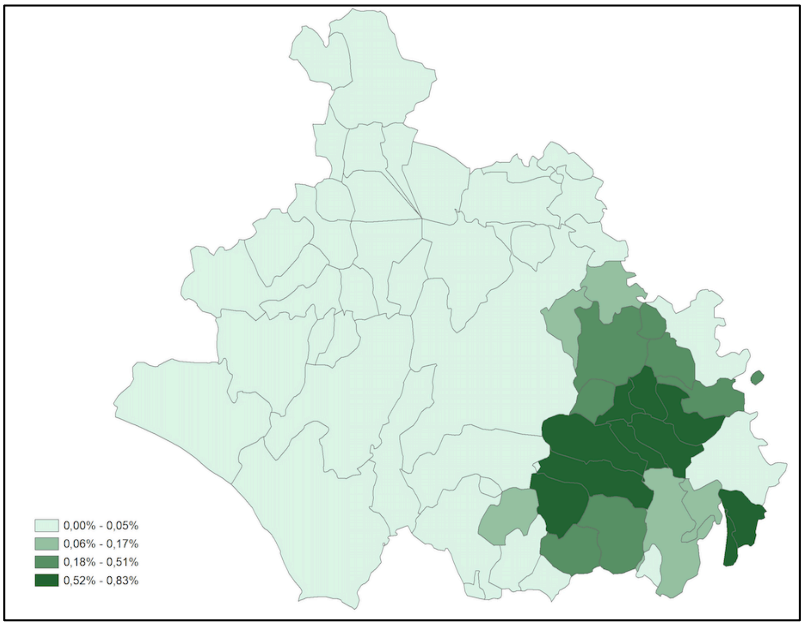


Figure 14 Economic dimension of hazelnut cultivation (VAL_ECO)

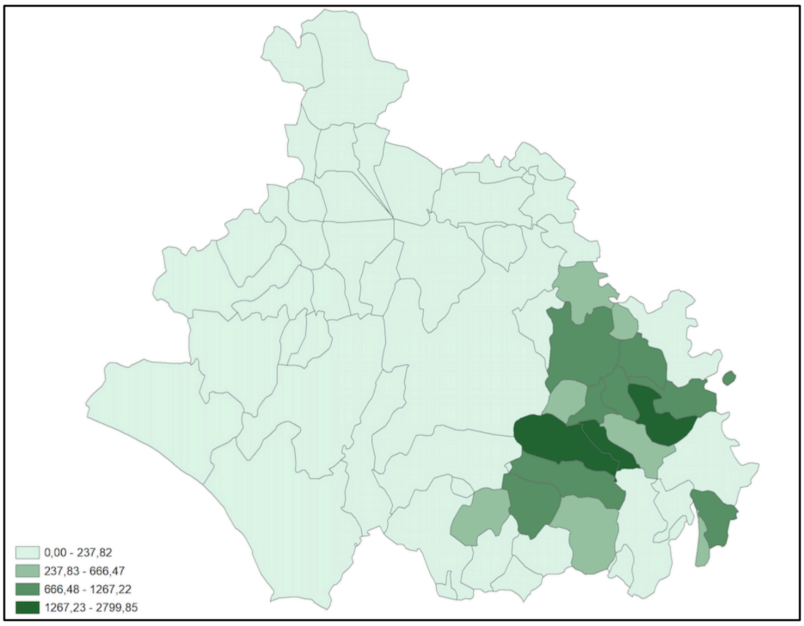


Figure 15 Social dimension of hazelnut cultivation (VAL_EMP)

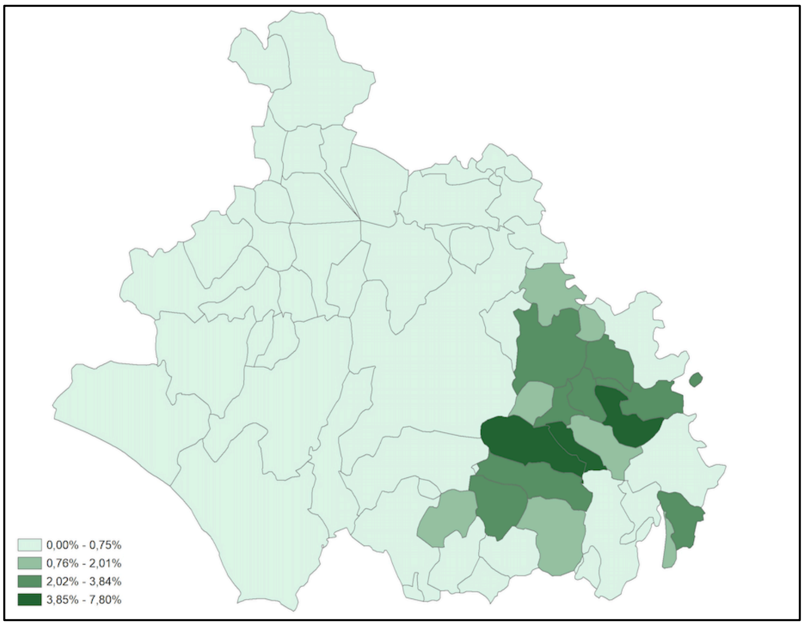


Figure 16 Identified hazelnut district

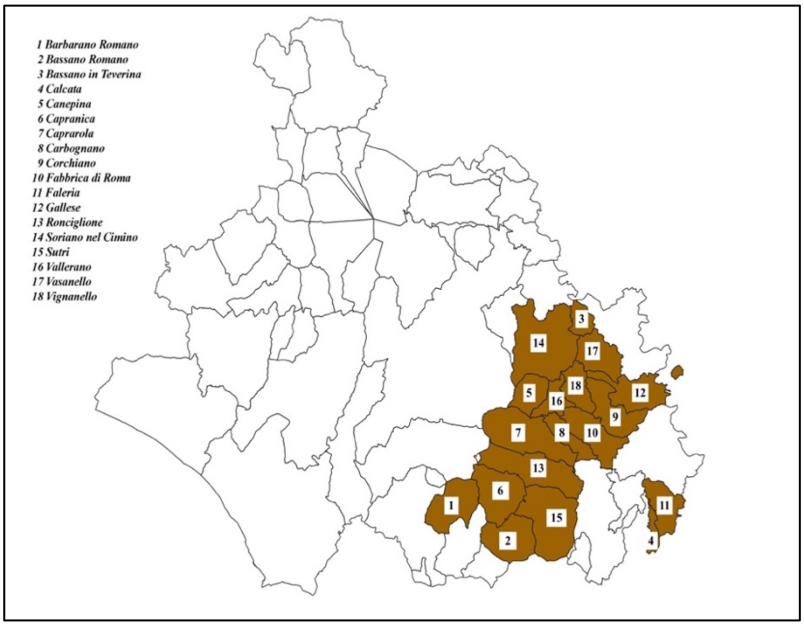


Table 10 Values of variables, indicators and IND_CRP to identify hazelnut district

Municipality	VAL_PRO	VAL_ECO	VAL_EMP	IND_PRO	IND_ECO	IND_EMP	IND_CRP
Acquapendente	0.0%	0.9	0.00%	0.000	0.000	0.000	0.000
Arlena di Castro	0.2%	10.8	0.03%	0.002	0.004	0.004	0.003
Bagnoregio	0.5%	21.9	0.06%	0.005	0.008	0.008	0.007
Barbarano Romano	9.5%	603.0	1.73%	0.114	0.215	0.221	0.190
Bassano Romano	27.9%	237.8	0.75%	0.335	0.085	0.096	0.207
Bassano in Teverina	37.5%	666.5	2.01%	0.450	0.238	0.257	0.329
Blera	1.3%	87.5	0.27%	0.016	0.031	0.035	0.029
Bolsena	0.0%	1.0	0.00%	0.000	0.000	0.000	0.000
Bomarzo	8.7%	348.0	1.03%	0.105	0.124	0.131	0.121
Calcata	69.1%	640.8	1.99%	0.830	0.229	0.256	0.518
Canepina	26.8%	387.3	1.12%	0.322	0.138	0.144	0.219
Canino	0.0%	1.7	0.00%	0.000	0.001	0.001	0.001
Capodimonte	0.0%	2.8	0.01%	0.001	0.001	0.001	0.001
Capranica	77.6%	1,037.0	2.79%	0.932	0.370	0.357	0.615
Caprarola	81.0%	2,799.9	7.80%	0.972	1.000	1.000	0.991
Carbognano	82.5%	2,381.1	6.59%	0.990	0.850	0.845	0.898
Castel Sant'Elia	9.1%	112.5	0.33%	0.109	0.040	0.043	0.072
Castiglione in Tev.	0.1%	2.6	0.01%	0.001	0.001	0.001	0.001
Celleno	0.9%	53.5	0.14%	0.011	0.019	0.018	0.017
Cellere	0.0%	3.1	0.01%	0.000	0.001	0.001	0.001
Civita Castellana	4.4%	62.8	0.20%	0.053	0.022	0.026	0.036
Civitella d'Agliano	0.2%	7.9	0.02%	0.002	0.003	0.003	0.003
Corchiano	57.8%	1,816.7	5.47%	0.693	0.649	0.701	0.681
Fabrica di Roma	70.1%	546.2	1.64%	0.842	0.195	0.210	0.513
Faleria	58.9%	886.7	2.57%	0.707	0.317	0.329	0.486
Farnese	0.1%	10.0	0.03%	0.002	0.004	0.004	0.003
Gallese	35.1%	925.0	2.67%	0.421	0.330	0.342	0.367
Gradoli	0.4%	9.1	0.03%	0.005	0.003	0.003	0.004
Graffignano	1.7%	23.8	0.07%	0.020	0.009	0.009	0.014
Grotte di Castro	0.7%	21.9	0.06%	0.008	0.008	0.008	0.008
Ischia di Castro	0.1%	13.4	0.04%	0.001	0.005	0.005	0.004
Latera	0.0%	0.1	0.00%	0.000	0.000	0.000	0.000
Lubriano	0.0%	0.0	0.00%	0.000	0.000	0.000	0.000
Marta	0.0%	0.5	0.00%	0.000	0.000	0.000	0.000
Montalto di Castro	0.0%	1.0	0.00%	0.000	0.000	0.000	0.000
Montefiascone	0.1%	1.6	0.00%	0.001	0.001	0.001	0.001
Monte Romano	0.0%	0.0	0.00%	0.000	0.000	0.000	0.000
Monterosi	0.6%	1.8	0.01%	0.007	0.001	0.001	0.004
Nepi	9.4%	177.4	0.50%	0.113	0.063	0.065	0.083
Onano	0.0%	0.0	0.00%	0.000	0.000	0.000	0.000
Oriolo Romano	2.5%	9.5	0.03%	0.030	0.003	0.004	0.018
Orte	3.5%	38.7	0.11%	0.042	0.014	0.014	0.027
Piansano	0.2%	10.3	0.03%	0.003	0.004	0.004	0.003
Proceno	0.0%	1.3	0.00%	0.000	0.000	0.000	0.000
Ronciglione	56.0%	1,034.5	3.09%	0.672	0.370	0.396	0.498
Villa S. Giov. in T.	4.1%	58.4	0.18%	0.049	0.021	0.023	0.033
San Lorenzo Nuovo	0.1%	1.2	0.00%	0.001	0.000	0.000	0.001
Soriano nel Cimino	50.2%	857.4	2.53%	0.603	0.306	0.324	0.433
Sutri	34.7%	585.5	1.71%	0.416	0.209	0.219	0.297
Tarquinia	0.0%	0.9	0.00%	0.000	0.000	0.000	0.000
Tessennano	0.0%	0.0	0.00%	0.000	0.000	0.000	0.000
Tuscania	0.0%	2.3	0.01%	0.000	0.001	0.001	0.001
Valentano	0.1%	4.1	0.01%	0.001	0.001	0.001	0.001
Vallerano	55.0%	1,032.3	2.99%	0.660	0.369	0.383	0.490
Vasanello	50.7%	808.7	2.31%	0.609	0.289	0.296	0.425
Vejano	1.9%	29.3	0.09%	0.022	0.010	0.012	0.016
Vetralla	4.7%	85.0	0.25%	0.057	0.030	0.032	0.042
Vignanello	83.3%	1,267.2	3.84%	1.000	0.453	0.492	0.695
Viterbo	1.2%	18.7	0.05%	0.015	0.007	0.007	0.010
Vitorchiano	17.0%	190.0	0.50%	0.204	0.068	0.064	0.129

3.4.3 Olive district identification

Figures 17, 18 and 19 show the cartographic representation of the variables that measure the productive, economic and social dimension (VAL_PRO, VAL_ECO, VAL_EMP) of the olive cultivation in the province of Viterbo.

The cartographic processing of the IND_CRP indicator generated by the combination of the three indicators IND_PRO, IND_ECO, IND_EMP derived from the normalization of the cited variables (table 11), is shown in figure 20. This productive district includes a total of 25 municipalities (the 42% of the total number of the municipalities in the province) and it is the larger among the crop selected.

Figure 17 Productive dimension of olive cultivation (VAL_PRO)

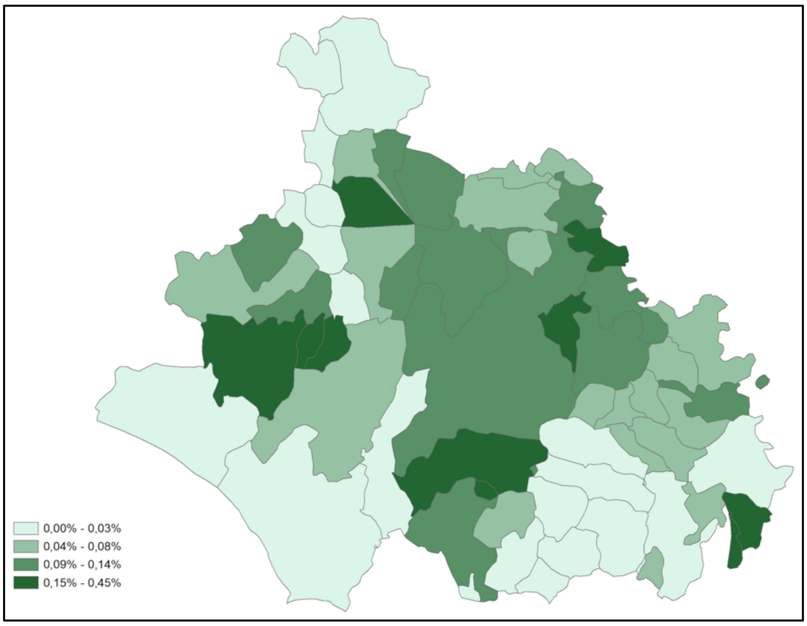


Figure 18 Economic dimension of olive cultivation (VAL_ECO)

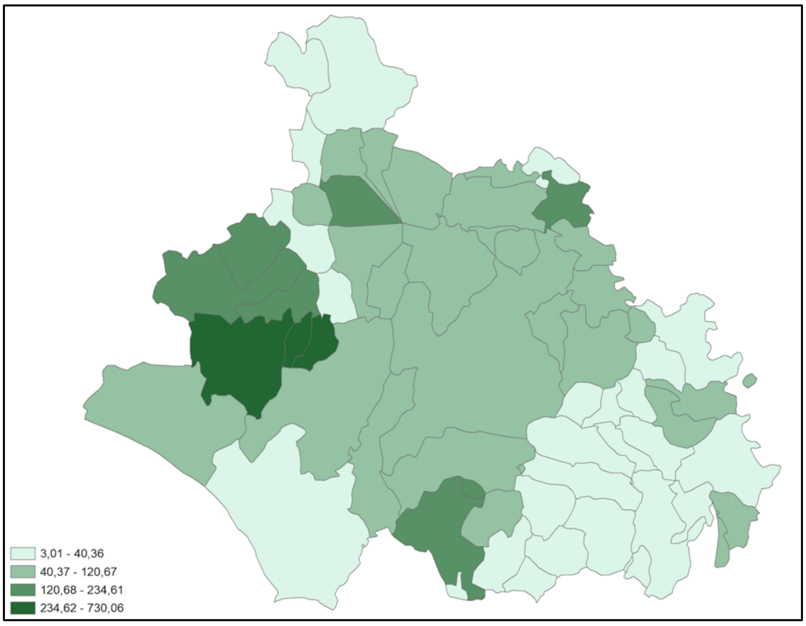


Figure 19 Social dimension of olive cultivation (VAL_EMP)

