DEPARTMENT OF AGRICULTURAL, FOOD AND ENVIRONMENTAL SCIENCES

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Comparison of the environmental sustainability of frozen peas from organic, sustainable, and integrated agriculture:

Case study of a pea producing company

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Student:

Alessia Marotta

Supervisor:

Prof. Daniele Duca

Assistant supervisor:

Dr. Alessio Ilari

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ACRONYNMS AND ABBREVIATIONS

LCA Life Cycle Assessment

UN United Nations

FAO Food and Agriculture Organization

WHO World Health Organization

EU European Union

GHG Greenhouse Gas

SDGs Sustainable Development Goals

LCT Life Cycle Thinking

LCM Life Cycle Management

GWP Global Warming Potential

SETAC Society of Environmental Toxicology and Chemistry

ISO International Organization for Standardization

LCI Life Cycle Inventory

LCIA Life Cycle Impact Assessment

C.O.VAL.M. Coltivatori Ortofrutticoli Valli delle Marche

FSA Farm Sustainability Assessment

SAI Sustainable Agriculture Initiative

FU Functional Unit

ADF Abiotic Depletion Factor

ADP Abiotic Depletion Potential

GWP Global Warming Potential

ODP Ozone Depletion Potential

HTP Human Toxicity Potential

FAETP Fresh Water Aquatic Ecotoxicity Potential

MAETP Marine Aquatic Ecotoxicity Potential

TETP Terrestrial Ecotoxicity Potential

POCP Photochemical Oxone Creation Potential

AP Acidification Potential

EP Eutrophication Potential

1. INTRODUCTION

This work is part of the activities carried out by the Department of Agricultural, Food and Environmental Science of Università Politecnica delle Marche for a Rural Development Program of Marche Region (PSR). The PSR refers to the bioconversion of agricultural and industrial-chain residues through the insect *Hermetia illucens*. Part of this project consists of the environmental sustainability evaluation of frozen peas production through a LCA analysis, which allows finding solutions for improving the industrial chain efficiency.

The UN estimates that the global population will grow up to 9,7 billion by 2050. The population growth along with the increasing urbanization are the socio-economic factors that drive the increasing food demand (FAO, 2009). Recent forecast of FAO estimates that 50-70% more food will need to be produced to satisfy the increasing level of food demand if no changes in the food systems, food waste and consumption patterns will come about (SAPEA, 2020).

According to a publication of the European Commission published in 2020, the food and beverage industry is one of the largest manufacturing sector in the EU. It is the major consumer of natural resources such as water and energy, thus contributing to GHG emissions and hence to climate change (European Commission, 2020). Food production is responsible for approximately 26% of global GHG emissions. Some authors derived data from the largest meta-analysis of food system impact studies to date, to estimates the global average GHG emissions per kilogram of food product deriving from different categories of food production: livestock and fisheries, crop production, land use, and supply chains.

- *Livestock and fisheries*

The term livestock is referred to animals raised for meat, dairy, eggs, and seafood production. Livestock contributes 31% of GHG emissions in many ways, including methane (CH_4) mainly produced by cattle through their digestive system, nitrous oxides (N_2O) from manures, emissions from pasture management, and fuel consumption from fishing vessels.

- *Crop production*

This category contributes 27% of food's direct emissions and includes N_2O from the application of fertilizers and manure, CH_4 emissions from rice production, and carbon dioxide (CO_2) from agricultural machineries. The 21% comes from crop production for direct human consumption, while 6% comes from the production of animal feed.

- *Land use*

Land use for livestock contributes 16% of food's emissions and that for crops for human consumption account for 8%, for a total of 24%. Beside the irreversible losses of biodiversity, deforestation for agricultural expansion is the second largest source of CO_2 emissions.

- *Supply chains*

The steps involved in the supply chains such as food processing, transport, packaging, and retail require energy and resource inputs that contribute 18% of food's emissions. Eating local produce may reduce transport emissions. However, transport does not contribute to supply chain emissions as much as food waste: 3,3 billion tons of CO_2 eq are emitted from production of food that ends up being wasted, either from consumers or losses along the supply chain. Therefore, food waste must be prevented to significantly reduce emissions with the use of durable packaging, refrigeration, and food processing. In fact, the waste of processed fruits and vegetables is 14% less than the fresh one.

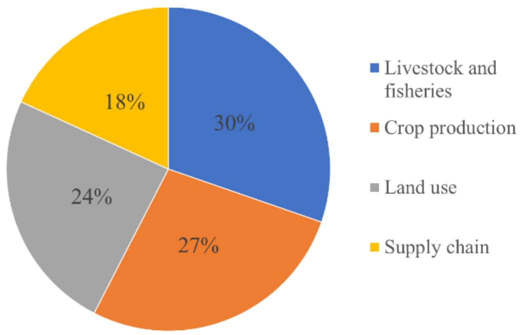

Figure 1-1: GHG emissions from different food production categories.

GHGs include CH_4, N_2O, and CO_2. The latter is the most important one, indeed kilograms of CO_2 eq is used as a reference to measure GHG emissions of food products. Different food products have significantly different emissions. In general, emissions from animal-based food production are higher than those deriving from plant-based food production; indeed, the production of one kilogram of the most impactful food product that is beef emits up to 60 kg of CO_2 eq while peas emit about 1 kg of CO_2 eq per kg of product.

By looking at the emissions related to each stage of the supply chain, GHG emissions for most food result mainly from land use changes and from processes at the farm stage such as the application of fertilizers and the CH_4 production by cattle. Transport contributes for less than 10% to emissions. Processing, transport, retail, and packaging account for a small share of emissions as well (Ritchie H. and Roser M., 2020).

New estimates by FAO indicate that globally around 14% of the world's food is lost from production before reaching the retail level. Food loss and waste significantly contribute to three environmental footprints: carbon footprint, land footprint, and water footprint. FAO estimated that the global carbon footprint of food loss and waste is 3,3 gigatons of CO_2 eq (7% of total GHG). Therefore, food loss and waste reduction become crucial to significantly improve the environmental sustainability of food systems. The advantages of reducing food loss and waste are lowering production costs, improving food security and nutrition, as well as contributing to environmental sustainability by decreasing GHG emissions (FAO, 2019).

A FAO report states that agricultural production contributes to climate change too and is in turn affected by climate change. Higher temperatures, increasing CO_2 concentration, precipitation changes, increased weeds, pests, and disease pressure heavily impact food security today and in the future, including food production and availability, stability of food supplies, access to food and food utilization. The awareness that the food system is strongly affected by climate change and the growing food demand must be translated into effective actions to ensure that food security may be achieved by future generations (FAO, 2009).

1.1. Sustainable food system

FAO affirms that unsustainable food