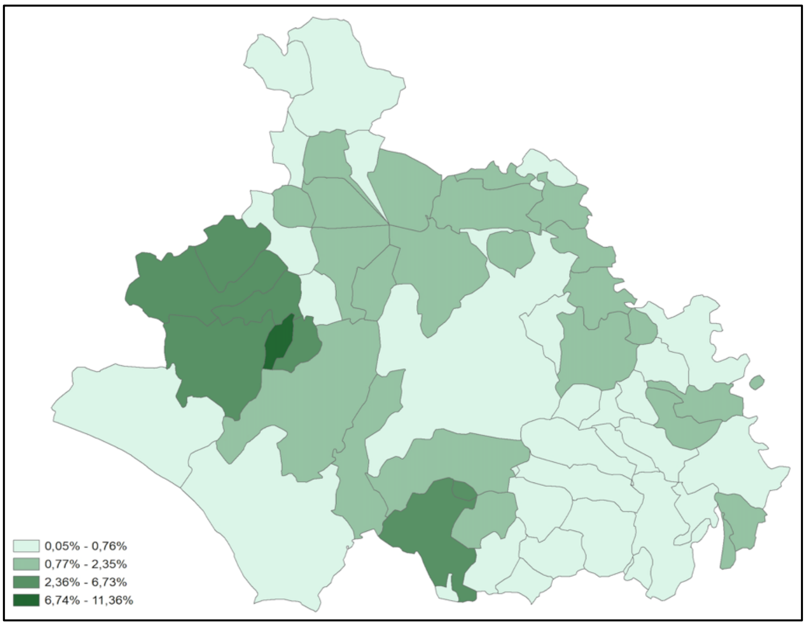
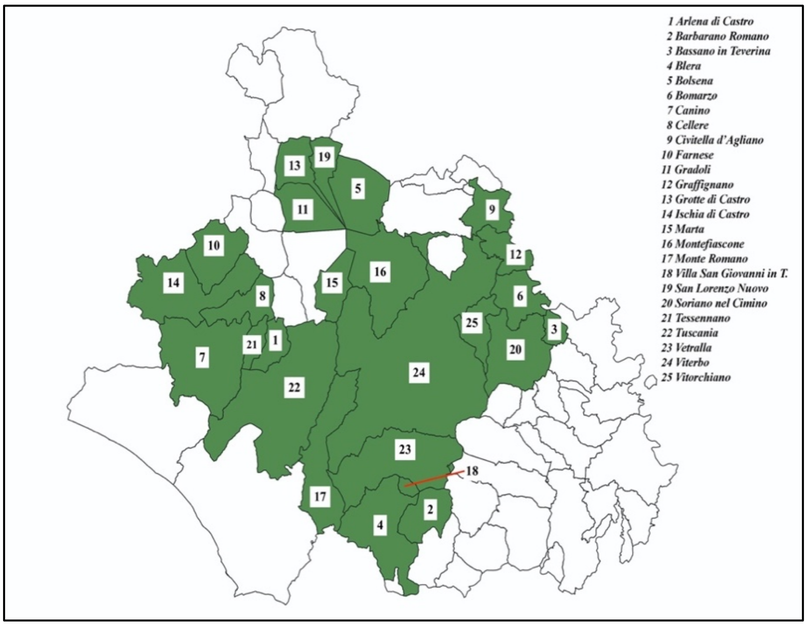


Table 10 Values of variables, indicators and IND_CRP to identify olive district

Municipality	VAL_PRO	VAL_ECO	VAL_EMP	IND_PRO	IND_ECO	IND_EMP	IND_CRP
Acquapendente	1.4%	13.1	0.18%	0.025	0.014	0.012	0.018
Arlena di Castro	19.1%	373.7	5.66%	0.424	0.510	0.496	0.478
Bagnoregio	4.4%	58.5	0.86%	0.093	0.076	0.072	0.081
Barbarano Romano	6.9%	120.7	1.82%	0.148	0.162	0.157	0.156
Bassano Romano	1.8%	4.2	0.07%	0.033	0.002	0.002	0.019
Bassano in Teverina	11.1%	54.3	0.86%	0.243	0.071	0.072	0.152
Blera	9.3%	170.0	2.81%	0.203	0.230	0.244	0.226
Bolsena	14.3%	101.5	1.48%	0.315	0.136	0.127	0.211
Bomarzo	9.2%	101.0	1.57%	0.200	0.135	0.135	0.160
Calcata	21.4%	54.7	0.90%	0.476	0.071	0.075	0.281
Canepina	5.0%	19.9	0.30%	0.106	0.023	0.023	0.064
Canino	19.3%	434.5	6.73%	0.430	0.593	0.590	0.543
Capodimonte	3.7%	64.4	0.96%	0.077	0.084	0.081	0.081
Capranica	1.3%	4.8	0.07%	0.023	0.003	0.002	0.014
Caprarola	1.5%	14.2	0.21%	0.027	0.015	0.014	0.020
Carbognano	4.9%	38.9	0.57%	0.104	0.049	0.046	0.071
Castel Sant'Elia	7.3%	24.8	0.39%	0.157	0.030	0.030	0.094
Castiglione in Tev.	6.3%	40.4	0.58%	0.136	0.051	0.048	0.088
Celleno	4.5%	73.2	1.04%	0.095	0.097	0.088	0.093
Cellere	9.6%	234.6	3.85%	0.211	0.319	0.336	0.294
Civita Castellana	2.7%	10.7	0.18%	0.055	0.011	0.012	0.033
Civitella d'Agliano	11.7%	146.2	2.35%	0.257	0.197	0.204	0.221
Corchiano	7.6%	66.1	1.05%	0.165	0.087	0.089	0.119
Fabrica di Roma	6.8%	14.6	0.23%	0.146	0.016	0.016	0.086
Faleria	18.9%	78.6	1.20%	0.420	0.104	0.102	0.257
Farnese	11.0%	223.2	3.46%	0.242	0.303	0.302	0.284
Gallese	10.7%	77.6	1.18%	0.234	0.103	0.100	0.158
Gradoli	26.5%	157.1	2.35%	0.592	0.212	0.203	0.381
Graffignano	22.3%	88.1	1.42%	0.496	0.117	0.122	0.302
Grotte di Castro	6.9%	61.9	0.90%	0.150	0.081	0.075	0.108
Ischia di Castro	5.6%	175.2	2.80%	0.121	0.237	0.244	0.208
Latera	3.4%	62.3	0.91%	0.071	0.082	0.077	0.076
Lubriano	4.7%	62.7	0.92%	0.100	0.082	0.077	0.087
Marta	14.2%	118.3	1.87%	0.315	0.159	0.161	0.224
Montalto di Castro	2.2%	47.6	0.71%	0.044	0.061	0.058	0.055
Montefiascone	11.8%	83.3	1.22%	0.259	0.110	0.103	0.173
Monte Romano	1.9%	95.4	1.40%	0.035	0.127	0.119	0.103
Monterosi	3.7%	3.2	0.05%	0.077	0.000	0.001	0.045
Nepi	2.0%	10.7	0.16%	0.040	0.011	0.010	0.024
Onano	0.3%	4.1	0.07%	0.000	0.001	0.002	0.002
Oriolo Romano	2.9%	3.0	0.05%	0.059	0.000	0.000	0.034
Orte	3.8%	11.6	0.17%	0.079	0.012	0.011	0.047
Piansano	1.2%	17.1	0.25%	0.022	0.019	0.018	0.020
Proceno	0.5%	26.5	0.33%	0.005	0.032	0.025	0.024
Ronciglione	2.1%	10.7	0.17%	0.041	0.011	0.011	0.025
Villa S. Giov. in T.	44.6%	177.4	2.89%	1.000	0.240	0.251	0.611
San Lorenzo Nuovo	9.4%	50.0	0.74%	0.205	0.065	0.061	0.129
Soriano nel Cimino	12.6%	59.2	0.92%	0.277	0.077	0.077	0.172
Sutri	0.8%	3.7	0.06%	0.011	0.001	0.001	0.007
Tarquinia	0.8%	11.6	0.17%	0.012	0.012	0.011	0.011
Tessennano	19.1%	730.1	11.36%	0.425	1.000	1.000	0.853
Tuscania	4.1%	85.2	1.33%	0.086	0.113	0.113	0.105
Valentano	1.3%	19.6	0.28%	0.023	0.023	0.021	0.022
Vallerano	5.4%	28.1	0.43%	0.116	0.034	0.034	0.072
Vasanello	6.9%	30.4	0.46%	0.149	0.038	0.036	0.091
Vejano	1.4%	6.1	0.10%	0.026	0.004	0.005	0.015
Vetralla	20.5%	101.7	1.58%	0.456	0.136	0.135	0.286
Vignanello	5.9%	24.6	0.39%	0.126	0.030	0.031	0.077
Viterbo	11.2%	47.2	0.71%	0.245	0.061	0.059	0.150
Vitorchiano	17.9%	55.1	0.76%	0.397	0.072	0.063	0.235

Figure 20 Identified olive district



3.4.4 Potato district identification

Figures 21, 22 and 23 show the cartographic elaborations of the indicators that measure the productive, economic and social dimension (IND_PRO, IND_ECO and IND_EMP) of the potato cultivation in the province of Viterbo.

Figure 21 Productive dimension of potato cultivation (VAL_PRO)

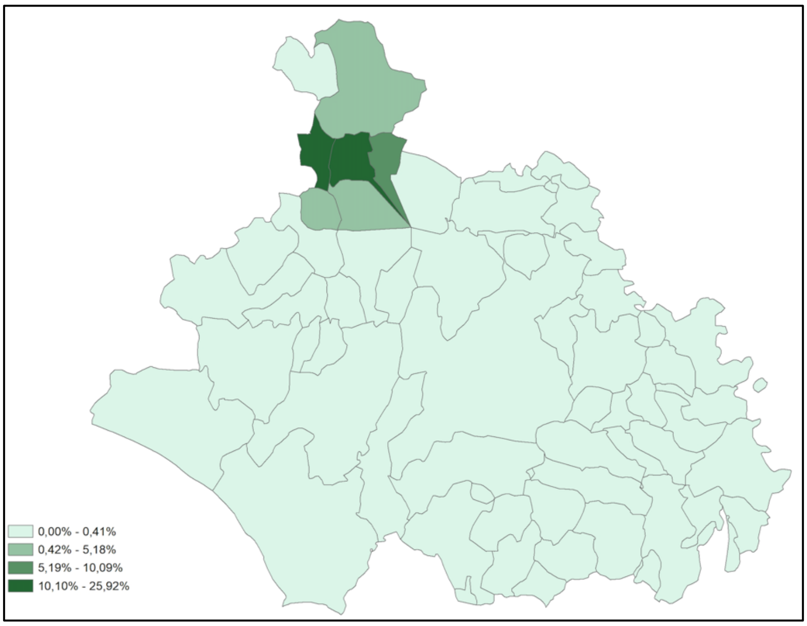


Figure 22 Economic dimension of potato cultivation (VAL_ECO)

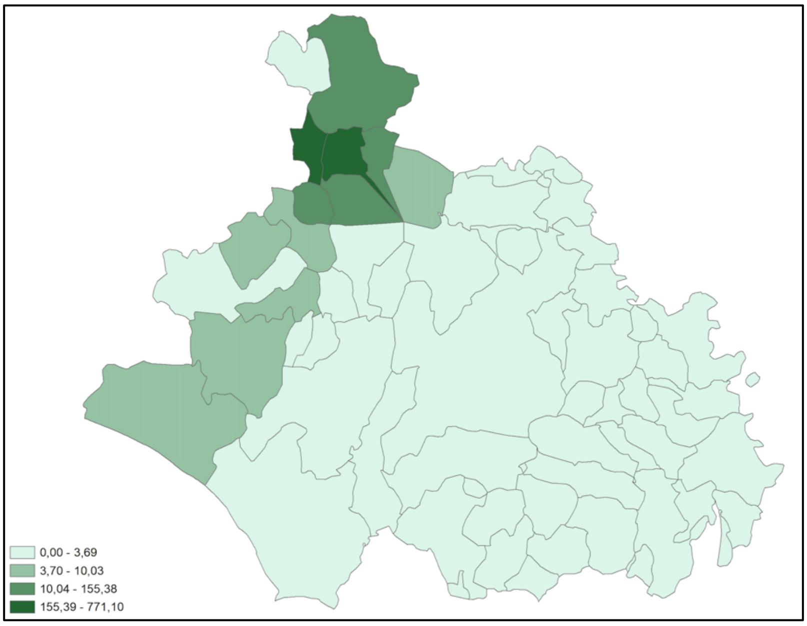


Figure 23 Social dimension of potato cultivation (VAL_EMP)

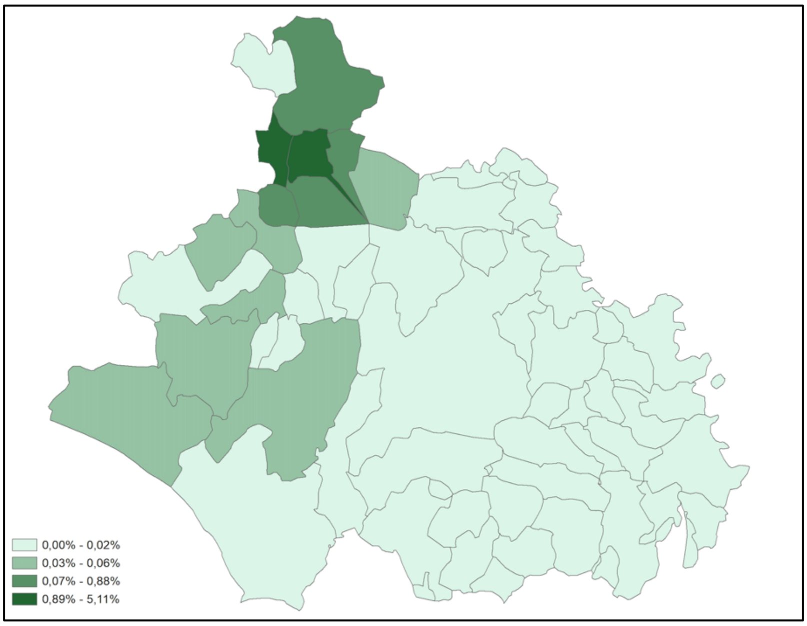
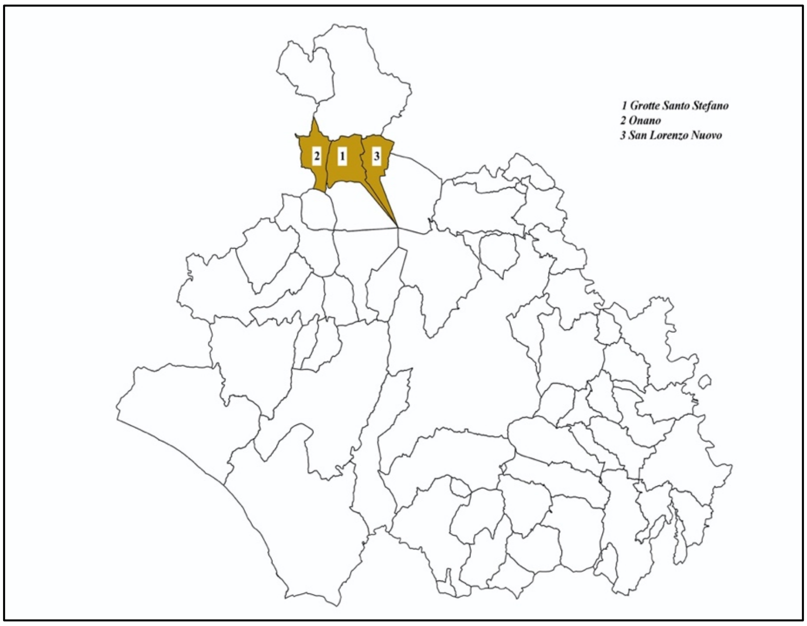


Table 12 Values of variables, indicators and IND_CRP to identify potato district

Municipality	VAL_PRO	VAL_ECO	VAL_EMP	IND_PRO	IND_ECO	IND_EMP	IND_CRP
Acquapendente	3.5%	95.43	0.5%	0.135	0.124	0.100	0.121
Arlena di Castro	0.0%	2.15	0.0%	0.001	0.003	0.002	0.002
Bagnoregio	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Barbarano Romano	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Bassano Romano	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Bassano in Teverina	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Blera	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Bolsena	0.4%	8.38	0.0%	0.016	0.011	0.009	0.012
Bomarzo	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Calcata	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Canepina	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Canino	0.2%	10.03	0.1%	0.006	0.013	0.012	0.011
Capodimonte	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Capranica	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Caprarola	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Carbognano	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Castel Sant'Elia	0.0%	0.01	0.0%	0.000	0.000	0.000	0.000
Castiglione in Tev.	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Celleno	0.0%	0.42	0.0%	0.000	0.001	0.000	0.000
Cellere	0.1%	4.75	0.0%	0.003	0.006	0.006	0.005
Civita Castellana	0.0%	0.23	0.0%	0.001	0.000	0.000	0.001
Civitella d'Agliano	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Corchiano	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Fabrica di Roma	0.4%	2.28	0.0%	0.014	0.003	0.003	0.008
Faleria	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Farnese	0.1%	8.44	0.0%	0.006	0.011	0.010	0.009
Gallese	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Gradoli	5.2%	88.73	0.5%	0.200	0.115	0.099	0.145
Graffignano	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Grotte di Castro	25.9%	667.03	3.7%	1.000	0.865	0.724	0.870
Ischia di Castro	0.0%	0.32	0.0%	0.000	0.000	0.000	0.000
Latera	2.5%	133.58	0.7%	0.098	0.173	0.146	0.142
Lubriano	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Marta	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Montalto di Castro	0.1%	4.09	0.0%	0.003	0.005	0.005	0.004
Montefiascone	0.0%	0.53	0.0%	0.001	0.001	0.001	0.001
Monte Romano	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Monterosi	0.3%	0.84	0.0%	0.013	0.001	0.001	0.007
Nepi	0.1%	1.17	0.0%	0.003	0.002	0.001	0.002
Onano	18.6%	771.10	5.1%	0.719	1.000	1.000	0.916
Oriolo Romano	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Orte	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Piansano	0.0%	0.37	0.0%	0.000	0.000	0.000	0.000
Proceno	0.0%	2.69	0.0%	0.001	0.003	0.003	0.003
Ronciglione	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Villa S. Giov. in T.	0.0%	0.14	0.0%	0.000	0.000	0.000	0.000
San Lorenzo Nuovo	10.1%	155.38	0.9%	0.389	0.201	0.172	0.272
Soriano nel Cimino	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Sutri	0.0%	0.06	0.0%	0.000	0.000	0.000	0.000
Tarquinia	0.0%	1.49	0.0%	0.001	0.002	0.002	0.002
Tessennano	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Tuscania	0.1%	3.69	0.0%	0.002	0.005	0.004	0.004
Valentano	0.2%	7.83	0.0%	0.007	0.010	0.008	0.009
Vallerano	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Vasanello	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Vejano	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Vetralla	0.1%	1.78	0.0%	0.005	0.002	0.002	0.003
Vignanello	0.0%	0.00	0.0%	0.000	0.000	0.000	0.000
Viterbo	0.2%	2.80	0.0%	0.009	0.004	0.003	0.006
Vitorchiano	0.2%	1.78	0.0%	0.008	0.002	0.002	0.005

The cartographic processing of the IND_CRP, which values are reported in the table 12 together with the values of the variables and indicators used for its evaluation, is shown in Figure 24. The territory under analysis includes only 3 municipalities (Grotte di Castro, Onano and San Lorenzo Nuovo), located in the northern area of the province of Viterbo, between the Lake of Bolsena, Umbria and Tuscany regions.

Figure 24 Identified potato district



CHAPTER 4

METHODOLOGICAL APPROACH

4.1 Definition of representative cultivation techniques

Following the identification of the production districts of the selected cultivation in the province, it was evaluated, for each single crop, which could be the "average" production technique used in such district. The knowledge of these techniques, in particular data about yields and typologies and quantities of production factors, will allow to assess the crops sustainability conditions.

For this purpose, a databases were built with the 2014-2017 FADN data (CREA, 2017a), which identified information, such as yield, price and technical coefficients for fertilizers (N,P,K), pesticides, mechanization and labor, for the selected crop. The records of this database report data about the productive process of the crop carried out in the farm included in FADN sample (Table 13).

Table 13 FADN data about selected crop for each farm

Information	Unit of measure
UAA Farm	ha
UAA Crop	ha
UAA Irrigated	ha
Gross Saleable Product per hectare	€/ha
Variable Cost per hectare	€/ha
Gross Margin per hectare	€/ha
Man Hour per hectare	h/ha
Machinery hour per hectare	h/ha
Price of Fertilizers used	€
Quantity of Fertilizers per hectare	quintals
Quantity of N (active substance)	active substance
Quantity of P (active substance)	active substance
Quantity of K (active substance)	active substance
Price of Pesticides used	€
Quantity of Pesticides per hectare	Kg
Cost of Energy per hectare	€/ha
m^3 of irrigation water per hectare	m^3/ha

After a first cleanup of the four databases (one for each selected crop), through the elimination of the wrong values for every single variable taken into consideration, the "average" production process was identified through the application of the compromise programming (CP).

Compromise Programming (CP) is a mathematical programming technique with the capability of handling multiple objectives in those situations where a high level of conflict between criteria does not allow the simultaneous optimization of all the considered objectives (Bilbao-Terol *et al.*, 2006). Through CP it is possible to identify the set of data that allows the definition of the "more representative" production process for each crop. The application of the CP is based on the determination of the so-called "degree of closeness" between the value of a target and its ideal value.

As the database variables are characterized by different unit of measure, to determine the degree of closeness, they have to be standardized. This measure expresses the relationship between the distance of each objective from its ideal and anti-ideal value of the same objective.

This distance can be measured through the following metrics:

$$DIST_1 = D_1 + D_2 + \ldots + D_n \quad where\ D_j = \left(\frac{x - Average_j}{Standard\ Deviation_j}\right)$$

$$DIST_2 = \sqrt{D_1^2 + D_2^2 + \cdots + D_n^2} \qquad where\ D_j = \left(\frac{x - Median_j}{Median_j}\right)$$

Obtained the $DIST_1$ and the $DIST_2$ values for each individual farm, for the identification of the crop production process, were taken into consideration the *k* farms that presented the two distances lower then two pre-defined values:

$$DIST_1 < d_1 \quad and \quad DIST_2 < d_2$$

The values of d_1 and d_2 are chosen for the single crops on the base of the number of farms in the sample and the specific distribution of considered variables.

To identify the representative production process it was calculated the average and the median of the *k* values of all variables and the for each variable a reasoned combination of this two figures was chosen.

The criteria adopted for the selection of d_1 and d_2 will be clarified in the context of the illustration of the individual crops, in the empirical part of the thesis.

4.2 Strong sustainability assessment

As presented in chapter 2, the Ecological Balance (EB) is the indicator able to translate in quantitative terms the level of environmental surplus/deficit of a production activity. EB is evaluated through the difference between the availability of resources on which the productivity of the process can count, the BioCapacity (BC), and the consumption of resources associated with the management of the process itself, measured by the Ecological Footprint (EF).

EB = BIOCAPACITY (BC) – ECOLOGICAL FOOTPRINT (EF)

Both EF and BC are measured in standard units called *global hectares (gha)*. One *gha* represent a standardize hectare with world average productivity (Monfreda, Wackernagel and Deumling, 2004; Galli *et al.*, 2007; Ewing, Reed, *et al.*, 2010; Passeri *et al.*, 2013).

4.2.1 The calculation of Ecological Footprint (EF) and BioCapacity (BC) in agriculture

Introduced by Rees (1992) and developed by Rees and Wackernagel (1994), the Ecological Footprint outlines the regenerative capacity of the planet required for man-made productions and sequester waste, and compares this to the environment available regenerative capacity (Mancini *et al.*, 2015).

The standard methodology for the calculation of the EF proposes the following equation:

$$EF_p = A \times Y_F \times EQF = A \times \frac{Y_n}{Y_w} \times EQF$$

Where:

- A (*Area*) is the used UAA of the crop;
- Y_F is the ratio between the National and World Yields;

- Y_n (*National Yield*) is the national average yield of culture;
- Y_w (*World Yield*) is the average yield for world production a single crop (Galli *et al.*, 2007);
- EQF (*Equivalent Factor*) is the proportionally factor necessary to convert a specific type of land (in this case agricultural) to global hectares (Wackernagel and Rees, 1996b; Monfreda, Wackernagel and Deumling, 2004).

The National Yield (Y_n) can be expressed as a ratio between the national production (P) of the single crop and the respective area dedicated to its cultivation. According to the last definition of Y_n, the EF_p equation can be simplified as follows:

$$EF_p = A \times \frac{(P/A)}{Y_w} \times EQF \Rightarrow EF_p = \frac{P}{Y_w} \times EQF$$

Instead, for the calculation of the BC, the standard methodology proposes the following equation:

$$BC = A \times \frac{Y_n}{Y_w} \times EQF$$

It is evident that the equations of the EF and BC are perfectly analogous, and for this reason the equation of BC can be transformed into:

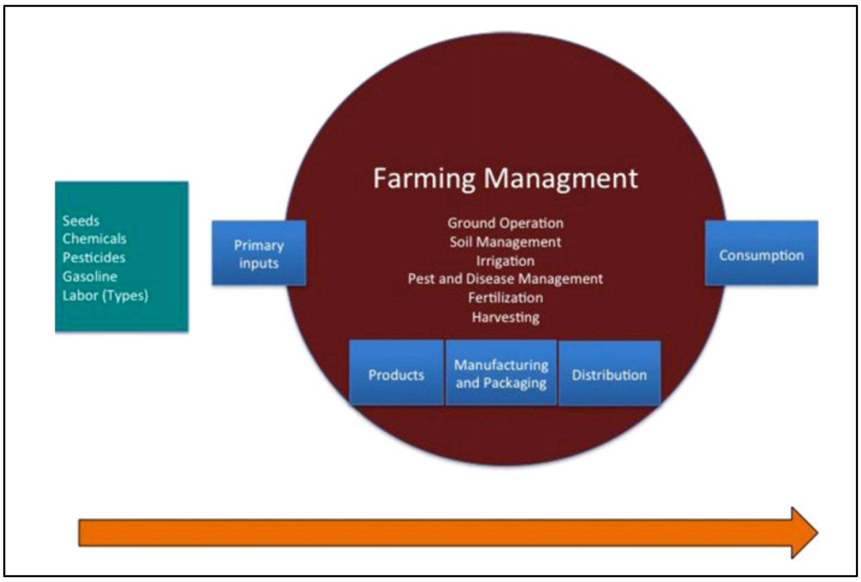
$$BC = \frac{P}{Y_w} * EQF$$

Considering that EQF and Y_w have constant values, it is only the quantity of production (P) that is only factor of calculation of the EF and BC. The equality of the two factors (EQF and Y_w) therefore means that all the crops absorb and supply the same resources to the ecosystem (Mózner, Tabi and Csutora, 2012).

The handicap of the classical methodology is the disregard for the different production techniques, consumption of natural resources and the supply of biocapacity, intrinsic characteristics of the different types of farms and territories, thus proposing a distorted evaluation. This is the reason why the classic method of the EF, in agricultural sector, fails to highlight and measure whether the productive activity involves an excessive exploitation or net generation of natural resources.

To fill this gap and therefore be able to assess the contribution of production technique to the sustainability of agricultural activity, Passeri *et al.* (2013) proposed a modification to the classic ecological footprint methodology. This modification is based on the assumption that the EF of a farm is the result of all the choices made by farmer in management, and in particular those related to the use of inputs for agricultural production activity (Figure 25).

Figure 25 Farming management Schema (Source; Passeri et al., 2013)



Taking into account all the n input factors in the calculation and their impact on the farm, the EF of a production technique ($EF_{farming}$) can be evaluated as the sum of the ecological footprint of each factors ($EF_{ifarming}$)[12]:

$$EF_{farming} = \sum_{i=l}^{n} EF_{ifarming}$$

In addition to the inputs, it is important take into account the balance that exists in the biological cycles and in the rules of the natural system. Through the use of inputs, man can intervene in normal cycles, modifying this balance and increasing the growth of plants

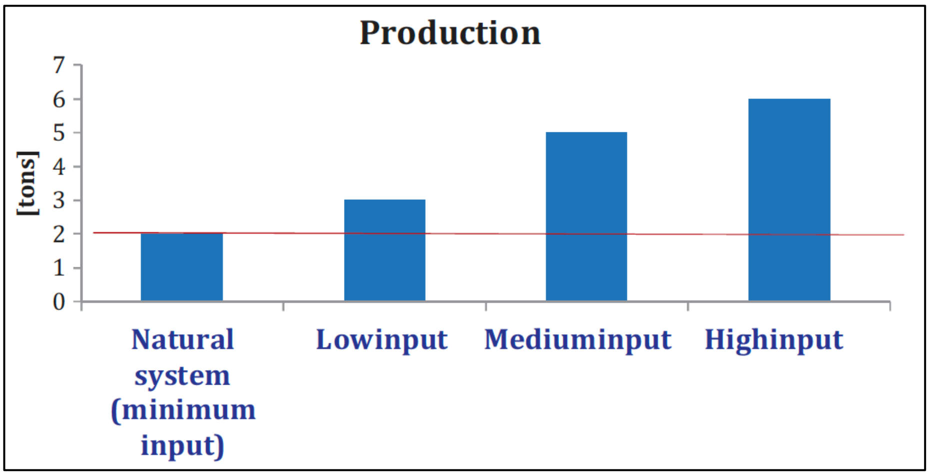
[12] For examples, the diesel used by the tractor in cultivation operations is included in the calculation, and therefore, it is part of the Ecological footprint, the direct emissions related to the use and not the sum of the emissions related to the extraction of oil, its transformation and its use.

and their resistance to pathogens, also modifying production per unit area or the seasonality of the products.

It is obvious that an agricultural system provides the human intervention on natural balances, but to limit the impact of agricultural activity it would be necessary to create a production system that deviates as little as possible form natural biologic cycles (with the minimum use of external inputs).

The system closest to the natural is the one that gets products with the minimum possible use of input (e.g. sowing and subsequent harvesting), and there are increasing production levels in proportion to the greater use of inputs (Figure 26).

Figure 26 Link between production and input levels (Source: Passeri et al., 2013)



Thus it is possible to establish, on the basis of the level of production obtained, how much a production system has been altered by the anthropic intervention functional to the agricultural activity and to express such alteration in terms of increase EF ($EF_{overproduction}$) through the equation:

$$EF_{overproduction} = \alpha \times \left(\frac{P_{farming\ tech\ n}}{Yw} \times EQF\right)$$

where:

$P_{farming\ tech\ n}$ it is the production that results of a certain technique;

α it is the proportionality factor that evaluates the overproduction of the crop compared to that obtainable by the technique with minimum input.

Based on this modification of the methodology, the consumption of natural resources of an agricultural production process (EF_p) is evaluated as:

$$EF_p = EF_{farming} + EF_{overproduction}$$

This equation, which combines the role of agricultural activity within the processes and measures the imbalance of the production system with the natural balances, makes it possible evaluate the farmer's choices.

In the areas affected by the agricultural production process, environmental services are also established, linked to the crops and other bioproductive areas of the farm. To evaluate these services, the BioCapacity (BC) indicator is used in its classical formulation, which allows for each type of soil on which the activities are carried out, to evaluate the supply of ecological services in terms of global hectares. The difference between BC, made available in the farm land, and EF linked to the choices of farmers and the over exploitation of the natural balances, makes it possible to assess the environmental performance of the agricultural processes of a farm and the definition of an Ecological Balance (EB).

$$EB = BC - EF$$

Both indicator expressed in equivalent hectares allow us to define, through a simple difference, the consumption or production of environmental resources of an agricultural production system. EB therefore makes possible to verify the existence of a condition of sustainability or unsustainability with regard to the productive technique of a crop, with respect to the environmental services that the crop itself is able to generate.

4.2.2 FarmSource (FarSo) model

The methodological proposal relating to the calculation of EB, which allows the calculation and assessment of the environmental performance of one or more farm production processes was implemented in 2013 by *Passeri et al.* in the analysis model, *Farm Source model* (*FarSo*).

This model developed in Excel during the research of this doctorate has been update and implemented. Specifically, they were updated the calculation factors Y_F and EQF with the 2018 data of Global Footprint Network (www.footprintnetwork.org). In addition, as regards the implementation of $EF_{Farming}$ calculation, was considered the *Average Forest-Carbon Sequestration* (AFCS). The AFCS is a key parameter in the calculation of the carbon component of EF and measure the "net carbon-sequestration capacity of forest ecosystems" (Mancini *et al.*, 2015). Overall, the study of Mancini et al. (2015) calculated an AFCS value of 0,73 t C ha^{-1} yr^{-1} (Lin *et al.*, 2018), and to convert the tons of carbon into tons carbon dioxide, the percentage of C inside the CO_2 molecule is calculated, through the ratio of the atomic mass[13], obtaining a conversion factor equal to 2,7 t C (t $CO_2)^{-1}$. The value of AFCS expressed in tons of carbon dioxide is 2,68 t CO_2 ha^{-1}. In accordance with above, the summation of the ecological footprint of each of the factors $EF_{ifarming}$ is:

$$EF_p = P \times Y_F \times EQF \times (AFCS)^{-1}$$

This model also allows the economic analysis of the productive process analyzed, through the evaluation of the single crop budget[14], expressed as a gross margin and calculated as the difference between revenue and variable costs.

The technical data sheet of each production process is divided into various section, which takes into account the various inputs and outputs of the crop (Bruni and Franco, 2003):

a. *Mechanization:* this section shows the cultivation operation data, with costs and factors that are the cause of the generation of the environmental impact, in particular fuel and electricity consumption.

b. *Raw material*: in this section all the inputs of the cultivation processes (fertilizers, pesticides, seeds, etc.) and their relative costs are collected. Furthermore, the fertilizers are distinguished between organic and chemical, and for the latter is considered the title of *N* (nitrogen), *P* (phosphorus) and *K* (potassium).

c. *Labor*: in this area are collected the needs for labor in the various periods of the year, taking into account the distinction of the operator's qualification. This distinction is made through the different rates of workers (i.e. machinery driver, skilled work, unskilled work).

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[13] The atomic mass of C is about 12 and of O is 16, then the CO_2 molecule has an atomic mass of 44.
[14] The crop budget takes into account the utilization of all production factors and of all the process involved along the entire cultivation process until the output production. (Blasi *et al.*, 2016).

d. *Economic results*: the spreadsheet processes the gross unitary income derived from the various revenue items (products, by-products, supplements) and the costs of the total worn-out production factors.

e. *CO_2 Emissions*: in this section, having recorded the quantities of raw materials used (see point b), the CO_2 emissions are obtained through the multiplication of the quantities of materials used by their emission coefficient.

f. *Ecological Balance*: this is the section where the use of natural resources expressed in global hectares (EF) is compared in a process with the capacity to provide environmental services (BC) of the same.

g. *Summary*: output section of the results where the economic and environmental data of the processes are reported (figure 27). It is important to underline that for trees and perennial crops it is calculated both the emission and absorption of CO_2 to determine the net GHG flow in the process.

Figure 27 Screenshot of the Summary Section of the implemented excel software

	A	B	C	D	E	F	G	H	I	J
1										
2		**CROP DATA**								
3		Category	Arboree							
4		Name	Sangiovese							
5		Perennial	Yes							
6		Yield (tons/ha)	9,000							
7		Min. input yield (tons/ha)	6,000							
8										
9										
10		**ECONOMIC RESULTS**			**CO_2 BALANCE**			**ECOLOGICAL BALANCE**		
11		Value of production	9.180,00		Energy	1,383		EF Inputs	1,688	
12		Subsidies	0,00		Fertilization	0,453		EF Overproduction	1,013	
13		**Revenues (€)**	**9.180,00**		Other inputs	0,001		**Ecological Footprint (gha**	**2,701**	
14		Mechanization costs	990,23		**Emissions (tons)**	**1,837**				
15		Input costs	308,20							
16		Labour costs	4.597,50		**Absorptions (tons)**	**4,222**		**Biocapacity (gha)**	**3,040**	
17		**Costs (€)**	**5.895,93**							
18		**Gross Margin (€)**	**3.284,07**		**Balance (tons)**	**2,385**		**Balance (gha)**	**0,339**	
19										
20										
21										

4.2.3 EF analysis applied to the transformation, packing and transport phases

For the analysis of the transformation and packing phase, only the vine supply chain, and therefore the wine production, was analyzed. This choice was made to create a basic analysis methodology with the aim of developing a model to analyze other crops in the future.

For the environmental impact assessment, tool such as carbon footprint, water footprint, or, more generally, a Life Cycle Assessment (LCA) approach are often used.

More rarely, procedures based on the calculation of the ecological footprint were adopted; an interesting example based on this approach is represented by the work of Niccolucci *et al.* (2008). In their study the unit considered was the 0,75 l bottle of wine to better allocate the contribution between the winery, packing and distribution phases (Niccolucci *et al.*, 2008) and the energy and the material data have been taken into account for the conversion in bioproductive area in terms of ecological footprint. For each input, the energy intensity coefficient used in the LCA was considered, including all the energy used in their useful life (from production to disposal). Therefore the calculated carbon dioxide productions are not only those directly determined by the mere bottling and distribution operation. Differently from such study and coherently with the EF approach adopted in the assessment on environmental impact of the cultivation, in this analysis only the CO_2 generated in the winery and packing process work and distribution of the bottles wine in considered, excluding the quantity of carbon dioxide generated by the industries for the production of every single material utilized in these processes.

The energy and material data for the winery and packing phases reported by Niccolucci *et al.* (2008) have been take into account for the conversion in bioproductive area in terms of ecological footprint. This "embodied energy" was converted into the correspondent amount of CO_2 emissions, and subsequently calculated the ecological footprint of the winery (EF_{winery}) and packing ($EF_{packing}$) phase. Since the "embodied energy" related to the single bottle, the calculation was carried out on the total of the bottles that can be produced per hectare.

The EF generated during the transport ($EF_{transport}$) of the wine bottle from the farm gate to the consumer was also calculated. Was considered that the road transport takes place on vehicle with a load capacity of 50 cases of wine (6 bottles per pack), with the average consumption of 12 km/l of diesel and a distance of 100 km to be covered.

The total Ecological Footprint of the calculation phases subsequent to the field ones (EF_{tpt}) is equal to:

$$EF_{tpt} = EF_{winery} + EF_{packing} + EF_{transport}$$

4.3 Weak sustainability assessment

The calculation of the weak sustainability condition will be performed only if the analyzed production process is unsustainable in a strong perspective. In this case, the loss of natural capital (Kn), represented by the negative value of the ecological balance (EB), must be compared with the increase in economic capital generated by the cultivation itself.

The methodology used for the economic side of the analysis, and therefore according to the weak sustainability approach, involves the evaluation of the individual crop budgets. These are evaluated in terms of Gross Margin, calculated as the difference between revenues and variable costs. The calculation takes into account the use of all the production factors and all the processes involved along the cultivation process up to the output production. Crop revenues are derived from the value of production, while costs are calculated by multiplying the quantity of each production factor by its price. The latter are assessed separately for each category (raw materials, labor, machinery and / or other costs) and then aggregated to obtain specific crop costs. Subsequently, the revenues, costs and gross margin of each crop are combined to determine the overall economic performance of the agricultural production system at farm level.

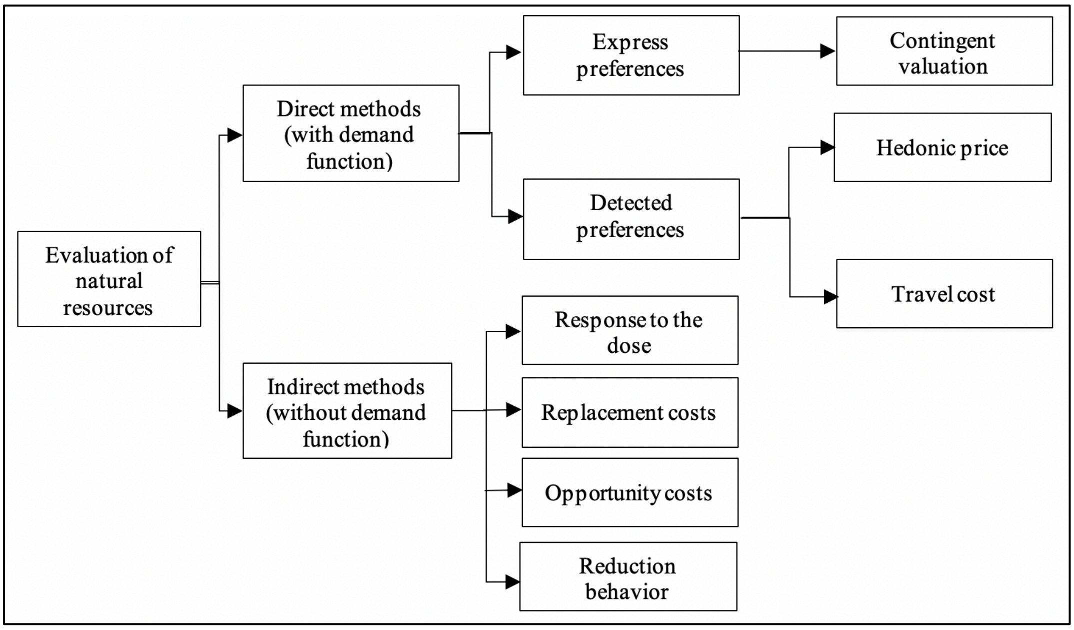
Regarding the evaluation of the loss of Kn it is possible use different methodologies that, in line with the weak sustainability perspective, refer to the neoclassical paradigm (figure 28).

These methodologies follow essentially two types of approaches, the first based on direct methods in which the demand function is reconstructed, the other on indirect methods where a demand function is not used (Franco *et al.*, 2018).

Approaches based on the demand function, resort to the preferences expressed or preferences detected. The *express preferences* are reconstructed with experimental methods which, through targeted interviews, allow to reach a measurement of utility. This measurement allow, in turn, the compilation of a request form for a certain good and through the aggregation of these request forms it is possible find to a demand curve.

The *detected preferences* are instead measured in so-called surrogate market. The usefulness of a good, for example, can be reflected in that of another good, if both are the object of exchange. This can cause phenomena of complementary or trade-off between the demand for one good and that of the other. If one of the two cannot be exchanged on a market, the second may show, in determining the price, the utility effect of the first.

Figure 28 Evaluation methods for environmental economics (Franco *et al.*, 2018)



The measurement techniques used in direct methods are those of contingent valuation, hedonic price and travel cost. The *contingent valuation* is the analytical method that exploits the expressed preferences. Respondents must declare their willingness to pay to avoid a certain degradation phenomenon, or to preserve a certain natural environment. Alternatively, may be request their willingness to receive compensation to accept a certain environmental degradation. *Hedonic price* refers to the surrogate market. It is derived from the market prices of the assets that incorporate it, isolating with statistical regression techniques the contribution of interest provides to the observed price. The analysis of *Travel costs*, on the other hand, determines the value of environmental goods from the expenditure made for their use: for example, the value of a nature reserve can be estimated on the basis of costs incurred for their visit.

The approaches to the evaluation of natural resources conducted with *indirect methods* are based on four different procedures:

- *Response to the dose*: corresponds, for example, to the effects of changes in a pathogen on the health of individuals. In this case it is necessary that the underlying quantitative relationships are known, at physical, chemical and biological level. When this occurs it is possible give a value to the variation of said agent on the basis of the economic effects that induces.
- *Replacement cost*: Reconstruction and estimation of the expenses necessary to support goods produced by man to replace compromised environmental goods and services.
- *Opportunity cost*: The maintenance of the conditions of a certain area, involves the renunciation of the economic benefits of alternative uses.
- *Reduction Behavior*: in the presence of a degrading element, individuals tend to put in place behaviors that have a cost. For example, the installation of acoustic insulation structures to eliminate a source of noise.

As part of this research study, for the calculation of the lost Kn the *opportunity costs* approach was chosen. The value of the Kn loss is obtained adding the economic value associated with the productive function and the monetary value of the ecosystem services provided by the natural capital, as reported in literature (Costanza *et al.*, 1997), both related to the negative value of EB expressed in hectares. Considering that EB is expressed in gha/ha, to obtain the deficit value in hectares and therefore the loss of natural capital, the value of Biocapacity (BC) is used as a conversion factor (Wiedmann and Lenzen, 2006):

The value of the productive function is obtained, in each case study, through the relationship between the market value of the land (€/ha) and the productive life of the cultivation. In the case of the annual crops (where the productive life is one year) as land value it was chosen the amount of the annual rent of a plot of land cultivated with the analyzed crop and located in the territory of analysis.

Summing up the values of the productive function with the values per hectare of the other functions, it possible to estimate the value of the Kn (€/ha). This figure, multiplied by EB (measured in hectares), expresses the monetary value of the loss of Kn.

To verify the existence of a (weak) sustainability condition, such value has to be compared with the gross margin associated to the cultivation, under the hypothesis that this margin is reinvested in the farming system becoming in effect an economic capital.

If this economic capital is greater than the value of the natural capital lost, then the productive process is sustainable, otherwise is not.

CHAPTER 5

RESULTS AND DISCUSSION

This chapter presents the results of the analysis according with the methodology illustrated above. For each individual crop, once the production district has been identified, the production process used for each crop has been determined.

The identification of the single production processes has allowed the calculation of the EF and the related ecological balance EB (strong sustainability evaluation) while their economic evaluation has been used to test the weak sustainability condition.

In the case of vineyard crop, it was also measured the EF related to the product transformation, packing and transport phase in order to expand the sustainability evaluation to the final product (a bottle of wine).

5.1 Grapes and Wine production

5.1.1 Definition of representative technique

In the 14 municipalities that characterize the productive district of the vineyard (Figure 28) are located 58 farms of the FADN database.

Following the defined methodology, $DIST_1$ and $DIST_2$ have been calculated. The threshold assigned to d_1 is 13, while to d_2 is 14. These values were chosen, considering the presence of farms in different areas of the territory, with distinct production techniques, and by observing the distribution of $DIST_1$ and $DIST_2$ (i.e. the "distance" of the production technique compared to the average and median technique) in order to eliminate the production processes very "distant" from the producers average behavior (Table 14). Figures 29 reported in the last row of the table (indicated as “reasoned value”) summarize the representative cultivation technique and are used to evaluate the EF and BC of the production process.

Figure 29 Identify wine districts

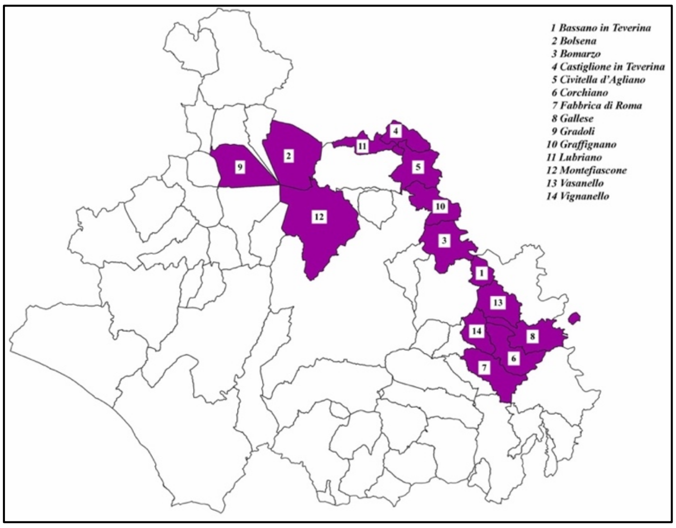


Table 14 Technical data of the identified farms and identification of the production process

Farm	$DIST_1$	$DIST_2$	Man hours (h/ha)	Machine hours (h/ha)	Yield (t/ha)	N (titre)	P (titre)	K (titre)	Fertilizer (q/ha)	PPP[15] (Kg/ha)	Energy (€)
F1	4.9	1.2	291	121	12.4	25	0	0	7.2	26.7	3
F2	4.6	1.2	267	146	13.1	25	10	0	19.7	5.2	0
F3	4.7	1.3	340	121	11.7	20	10	10	4.9	18.4	203
F4	3.7	1.4	451	265	13.3	6	15	15	22.8	51.7	44
F5	4.8	1.4	276	138	11.2	18	46	10	2.8	5.3	0
F6	5.8	1.6	391	87	6.1	20	10	10	2.6	10.6	0
F7	4.4	1.6	451	265	11.5	10	10	8	2.7	17.7	44
F8	4.7	1.6	723	98	14.2	20	10	10	3.2	32.7	98
F9	5.5	1.8	458	141	8.8	15	5	8	2.8	16.4	0
F10	6.5	1.8	106	85	6.0	18	46	0	3.5	19.8	0
F11	4.9	1.9	350	200	6.0	8	20	24	8.0	55.0	0
F12	5.6	1.9	500	25	2.5	34	0	0	2.0	5.8	400
F13	3.8	2.0	731	263	16.4	10	10	9	4.0	23.4	0
F14	4.7	2.0	711	70	16.9	11	22	16	4.9	45.1	0
F15	4.2	2.0	731	263	13.7	7	0	0	5.3	19.9	0
F16	6.9	2.0	121	58	3.8	15	15	20	3.2	3.2	0
F17	5.0	2.1	897	78	14.5	20	10	10	9.8	68.0	0
F18	4.5	2.2	725	287	13.1	7	7	0	2.5	11.7	0
F19	3.7	2.2	750	300	16.4	20	10	10	4.0	30.0	0
F20	5.4	2.6	22	7	17.5	18	46	12	4.2	2.4	28
F21	4.0	2.6	245	157	25.0	6	8	15	1.8	4.1	0
F22	4.4	2.8	828	270	26.2	13	0	46	3.2	66.7	0
F23	3.8	4.1	209	76	10.8	20	10	10	4.1	41.8	62
F24	6.3	4.4	1070	370	11.5	8	7	6	12.6	29.6	185
F25	7.1	4.6	1282	368	34.5	13	0	46	3.3	86.4	0
F26	5.6	5.7	176	60	18.1	7	7	7	0.4	1.5	37
F27	8.2	6.0	1034	517	45.2	3	3	7	2.0	10.4	172
F28	10.6	7.7	989	495	63.0	5	5	5	4.5	97.1	247
F29	12.2	10.8	1267	1167	32.0	14	7	12	9.7	66.0	0
F30	8.1	13.9	493	125	31.7	25	10	0	6.0	75.7	737
Average			563	220	17.6	15	12	11	5.6	31.6	174
Median			475	143	13.5	15	10	10	4.0	21.6	98
Reasoned Value			**300**	**100**	**16,0**	**15**	**10**	**10**	**3.5**	**20,0**	**80**

[15] Plant Protection Product (PPP)

5.1.2 Determination of EF and BC for the production phase

As reported in the methodology, the identified production technique allows to measure the strong sustainability of the process. In this paragraph the results of the analysis of the production phase will be reported.

To determine the EF value, the $EF_{farming}$ and $EF_{overproduction}$ components were calculated and added together. The $EF_{farming}$, as shown in table 15, has a total value of 1.827 gha/ha. Analyzing the data in details of its components, it is the fuel used that has the highest EF value, in fact contributes for about 76% to the formation of the $EF_{farming}$. The other components, on the other hand, stand at a value ranging from 7% to 9%. It is interesting note that in the case of fertilizers, it is nitrogen (N) that has a considerably higher EF on than of phosphorous (P) and potassium (K). And considering the total EF generated by fertilizers, around the 98% is attributable to nitrogen.

Table 15 $EF_{farming}$ of Vineyard per ha

Input	**Quantity**	**Emissions (ton CO_2)**	**AFCS (ha/ton CO_2)**	**YF**	**EQF (gha/wha)**	**EF (gha/ha)**
Fertilizer (N)	53 Kg	1.97E-01	0.376	1.68	1.29	0.158
Fertilizer (P)	35 Kg	2.28E-03	0.376	1.68	1.29	0.002
Fertilizer (K)	35 Kg	1.30E-03	0.376	1.68	1.29	0.001
Other inputs	20 Kg	5.84E-04	0.376	1.68	1.29	0.000
Gasoline	244 Kg	1.74E+00	0.376	1.68	1.29	1.380
Electricity	400 Kwh	1.,60E-01	0.376	1.68	1.29	0.128
Input	**Quantity**	**EF per capita**	**h/year**			**EF (gha/ha)**
Labour	290 h	4.44	8,760			0.147
$EF_{farming}$						**1.827**

For the calculation of the $EF_{overproduction}$, it was considered the average yields P of the vineyard; while the minimum input yield (P_{min}) was evaluated by considering the minimum production values found in the generated database. As reported in Table 16, the $EF_{overproduction}$ is 3.378 gha/ha and its sum with $EF_{farming}$ (1.827 gha/ha), generates an EF_p (ecological footprint of the production phase) equal to 5.205 gha/ha.

By subtracting the EF_p value from the Biocapacity (BC), is obtained the value of the Ecological Balance (EB). The EB value obtained from the production phase is equal to 0.200 gha/ha and, being positive, determines the environmental sustainability of the vineyard production process in the field phase.

Table 16 Calculation of $EF_{overproduction}$, EF, BC and EB for vineyard

P (ton/ha)	16
P_{min} (ton/ha)	6
α	0.625
Y_w (t/ha)	7.46
EQF (gha/ha)	2.52
$EF_{overproduction}$	3.378
$EF_{farming}$	1.827
EF_p (gha/ha)	5.205
BC (gha/ha)	5.405
EB (gha/ha)	0.200

5.1.3 Calculation of the EF, BC and EB of the wine production

The unit considered for the analysis is the 0.75 liter bottle of wine. Considering a 70% wine yield[16] and estimating that only the 70% of the wine produced can be bottled and sold as a quality wine, the total number of bottles (0.75 l) produced per hectare is about 10.400 units (Table 17).

Table 17 Wine production per hectare and relative number of bottles for Sangiovese and Trebbiano

	Unit	Figure
Vineyards	*ha*	1
Yield of grape	*ton/ha*	16
Annual yields of wine	*l/ha*	7,840
Bottle	*l*	0.75
Bottle per ha	*n/ha*	10,400

The analysis applied to the winery, packing and transport phases (Tables 18) shown an Ecological Footprint (EF_{tpt}) of 0.724 gha/ha. Of the three components considered,

[16] The 70% yield means that every 100 quintals of grapes, the wine produced will be equal to 70 hectoliters.

transport has the greatest weight (about 86%) on the total value, while winery and packing phases account respectively for about 9% and 5%.

Table 18 Calculation of EF of winery, packing and transport phases

	MJ	**ton CO_2**	**AFCS (ha/ton CO_2)**	**YF**	**EQF (gha/wha)**	**EF (gha/ha)**
Winery	2.60E+02	2.89E-02	0.376	1.68	1.29	0.063
Packing	4.22E+02	4.68E-02	0.376	1.68	1.29	0.038
Transport[17]		7.07E-01	0.376	1.68	1.29	0.623
Tot. EF_{tpt}						**0.724**

As shown in table 19, the sum of the EF values relating to the cultivation of the vineyard, and the production and transport of the wines is 5.929 gha/ha. The difference between BC and EF provides the value of the EB that, when negative, reports an ecological deficit indicating an environmentally unsustainable process.

In the analysis, the EB value of the total wine production process is -0.524 gha/ha, determining an environmental unsustainability.

Table 19 Summary table of the EF, BC and EB (gha/ha)

EF_p	**5.205**
EF_{tpt}	0.724
EF	5.929
BC	5.405
EB	-0.524

5.1.4 Economic result of the wines productions

The economic results of the production, transformation and distribution phases where calculated by evaluating the gross margin as the difference between revenues and costs (Table 20).

[17] The ton of CO_2 have been calculated considering a distance of 100 km, a maximum load per trip of 50 cases of wine (6 bottle per cases), and an average consumption of the transport vehicle of 12 km/l. All bottles are transported through 35 trips (3,467 km in total).

Table 20 Calculation of Gross Margin of the wine production activity (data per ha)

	Grapes product (ton)	16
	n. of bottle per ha	10,400
	Average bottle price (€)	5
	Revenues (€)	***52,000***
Field phase	Mechanization	1,265
	Raw material	330
	Labor	4,100
	Vineyard depreciation	800
	Costs (€)	***6,495***
Transformation and transport phase[18]	Winery phase	5,824
	Packing phase	19,760
	Transport phase	419
	Costs (€)	***26,003***
	Total Costs (€)	**32,498**
	Gross Margin (€)	**19,502**

Assuming an average sales price of the bottle of wine of 5.00 €, the revenues generated are equal to 52,000 €/ha. The total costs incurred in the field phase and in the subsequent processes, up to the transport phase of all the bottles of wine, amount to about 32,500 €/ha. The costs related to the field phase (about 6,500 €/ha) are only the 20% of the total costs incurred, while the remaining 80% (about 26,000 €/ha) are attributable to the transformation and transport phase.

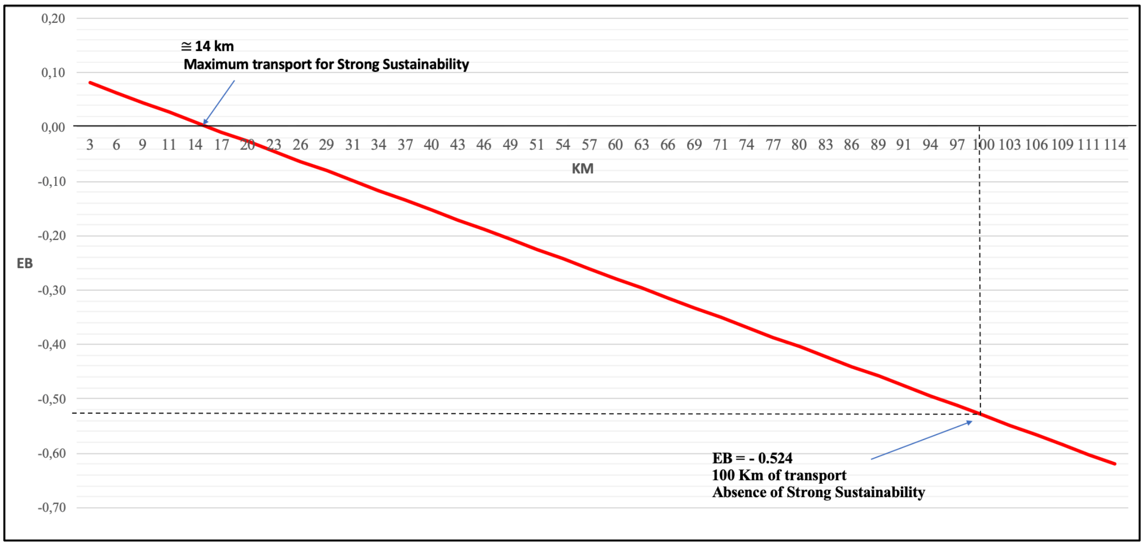
5.1.5 Comparison of economic and environmental results

In a strong sustainable perspective, the value of ecological footprint is greater than the biocapacity, which allow stating that all the process of wine production is not environmentally sustainable. Analyzing the various phases of production from the field to the sales, the value of the EB remains positive up until the transport phase. In fact, the EF generated by the transport of all the bottles, considering a distance of 100 km, is equal to 0.623 gha/ha, a figure that raises the total EF value by 11%.

[18] The costs of the winery and packing phases are taken from the study of UNICESV (University Research Center for Competitive Development in the Wine Sector) of the University of Florence (www.verifywine.it).

Being the transport phase that can determines the strong sustainability or unsustainability of the process, it has been calculated what is the maximum distance, in terms of km, which allows the whole process to be environmentally sustainable. From the analysis carried out by simulating the evolution of the EB on the basis of the km carried out for the transport of all the bottles (figure 30), it is possible deduce that the maximum distance available to remain in a strong sustainability limit is around 14 km. It means that, in order to be able to transport all the bottles wine, in a sustainable manner, the transport range must be reduced of about the 86%.

Figure 30 Maximum transport (Km) of the wine which determine Strong Sustainability



The weak sustainability approach requires to verify if the loss of natural capital, associated to the EB deficit, is “replaceable” by the economic capital created by the production activity. Given that the EB deficit occurred in the transport phase, the comparison of the economic and the environmental results was made considering the entire wine production process and the loss of natural capital per hectare of vineyard.

Tables 21 shows the calculation and the results of the productive, biological and recreational function of the natural capital involved in the cultivation. The average land value, in the identifies area, is of 20,000 €/ha (CREA, 2017) and, considering a productive life of a vineyard of 25 years, the value per hectare of productive function is 800 €. The other functions of the natural capital are the biological one (pollination and biological control) and recreational, whose value are considered as estimated by Costanza et al. (1997). Basing on these data, the value of the Kn is 895 €/ha.

Table 21 Calculation of the loss of Natural Capital (Kn) for one hectare of vineyard

	Ecosystem services	**€/ha**
Productive function		800
Biological function[19]	Pollination	13
	Biological control	22
Recreational function[19]	Recreation	60
Value of Kn		895

Table 22 explains the evaluation of the value of Kn loss associated to the negative value of the ecological balance of the wine production (EB=-0.524). This value, after being converted using BC, was multiplied by the value of Kn to obtain the monetary amount of natural capital loss.

Table 22 Calculation of the value Loss Kn of vineyard

	EB (gha/ha)	**BC (gha/ha)**	**Loss of Kn (ha/ha)**	**Value of Kn (€/ha)**	**Value of loss of Kn (€)**
Vineyard	-0.524	5.405	-0,097	895	87

If the value of the loss of Kn (87 €/ha) is compared with the gross margin generated by the sale of all the bottles produced (19,502 €/ha), emerges that the economic performance is largely able to guarantee the full compensation of the ecological deficit.

In this case, if the transport phase is also considered, the entire production process is unsustainable from a strong sustainability point of view; but, at the same time, it is sustainable according to the principle of weak sustainability.

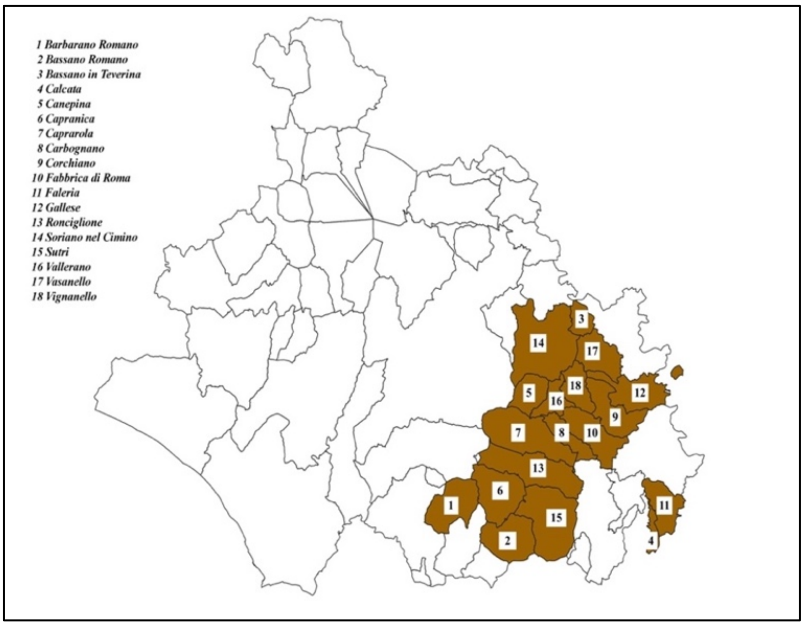
[19] Source Costanza *et al.* (1997)

5.2 Hazelnut production

5.2.1 Definition of representative technique

In the 18 municipalities that characterize the productive district of the hazelnut (Figure 31) there is a total of 175 farms surveyed by FADN.

Figure 31 Identify Hazelnut districts



For these farms, according to the methodology, $DIST_1$ and $DIST_2$ have been calculated. The threshold assigned to d_1 is 5, while to d_2 is 4.5.. These values were chosen by observing the distribution of $DIST_1$ and $DIST_2$ (i.e. the "distance" of the production technique compared to the average and median technique) in order to eliminate the processes very "distant" from the average behavior of the producers in the area.

This choice involved the identification of a total of 67 farms, which, according to their production techniques, were distinguished in two groups. The first group, which includes 17 farms, is characterized by a production process that uses compost for soil fertilization and does not provide irrigation of the crop (Table 23), while the second (50 farms) is characterized by a production process that uses "chemical" products for fertilization and provide the irrigation of the crop (Table 24). To facilitate the discussion, the first group will be called "*Compost and not irrigated Farm"* and the second "*NPK and irrigated Farm"*.

Table 23 Technical data of the "Compost and not irrigated Farm" group

Farm	DIST₁	DIST₂	Man hours (h/ha)	Machine hours (h/ha)	Yield (t/ha)	Compost (q/ha)	PPP[20] (Kg/ha)	Energy (€))
F1	3.5	1.7	80	24	15.2	3.2	0.0	11
F2	4.1	1.9	136	40	11.9	32.8	0.0	0
F3	4.5	1.9	8	8	20.2	8.0	8.5	90
F4	3.0	2.0	187	58	25.0	2.5	0.0	33
F5	5.0	2.0	7	7	13.5	5.9	5.3	61
F6	3.9	2.0	179	56	24.0	3.2	4.0	36
F7	2.1	2.1	132	19	14.8	4.7	0.0	73
F8	4.5	2.3	299	37	12.2	1.4	0.0	82
F9	4.1	2.3	5	5	19.5	9.1	6.5	137
F10	3.4	2.4	207	34	27.2	5.4	0.0	44
F11	3.8	2.5	293	117	22.5	0.4	2.2	147
F12	3.4	2.5	267	47	23.3	10.8	6.2	60
F13	4.8	2.7	300	150	25.0	5.0	25.0	0
F14	3.4	2.7	119	40	45.2	7.0	0.0	0
F15	3.6	2.8	200	40	27.0	2.5	0.8	0
F16	4.6	3.3	100	40	14.4	2.6	18.0	400
F17	4.9	3.7	3	3	22.2	18.8	6.3	29
Average			148	43	21.4	7.3	8.3	71
Median			136	40	22.2	5.0	6.3	44
Reasoned Value			**135**	**40**	**19.0**	**3.5**	**8.0**	**50**

Table 24 Technical data of "NPK and irrigated Farm" group

Farm	DIST₁	DIST₂	Man hours (h/ha)	Machine hours (h/ha)	Yield (t/ha)	N (titre)	P (titre)	K (titre)	Fertilizer (q/ha)	PPP[20] (Kg/ha)	Energy (€))	Water (m^3/ha)
F1	2.7	0.9	94	9	12.0	20	0	0	0.92	0.0	0	0
F2	4.0	1.0	68	13	16.8	35	0	0	5.00	5.0	125	82
F3	3.8	1.0	92	9	10.3	20	10	0	6.83	17.9	49	1
F4	3.1	1.0	81	81	22.0	0	20	10	3.69	4.1	167	1
F5	2.8	1.0	125	9	11.3	18	46	0	2.08	7.1	0	0
F6	3.3	1.2	55	55	21.9	20	10	10	1.83	1.8	293	1
F7	3.5	1.3	54	54	20.7	20	10	0	2.19	0.0	274	3
F8	1.7	1.4	49	39	24.4	25	15	10	7.61	0.0	209	5
F9	4.3	1.4	44	26	22.9	15	15	20	3.46	5.2	57	0
F10	4.4	1.4	51	28	17.5	20	10	10	1.45	1.4	19	0
F11	3.7	1.4	61	28	18.2	25	10	0	0.74	0.4	0	0
F12	3.4	1.5	105	105	22.1	0	20	10	1.25	1.7	219	1
F13	3.6	1.5	163	50	21.3	20	10	10	6.12	9.1	213	0
F14	1.9	1.5	78	39	22.4	25	15	10	8.30	0.0	139	85
F15	4.0	1.6	65	65	12.6	0	10	5	1.95	2.2	141	0
F16	4.1	1.6	163	63	21.3	15	5	8	2.83	1.1	88	0
F17	5.0	1.6	49	49	9.3	0	20	15	1.37	1.5	177	0
F18	5.0	1.7	93	55	15.9	20	10	10	3.13	0.0	0	0
F19	4.6	1.7	142	14	19.1	25	10	0	4.57	0.0	0	1
F20	3.8	1.7	136	104	16.3	15	35	10	5.22	0.0	161	40
F21	4.6	1.7	61	17	20.0	22	10	5	0.93	0.0	32	0
F22	3.2	1.7	43	19	30.0	25	15	0	5.91	9.5	37	49
F23	4.5	1.8	43	43	13.7	20	10	0	1.90	0.0	174	0
F24	4.2	1.8	114	42	21.1	20	10	10	5.95	7.6	542	134
F25	3.7	1.8	252	7	22.1	20	10	10	5.03	1.0	101	72
F26	4.3	1.8	52	33	24.8	18	46	12	17.03	4.3	356	0

[20] Plant Protection Product (PPP)

F27	3.8	1.8	81	11	9.6	25	10	0	0.56	0.0	63	0
F28	4.8	1.9	80	80	23.1	20	10	10	2.28	2.7	268	8
F29	5.0	1.9	38	38	12.8	20	10	0	2.30	0.0	0	0
F30	4.7	2.0	181	48	28.6	18	46	0	4.69	5.3	263	82
F31	4.7	2.0	190	82	35.2	20	10	10	1.27	1.8	101	0
F32	4.2	2.0	22	22	35.0	20	10	0	1.56	1.4	341	2
F33	2.8	2.1	231	77	23.7	20	10	10	5.15	0.0	134	40
F34	4.5	2.1	60	43	15.4	15	6	2	5.31	1.3	57	0
F35	4.0	2.1	52	52	34.2	20	10	10	1.81	1.3	203	1
F36	2.6	2.2	32	32	24.5	20	10	0	0.27	3.7	290	1
F37	4.1	2.2	231	77	20.6	20	10	10	4.94	18.5	82	2
F38	3.3	2.3	84	30	22.0	20	10	10	1.54	9.7	32	0
F39	4.4	2.3	239	78	28.8	20	10	10	4.84	7.2	132	30
F40	4.8	2.4	114	18	26.0	20	10	10	1.04	0.0	25	0
F41	4.9	2.4	197	20	42.9	13	0	46	3.52	4.1	290	0
F42	4.9	2.5	100	27	23.0	25	15	0	4.55	5.3	14	0
F43	3.3	2.8	150	90	23.2	10	0	0	5.39	0.0	1220	789
F44	3.7	2.8	93	58	12.6	0	20	10	0.59	8.7	220	0
F45	2.0	3.1	149	90	23.0	25	0	0	1.35	23.0	33	568
F46	4.4	3.3	309	103	25.7	22	12	18	0.62	6.2	200	34
F47	4.4	3.4	150	16	14.8	15	5	5	3.16	2.7	37	0
F48	3.4	4.0	234	121	26.0	20	10	10	4.37	21.6	296	1
F49	4.7	4.0	80	26	22.3	27	0	0	3.00	4.5	42	0
F50	4.7	4.4	226	136	27.3	22	13	8	1.25	8.6	333	37
Average			113	49	21.4	18	13	7	3.5	6.1	165	71
Median			93	43	22.0	20	10	10	2.9	4.4	133	5
Reasoned Value			**110**	**50**	**21.7**	**20**	**10**	**10**	**3.5**	**5.5**	**160**	**71**

5.2.2 Determination of EF and BC for the production phase

Tables 25 and 26 show the $EF_{farming}$ of the two representative farms. The "*Compost and not irrigated Farm"* has an $EF_{farming}$ lower (0.710 gha/ha) than the other one (1.465 gha/ha). In both typologies of process, the greatest contribution to the EF final value is provided by the fuel consumption. In fact, in the case of the "*NPK and irrigated farm*", the EF of the fuel used is equal to 63% of the total EF, while in the other farm it is equal to 57%. Furthermore, the use of "less natural" fertilization products leads to a clear increase in the $EF_{farming}$ of about 15%; the contribution to this process is mainly given by nitrogen (N), which determines about the 99% of the EF resulting from the fertilization.

Table 25 $EF_{farming}$ of "Compost and not irrigated Farm"

Input	Quantity	Emissions (ton CO_2)	AFCS (ha/ton CO_2)	YF	EQF (gha/wha)	EF (gha/ha)
Compost	700 Kg	5.60E-03	0.376	1.68	1.29	0.0045
Other inputs	8 Kg	2.33E-04	0.376	1.68	1.29	0.0002
Gasoline	219 Kg	6.94E-01	0.376	1.68	1.29	0.5563
Electricity	250 Kwh	1.00E-01	0.376	1.68	1.29	0.0801
Input	**Quantity**	**EF per capita**	**h/year**			**EF (gha)**
Labour	135 h	4.44	8,760			0.0684
Tot. $EF_{farming}$						**0.7095**

Table 26 $EF_{farming}$ of "NPK and irrigated Farm"

Input	Quantity	Emissions (ton CO_2)	AFCS (ha/ton CO_2)	YF	EQF (gha/wha)	EF (gha/ha)
Fertilizer (N)	74 Kg	2.78E-01	0.376	1.68	1.29	0.2224
Fertilizer (P)	37 Kg	2.41E-03	0.376	1.68	1.29	0.0019
Fertilizer (K)	37 Kg	1.37E-03	0.376	1.68	1.29	0.0011
Other inputs	7 Kg	1.93E-04	0.376	1.68	1.29	0.0002
Gasoline	365 Kg	1.16E+00	0.376	1.68	1.29	0.9272
Electricity	800 Kwh	3.20E-01	0.376	1.68	1.29	0.2564
Input	**Quantity**	**EF per capita**	**h/year**			**EF (gha)**
Labour	110 h	4.44	8,760			0.0558
Tot. $EF_{farming}$						**1.4650**

For the calculation of the $EF_{overproduction}$ (Table 27), was considered the average yields P of the two types of farms considered; while the minimum input yield of (P_{min}) was defined through an interview with an expert in the hazelnut sector. The $EF_{overproduction}$ of the "*Compost and no irrigated Farm"* is 3.207 gha/ha, while for the others farms considered is 5.040 gha/ha.

Table 27 Calculation of $EF_{overproduction}$, EF_p, BC and EB for the two types of hazelnut farms being analyzed

	"Compost and not irrigated Farm"	**"NPK and irrigated Farm"**
P (ton/ha)	1.900	2.700
P_{min} (ton/ha)	0.500	0.500
α	0.737	0.815
Y_w (t/ha)	1.100	1.100
EQF (gha/ha)	2.520	2.520
$EF_{overproduction}$	3.207	5.040
$EF_{farming}$	0.710	1.465
EF_p (gha/ha)	3.917	6.505
BC (gha/ha)	4.353	6.185
EB (gha/ha)	0.436	-0.320

As presumable, the highest value of EF_p ($EP_{farming}$+ $EF_{overproduction}$) is found on the farms that use chemical fertilization methods with accurate input of NPK and with crop irrigation (6.505 gha/ha), while for the other farm the value is lower by 2.588 gha/ha. The

EB obtained from the difference between BC and EF_p shows two level of (strong) sustainability, one positive and the other negative. The negative value, although slightly below zero (-0.320 gha/ha), determines an environmental unsustainability for the farms that provide to irrigate the crop and fertilize it with chemicals. In the case of "*Compost and no irrigated Farm",* there is an environmental sustainability of the process, with a positive value of EB equal to 0.436 gha/ha.

5.2.3 Economic result of the hazelnut production

Table 28 shows the economic results of the two types of farms taken into consideration. The hazelnut "*NPK and irrigated Farm*" has a better economic performance, with a Gross Margin of about 6,000 € per hectare. Instead, the other farm considered has a Gross Margin lower by about 2,500 €/ha, mainly due to a lower yield (1.90 ton/ha with respect to 2.70 ton/ha). The variable costs of the two different production process are lower than 220 €/ha in the *"Compost and no irrigated Farm"*.

Table 28 Calculation of Gross Margin of the hazelnut cultivation process (data €/ha)

	"Compost and not irrigated Farms"	**"NPK and irrigated Farms"**
Product (ton)	1.90	2.70
Price (€/t)	3210	3270
Revenues (€)	**6,099**	**8,829**
Fertilizer	315	296
Pesticides	200	244
Fuel	346	577
Water	0	101
Labour	1,905	1,600
Other costs	101	267
Variable Costs (€)	**2,867**	**3,085**
Gross Margin (€)	**3,232**	**5,744**

Going into the details of the items collected in table 28, it is possible understand what are the elements that determine this inequality in the costs. In both analyzed cases, fertilizers and pesticides have a fairly similar percentage weight on the total variable costs (10% for the former and 7% for the latter). Leaving aside the cost of water, which is obviously present only in the farms that provide for irrigation of the crop, it is the labour that represents more than half of the variable costs. In fact, in the case of the *"Compost and no irrigated Farm"* the labour cost is equal to 1,905 €/ha, about 300 € higher than the other typology of farms identified.

5.2.4 Comparison of economic and environmental results

In a strong sustainability perspective, the production process that involves the non-irrigation of the hazelnuts and the use of compost for the soil fertilization is environmentally sustainable (EB of +0.440 gha/ha), while the more intensive production process, with an EB of -0.319 gha/ha, is environmentally unsustainable.

The Gross Margin, on the other hand, in the both case studies have positive values, and for the comparison of economic and environmental results, it has to be taken into consideration only the "*NPK and irrigated Farm"* because it is unsustainable from a strong point of view.

The weak sustainability approach requires to verify if the loss of Kn, associated to the EB deficit, is "replaceable" by the economic capital created by the production activity. Tables 29 and 30 show the calculation and the results of the productive, biological and recreational function of the natural capital involved in the cultivation. The land value of the hazelnut in the identifies area, following an interview with experts in the sector, is about 70,000 €/ha and, considering a productive life of a hazelnut orchard of 40 years, the value per hectare of productive function is 1,750 €. The other functions of the Kn are the biological one (pollination and biological control) and recreational, which have to be added to the previously calculated productive function to identify the monetary value per hectare of Kn (Table 28).

Table 29 Calculation of the loss of Natural Capital (Kn) for each hectare of hazelnut grove

	Ecosystem services	€/ha
Productive function		1,750
Biological function[21]	**Pollination**	13
	Biological control	22
Recreational function[19]	**Recreation**	60
Loss of Kn		**1,845**

[21] Source Costanza *et al.* (1997)

Table 30 Calculation of the value of Kn Loss in hazelnut "NPK and irrigated farm"

EB (gha/ha)	BC (gha/ha)	Loss of Kn (ha/ha)	Value of Kn (€/ha)	Value of loss of Kn (€/ha)
-0.320	6.185	-0.052	1,845	-95

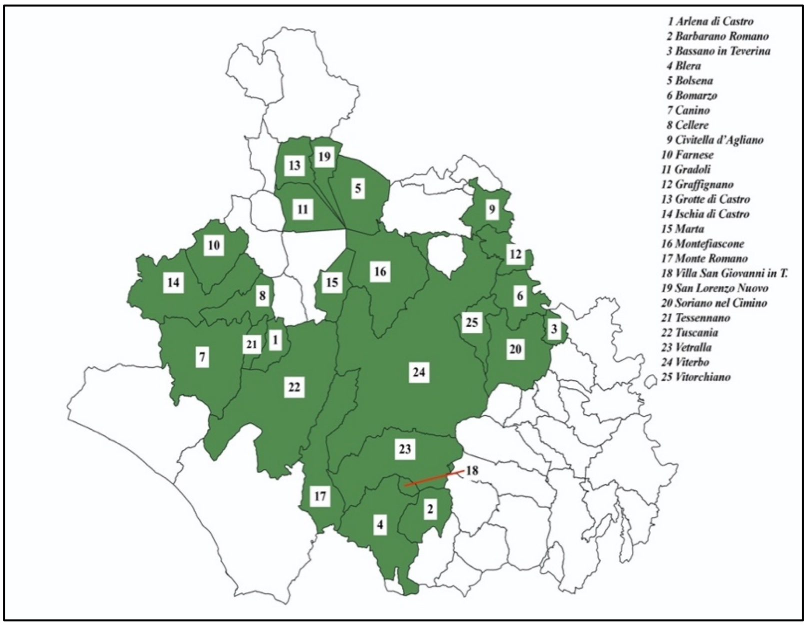
Comparing the loss of Kn value (95 €/ha), with the Gross Margin of the "NPK and irrigated Farms" (3,232 €/ha), emerge that the economic performance is largely able to guarantees a full compensation for the ecological deficit, considered as a loss of natural capital. This condition states the weak sustainability of the process.

5.3 Olive production

5.3.1 Definition of representative technique

In the 25 municipalities that characterize the olive productive district (Figure 32), the FADN database reports a total of 114 farms; for these farm, according to the methodology adopted, the two indicators $DIST_1$ and $DIST_2$ have been calculated.

Figure 32 Identified olive district



The threshold value assigned to $DIST_1$ is 5, while to $DIST_2$ is 2. These values were chosen, considering the many observations and the presence of the companies throughout the territory, with distinct production techniques, and by observing the distribution of $DIST_1$ and $DIST_2$ (i.e. the "distance" of the production technique compared to the average and median technique) in order to eliminate the production processes very "distant" from the average behavior of the producers in the area.

This choice led to the selection of 15 farms (table 31), through which the olives production process could be identified. The identified production process (reported in the last row of table 31) involves a low use of fertilizers and does not present activities that involve energy expenditure and water consumption due to irrigation.

Table 31 Technical data of the identified farms and identification of the production process

Farm	$DIST_1$	$DIST_2$	Man hours (h/ha)	Machine hours (h/ha)	Yield (t/ha)	N (titre)	P (titre)	K (titre)	Fertilizer (q/ha)	PPP[22] (Kg/ha)
F1	1.8	0.7	148	58	29.7	18	46	10	1.2	7.2
F2	2.5	0.7	93	59	30.9	47	10	10	2.7	7.7
F3	3.7	1.0	202	51	33.7	20	10	10	1.8	0.0
F4	3.8	1.0	106	25	25.9	18	46	0	2.2	9.5
F5	3.2	1.0	113	30	33.0	36	0	0	3.3	9.5
F6	4.9	1.1	71	53	22.4	18	46	0	2.3	6.5
F7	3.8	1.1	93	46	26.2	34	0	0	1.5	9.8
F8	4.2	1.2	67	50	29.4	0	0	0	0.0	4.2
F9	3.6	1.3	101	50	29.4	18	46	0	1.2	5.9
F10	4.9	1.3	96	58	19.2	0	0	0	0.0	0.0
F11	4.3	1.3	147	21	24.4	26	0	0	0.7	1.1
F12	4.3	1.4	126	29	35.3	0	0	0	0.0	21.0
F13	3.5	1.4	58	44	27.7	18	46	0	1.8	10.2
F14	2.8	1.5	144	72	39.7	72	0	0	3.3	10.7
F15	4.7	1.6	286	71	28.9	0	0	0	0.0	7.1
Average			123	48	29.4	22	17	2	1.5	7.4
Median			106	50	29.4	18	0	0	1.5	7.2
Reasoned Value			**100**	**45**	**30.0**	**18**	**46**	**10**	**1.5**	**7.0**

5.3.2 Determination of EF and BC for the production phase

The $EF_{farming}$ of the representative farm in the olive district is equal to 0.829 gha/ha; in table 32 is possible to analyze specifically which inputs contributes most to the final value. In the production process is used a total of 26 kg/ha of N, 67 kg/ha of P and 15 kg/ha of K, generating an EF of 0.0823 gha/ha (about a 10% of the $EF_{farming}$). The factor that substantially contributes to the increase in $EF_{farming}$ value is also in this case the use of gasoline. In fact, in the various cultivation activities are consumed approximately 274 kg of gasoline, producing an EF of 0.6954 gha/ha, equal to about the 84% of the $EF_{farming}$.

[22] Plant Protection Product (PPP)

The other inputs are the factors that impact less on the value of $EF_{farming}$ (only 0.01% of the final value).

For the calculation of the $EF_{overproduction}$ (Table 33) was considered the average olives yields P; while the minimum input yield value (P_{min}) was supposed a value of 1.5 ton/ha. The $EF_{overproduction}$ is equal to 2.554 gha/ha, which added to the $EF_{farming}$ value (0.829 gha/ha) allows to obtain an EF_p equal to 3.383 gha/ha. Since the BC calculated is equal to 5.108 gha/ha, the resulting EB, obtained from the difference between BC and EF_p, is positive and equal to 1.725 gha/ha. The positive value of EB, therefore, determines the environmental (strong) sustainability of the olive production process taken into consideration.

Table 32 $EF_{farming}$ of Olive crop per ha

Input	Quantity	Emissions (ton CO_2)	AFCS (ha/ton CO_2)	YF	EQF (gha/wha)	EF (gha/ha)
Fertilizer (N)	26 Kg	9,79E-02	0.376	1.68	1.29	0.0784
Fertilizer (P)	67 Kg	4.34E-03	0.376	1.68	1.29	0.0035
Fertilizer (K)	15 Kg	5.37E-04	0.376	1.68	1.29	0.0004
Other inputs	7 Kg	1.32E-04	0.376	1.68	1.29	0.0001
Gasoline	274 Kg	8.68E-01	0.376	1.68	1.29	0.6954
Input	**Quantity**	**EF per capita**	**h/year**			**EF (gha)**
Labour	100 h	4.44	8,760			0.0507
Tot. $EF_{farming}$						**0.8285**

Table 33 Calculation of the $EF_{overproduction}$, EF_p, BC and EB for the olive

	Olive
P (ton/ha)	3.000
P_{min} (ton/ha)	1.500
α	0.500
Y_w (t/ha)	1.480
EQF (gha/ha)	2.520
$EF_{overproduction}$	2.554
$EF_{farming}$	0.829
EF_p (gha/ha)	3.383
BC (gha/ha)	5.108
EB (gha/ha)	1.725

5.3.3 Economic result of the olives production

Table 34 summarizes the economic results of the olive production process. The production of 3 t/ha and a sale price of olives at 600 €/t, allowed to obtain a revenue of 1,800 € per hectare of crop.

The variable costs for the management of the olive crop are equal to 2,107€. Surely it is the labour that affects the final amount of these costs, in fact its value is equal to about the 68% of the total. The high value of labour costs is due to the fact that the operation carried out in the fields, although nowadays partly automated, involves a high use of human intervention. In this context, the mechanization (for fertilization, pruning, harvesting, transport) implies a significant fuel consumption, in fact its incidence on the final value of variable costs is equal to about the 21%. Instead the costs of the inputs used and of the *other costs*, represent respectively the 7% and 4% of the variable costs of the entire production process.

Since the production process is characterized by variable costs greater than the revenues, it is characterized by a negative Gross Margin of -307 €/ha.

Table 34 Calculation of Gross Margin of the olive crop (data €/ha)

	Olive
Product (ton)	3.00
Price (€/t)	600
Revenues (€)	**1,800**
Fertilizer	56
Pesticides	98
Fuel	433
Labour	1,440
Other costs	80
Variable Costs (€)	**2,107**
Gross Margin (€)	**-307**

The analysis therefore highlights the sustainability of the production process from an environmental point of view, where the 34% of biocapacity provided by the olive orchard is not used and still remain available, while the negative value of the Gross Margin results in an economic unsustainability of the process.

5.4 Potato production

5.4.1 Definition of representative technique

In the 3 municipalities that characterize the olive productive district in the north of the Viterbo province (Figure 33), there were a total of 28 FADN farms. For such farms $DIST_1$ and $DIST_2$ have been calculated.

The threshold assigned to d_1 is equal to 11, while to d_2 is equal to 16. These values were chosen, considering the many observations and the presence of the farms on a very restricted area of the territory. and by observing the distribution of $DIST_1$ and $DIST_2$ (i.e. the "distance" of the production technique compared to the average and median technique) in order to eliminate the production processes very "distant" from the average behavior of the producers in the area. This choice involved the identification of a total 24 farms (table 35).

The identified production process (last row of table 35) involves a sustained use of fertilizers, with an amount per hectare equal to 1.4 tons and 27 kg/ha of plant protection products (PPPs). The production process, being the potato a horticulture, provides irrigation with a consumption of 520 cubic meters per hectare of water and an estimated electric consumption of 800 €/ha.

Figure 33 Identified potato district

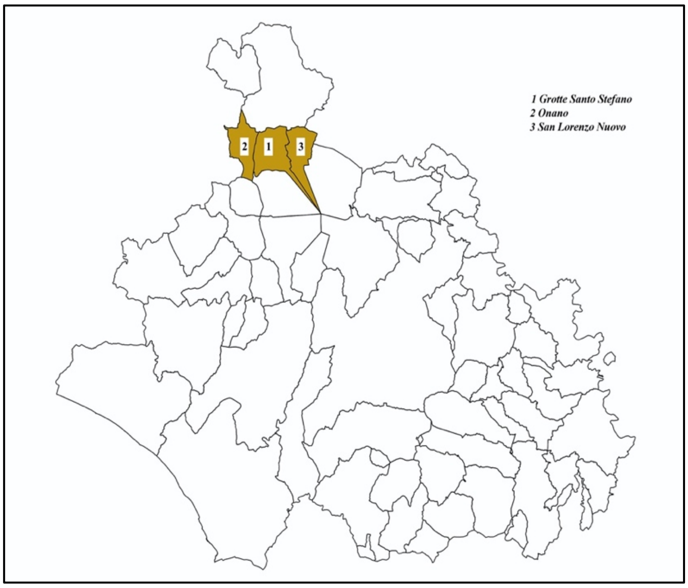


Table 35 Technical data of the identified farms and identification of the production process

Farm	$DIST_1$	$DIST_2$	Man hours (h/ha)	Machine hours (h/ha)	Yield (t/ha)	N (titre)	P (titre)	K (titre)	Fertilizer (q/ha)	PPP (Kg/ha)	Energy (€/ha)	Water (m^3/ha)
F1	3.5	5.2	232	137	400.0	0	0	0	0.0	0.6	2,000	737
F2	3.7	5.6	257	95	381.0	0	0	0	0.0	0.7	2,000	857
F3	3.9	5.9	181	143	218.6	65	56	10	6.8	53.2	500	40
F4	5.0	7.4	300	175	226.3	20	10	10	10.0	11.5	0	300
F5	5.0	7.5	333	100	400.0	0	0	0	0.0	0.6	2,000	222
F6	5.2	7.7	333	167	300.0	46	0	0	23.2	27.2	0	200
F7	5.1	7.7	160	111	199.5	66	10	10	2.4	40.6	650	49
F8	5.5	8.1	222	222	444.4	0	0	0	0.0	0.7	1,800	667
F9	5.4	8.2	220	220	350.0	66	20	20	31.9	98.2	0	4,800
F10	6.6	9.9	217	94	270.0	65	56	10	9.0	42.6	763	72
F11	6.7	10.1	250	125	150.0	20	10	10	17.5	11.0	0	150
F12	7.2	10.7	444	222	400.0	66	20	20	31.9	98.2	0	4,800
F13	7.3	10.9	333	167	233.3	20	10	10	17.5	50.0	0	600
F14	7.6	11.3	146	85	346.2	0	0	0	0.0	0.9	3,000	1,385
F15	7.5	11.4	119	38	308.4	47	10	10	6.1	20.0	0	0
F16	7.7	11.5	284	227	425.5	97	20	20	54.0	111.1	0	1,067
F17	8.9	13.4	102	75	260.2	66	10	10	3.7	19.8	350	72
F18	9.8	14.3	205	205	204.7	56	10	10	12.3	37.2	3,000	614
F19	9.9	14.5	179	179	238.5	20	10	10	14.8	35.1	3,000	89
F20	9.8	14.6	212	21	395.5	40	20	20	20.8	7.6	500	1,422
F21	10.1	15.0	500	50	550.0	0	0	0	0.0	43.8	200	500
F22	10.0	15.1	573	76	193.5	0	0	0	0.0	0.0	0	0
F23	10.4	15.7	250	250	480.0	97	20	20	54.0	111.1	0	1,067
F24	10.6	15.7	182	45	400.0	0	0	0	0.0	0.6	2,000	909
Average			260	135	324.0	54	18	13	19.7	35.7	907	859
Median			227	131	327.3	61	10	10	16.1	27.2	425	550
Reasoned Value			**225**	**125**	**320.0**	**66**	**10**	**10**	**10.0**	**28.0**	**800**	**520**

5.4.2 Determination of EF and BC for the production phase

The $EF_{farming}$ of the productive process selected for the potato crop is equal to 6.286 gha/ha. It is the highest $EF_{farming}$ value found in the different cases of analysis object of study. Its total value is represented for about 2/3 by the energy factors used (gasoline 46% and electricity 20%) in the production process. The consumption of gasoline is quite high, in fact from the available data is obtained a consumption of about 1,140 kg, which is due to the considerable mechanization of the production process.

The inputs used to fertilize the soil, on the other hand, contribute for about 32% of the final value of the $EF_{farming}$ and obviously it is the nitrogen that has a greater EF (1.64 gha/ha). The remaining 2% of the $EF_{farming}$ is given by the other inputs present in the production process that, although to a small extent, contribute to the high value of the ecological footprint.

Table 36 $EF_{farming}$ of potato crop per ha

Input	Quantity	Emissions (ton CO_2)	AFCS (ha/ton CO_2)	YF	EQF (gha/wha)	EF (gha/ha)
Fertilizer (N)	666 Kg	2.48E+00	0.376	1.68	1.29	1.9834
Fertilizer (P)	100 Kg	6.50E-03	0.376	1.68	1.29	0.0052
Fertilizer (K)	100 Kg	3.70E-03	0.376	1.68	1.29	0.0030
Other inputs	28 Kg	8.17E-04	0.376	1.68	1.29	0.0007
Gasoline	1,140 Kg	3.62E+00	0.376	1.68	1.29	2.8976
Electricity	4000 Kwh	1.60E+00	0.376	1.68	1.29	1.2822
Input	**Quantity**	**EF per capita**	**h/year**			**EF (gha)**
Labour	225 h	4.44	8,760			0.1140
Tot. $EF_{farming}$						**6.2860**

For the calculation of the $EF_{overproduction}$ (Table 37) it was considered the average yields P of the potato; while the minimum input yield value (P_{min}) was supposed a value of 12 tons/ha. Being a horticultural crop, characterized by a high level of complexity in the cultivation (determined by the nutrient inputs to allow the perfect growth of the plant and also by a close struggle against biotic and abiotic adversities) it was assumed that P_{min} was about the 40% of the average production (P) present in the analyzed data.

The $EF_{overproduction}$ is equal to 3.5 gha/ha, which added to the $EF_{farming}$ value (6.286 gha/ha) allows to obtain an EF_p equal to 9.789 gha/ha. Since the BC calculated is equal to 5.604 gha/ha, the resulting EB, obtained from the difference between BC and EF_p, is equal to -4.185 gha/ha. The negative value of EB determines the environmental unsustainability (in a strong sense) of the considered potato production process.

Table 37 Calculation of the $EF_{overproduction}$, EF_p, BC and EB for the potato

	Potato
P (ton/ha)	32.00
P_{min} (ton/ha)	12.00
α	0.625
Y_w (t/ha)	14.39
EQF (gha/ha)	2.520
$EF_{overproduction}$	3.502
$EF_{farming}$	6.286
EF_p (gha/ha)	9.789
BC (gha/ha)	5.604
EB (gha/ha)	-4.185

5.4.3 Economic result of the potatoes production

Table 38 summarizes the economic results of the potato production process.

The production of 32 t/ha and a sale price of potato at 300 €/t, allowed to obtain a revenue of 9,600 € per hectare of crop.

Variable costs are approximately the 93% (8,924 €/ha) of the revenues. The item that has the greatest impact on the total value of costs is the labour, which represents about the 40% of the total. Another item that has a significant impact is the fuel (1,802 €/ha) that in percentage terms on the total of the cost is equal to 21%. These cost-per-hectare reveal both the strong mechanization and the work request to carry out the crop, as is common practice in horticulture. The difference between the revenues and the variable costs results in a Gross Margin of 675 €/ha. The positive value of the Gross Margin determines the economic sustainability of the potato production process taken into consideration.

Table 38 Calculation of Gross Margin of the potato crop (data €/ha)

	Potato
Product (ton)	32.0
Price[23] (€/t)	300
Revenues (€)	**9,600**
Fertilizer	450
Pesticides	980
Water	684
Fuel	1,802
Lubricant	834
Electricity	800
Labour	3,375
Variable Costs (€)	**8,925**
Gross Margin (€)	**675**

5.4.4 Comparison of the economic and environmental results

In a strong sustainability perspective, the production process of potato is environmentally unsustainable (EB of -4.185 gha/ha). On the other hand, the gross margin has positive value and the comparison of economic and environmental results is presented below.

[23] Since the horticultural crops are highly profitable, in this case the price of the potato used, derived from the average prices of the product (period August 2018 – September 2019), collected by ISMEA Mercati (http://www.ismeamercati.it)

The weak sustainability approach requires to verify if the loss of Kn, associated to the EB deficit, is “replaceable” by the economic capital created by the production activity. Tables 39 and 40 show the calculation and the results of the productive and biological function of the natural capital involved in the cultivation.

Since the potato is an annual crop, as a value of the land, following an interview with expert in the sector, was chosen the annual rental cost of one hectare of land cultivated with potatoes (1,000 €/ha) in the area under analysis. Considering a productive life of the potato crop of 1 year, the value per hectare of the productive function is € 1,000. The other functions of the Kn identified are the biological one (Pollination and Biological control and food production), which if added to the previously calculated productive function allow to identify the loss of Kn per hectare (Table 39).

Table 39 Calculation of the loss of Natural Capital (Kn) for each hectare of potato.

	Ecosystem services	€/ha
Productive function		1,000
Biological function[24]	**Pollination**	13
	Biological control	22
	Food production	49
Loss of Kn		**1,084**

Table 40 Calculation of the value Loss Kn of potato crop

	EB (gha/ha)	BC (gha/ha)	Loss of Kn (ha/ha)	Value of Kn (€/ha)	Value of Kn Loss (€/ha)
Potato	-4.185	5.604	-0.747	1.084	810

Comparing the value of the loss of Kn (810 €/ha) with the Gross Margin previously calculated (675 €/ha), it emerges that in this case the economic performance is not able to guarantees a full compensation for the ecological deficit, considered as a loss of natural capital. It implies that the representative potatoes production process, at least on the base of the assumed coefficients, it is not sustainable even in a weak perspective.

[24] Source Costanza *et al.* (1997)

5.5 A comparative framework

With regard to the environmental and economic sustainability of the crops under analysis, interesting and quite different results, considering the diversity of crops and cultivation areas, were found.

Table 41 shows a summary scheme, which reports for each crop if it is environmentally and economically sustainable. The sign + identifies a sustainability condition, the sign – an unsustainability condition; the sign +/- means that we are facing with a crop that may or may not be sustainable depending on the production process characteristics.

The case of the vineyard is characterized by a deepening of analysis including, in addition to the mere process of agricultural production, also the phases of winery, bottling and transport of the bottles wine for the sale.

Table 41 A comparative framework of the economic and environmental sustainability of the analyzed crop

	Economic Sustainability	**Environmental Sustainability**
Vineyard	+	+
Hazelnut	+	+/-
Olive	-	+
Potato	-	-

The EB of the identified production process is +0.200 gha/ha, with an EF that uses about the 96% of the BC (5.405 gha/ha) of the ecosystem involved in the cultivation. The positive value of EB therefore determines the strong sustainability of the process in the field phase. As already mentioned, unsustainability occurs when the wine produced is transported over about 15 km to be sold.

It can be considered that in some cases, for example varieties with a low yield per hectare or in presence of wines with denomination, and therefore forced to apply specific disciplinary rules, the quantity of bottled wine is reduced. Therefore, decreasing the number of bottles, the impact of transportation is more limited and, increasing the transport distance, it makes the whole process sustainable.

In more general terms, to increase the sustainability of the whole wine production process, it is important to increase the environmental efficiency of the singles production stages. Certainly, there is a need to improve the field phase in terms of environmental sustainability, mainly through more accurate agricultural techniques; about this, the adoption of precision agriculture methods can positively affect the input utilization and the mechanization of the process. For the winery phase, it is important to implement production techniques which reduce electricity, water and fuel consumption. The bottling and transport phases are rather connected to each other; in fact, the type of packing chosen can improve and/or worsen the EF of the transport phase. Concerning this last point, the wine sector is already focusing on improving packing, looking, for example, at lighter glass bottles, and packaging that can allow the transport of more bottles in a single transport. Obviously in the transport phase it is necessary use vehicles characterized by a lower fuel consumption per km or use alternative vehicles.

Table 42 Ecological Balance and Gross Margin of the hazelnut, olive and potato production processes

		EB (gha/ha)	**Gross Margin (€/ha)**
Hazelnut	*“Compost and not irrigated farms”*	0.436	+3,232
	“NPK and irrigated Farms”	-0.320	+5,744
Olive		+1.725	-307
Potato		-3.320	+ 675

For the other crops considered (hazelnut, olive, potato), the analysis of economic and environmental sustainability was carried out only in the field phase, leaving the space for a future deepening. Table 42 summarizes the values of Ecological Balance and Gross Margin for the field phase for these three cultivation.

The environmental (strong) sustainability of the hazelnut cultivation is strongly linked to the production technique; in fact, between the two cultivation technique analyzed it results to be environmentally unsustainable the one that involves the plants irrigation, a greater use of chemical fertilizers and a more intense level of mechanization.

This is not true in a weak sustainability approach; in fact, in both cases the Gross Margin is able to fully compensate the loss of natural capital.

It is therefore obvious how, to preserve environmental sustainability in an ecological perspective, a careful management of the hazelnut production process has to be considered. This means carrying out meticulous fertilization plans and defense interventions, to the same time, improving the irrigation methods and the mechanization strategy to limit the fuel consumption.

The olives production process is environmentally sustainable in a strong sense, but it is not profitable in an economic perspective. Among the weaknesses of olive cultivation in the Viterbo province there are: high production costs, a delay in the incorporation of technological innovation, lack of investments, an almost absent generational turnover. This situation brought to the failure to modernize production techniques in a way that, even preserving and improving the environmental sustainability, the cultivation can reach profitability conditions.

The combination of all these aspects, together with the fact that non-entrepreneurial olive tree cultivation is widespread in the area, entails excessive costs that undermine its economic convenience.

These generalized economically negative conditions could lead to phenomena of land abandonment or, for the farmers that want to maintain their economic activity, to explant the olive trees and to substitute them with more profitable crops. Most profitable crops that, as this study has confirmed, may have a higher environmental impact and may require more natural resource than those available, increasing the unsustainability of the local agricultural systems.

The overexploitation of the ecosystems, leading to natural capital loss, represents a cost in a weak sustainability perspective as well as violating the condition of strong sustainability; it is therefore important to recognize the role and function that an olive grove, in a healthy and well-managed condition, plays to balance ecosystems.

Consequently, in order to preserve the crops, it is necessary provide payments for ecosystem services that olive trees offer and then compensate the economic losses. This and other public initiatives undertaken at the level of governance can certainly ensure that olive cultivation continues to preserve the sustainability of ecosystems.

The last crop analyzed in this study is the potato, which, as most vegetables, is characterized by an economic profitability. Nevertheless, to make this profitability significant, it is necessary to adopt intensive techniques that require important quantities of inputs (fertilizers, pesticides, water) and many mechanical interventions in the cultivation phase. This situation could cause a negative trade-off between ecological and economic performance that avoid the cultivation to be sustainable, even in a weak perspective.

This is the case of the potatoes cultivation considered in our case; in fact, the entity of the gross margin is not enough to compensate the monetary value of the natural capital lost in the production cycle. Differently from the case of the hazelnuts, where the loss of natural capital, when present, is easily compensated by the gross margin generated, this is the only crop that shows a condition of unsustainability, independently from the chosen definition of sustainability.

This cultivation, as many horticultural crop, requires a significant upgrade from the technological point of view to be sustainable, considering that its environmental unsustainability is caused by a high ecological footprint, mainly due to nitrogen fertilizers and consumption of fuel and electricity. According to the data analyzed, these are aspects to be improved to make the production process environmentally sustainable preserving its economic convenience. Technological innovation is essential in preserving environmental sustainability and, at the same time, reducing the incidence of costs.

CONCLUSIONS

The agricultural sector is characterized by the peculiarity of producing goods by controlling biological cycles. This feature, unique in its kind, means that in the exercise of its activity agriculture manages the production processes within the limits imposed by the natural ecosystems. At the same time, it manages inputs that condition the natural biological cycles of crops and that generate impacts on other biological and physical systems.

This strong influence should be controlled to carry out agricultural techniques able to provide an economic benefit and, at the same time, to guarantee a condition of "sustainability" of the processes. The problem is that, starting from the Brundtland report in 1987, the concept of sustainability was defined differently and declined in many ways. These distinctions and features which have characterized, and still characterize, the definition of sustainability is not only a "formal" problem but result in different perspectives and consequences both in scientific and political field.

Classical economic paradigm, which requires continuous economic growth over time, has, as fundamental assumption, the belief in the possibility of making natural capital and man-made capital interchangeable. From this perspective, the idea of (weak) sustainability is based on the condition that the total capital, represented by the sum of natural and man-made capital, must remain constant over time, even if, with the normal progress of human civilization, the weight of natural capital progressively decreases in favor of the man-made capital.

The Bioeconomic paradigm, which instead refers to a strong concept of sustainability, starts from the assumption that the two forms of capital are not substitutable but complementary, because the production of man-made capital depends on the availability of natural capital. The excessive use of natural resources is therefore not admissible, because, since they cannot be substituted, their impoverishment gives rise to irreversible processes.

The deep dichotomy which lies under the concept of weak and strong sustainability implies the need to define, in any analysis, study and governance choice aiming to sustainability, the concept of sustainability to be adopted.

Without a clear definition of the approach it is not possible to talk about sustainability in the broad sense. In fact, the choice of one of the two definition has direct implications on the evaluation methodology, on the choice of indicators and on the interpretation of the results of the empirical analyses.

Moving from these considerations, in this thesis it was proposed a study to evaluate the sustainability of the main crops in the province of Viterbo, taking into consideration the differences in terms of methodology and results deriving from a definition strong or weak of sustainability.

The analysis carried out in this study was based on the ecological footprint as a methodologic and operative tool able to evaluate the impact on the natural capital caused by a human activity. This feature, according with many scholars, makes the ecological footprint an indicator able to check the condition of strong sustainability. In fact, in our case, if the exploitation of an agricultural process causes a reduction in the natural capital then that process is not sustainable (in strong sense).

It follows that, adopting an ecological footprint approach, the strong sustainability of a production process automatically implies its weak sustainability; obviously the vice versa it is not true. Indeed, in a strong sustainability paradigm the key for sustainability is all confined within the technical path of the agricultural process, while in a weak perspective the sustainability can be always achieved, as long as the economic performance is able to provide a sufficient revenue.

In this regard, the methodology proposed in the thesis, even if it needs further study and future improvements, has shown the capacity to capture the theoretical background underlined by the definition of strong and weak sustainability and to define a solid framework to evaluate empirically the existence of such two condition. This conclusion permits to answer in a positive way to the first research question posed in the introduction of this thesis.

The empirical analysis, performed on four different crops that play a relevant role in the agricultural sector of the studied area, reached interesting results but, at the same time, showed some limitations.

An interesting outcome of the study is the difference in sustainability condition showed by the four crop. According to the results, two of them are strongly sustainable (olive and vineyard), one is at the border between strong and weak sustainability (hazelnut) and one in not sustainable at all (potato).

Apart from the analytical results, presented and discussed in the last part of the thesis, it is important to underline that, by means of the proposed approach, it was possible to define and to assess an indicator, namely the ecological balance, able to state the condition of strong sustainability of each crop analyzed. This indicator, which evaluate the variation of natural capital in physical terms, was also utilized to state the weak sustainability condition, once converted in monetary terms according to the methodologies provided by the environmental economics theory.

As a consequence, it can be stated that also the second research question was positively addressed. Nevertheless, they cannot be ignored some limitation which concern mainly the empirical utilization of the methodology.

Among them it must be mention the choice of defining one (two in the case of hazelnut) representative production technique for each crop. For different reasons (the dimension of the area, the different farm structures, the farmer knowledge and investment possibility) a single technical path is not sufficient to resume the way in which a cultivation is carried out in a productive district.

Another limitation is linked to the choice of some parameters used in the ecological footprint evaluation model. A typical example is represented by “minimum input yield”, a value that, to be measured with a sufficient reliability, will require a specific experimental agronomic design.

Anyway, beyond its limitations, this study demonstrates and confirms that in verifying the sustainability of a human activity, it is essential to define in advance the type of sustainability that is taken into consideration and then measured. This is important to prevent the a generic and vague definition of what sustainable is, ignoring the effective impacts on the ecosystems and the possible trade-off between the ecological and economic dimensions.

Differently, the development of a scientifically rigorous and coherent methodology can offer a significant contribution to the management and improvement of the production processes of the agri-food chain. The set of indicators made available by this research can provide useful information and assessments on the level of crop sustainability, and in the future perspective of the agri-food supply chain, becoming a useful tool for technical and political interventions.

From a technical point of view, indicators can highlight what are the specific problems in a production process and therefore suggesting targeted interventions, also by means of scientific research, aimed at increasing the sustainability of production processes. Instead, from a political point of view, a coherent approach can provide fundamental decision-making information to policy makers. This is not a possibility to be underestimated, since the policy makers intervene at local, national or international level with laws, regulation and policies on agri-food chains through funding targeted to the issues. This applies in particular to agricultural policies relating to the second pillar, especially as regards the agri-environmental measures contained in the regional rural development plans.

As a conclusion, it can be stated that this study offers a possible contribution to clarify the concept of sustainability and to provide a useful tool to respond to institutional and public requests to achieve more sustainable agricultural systems and, consequently, more sustainable food.

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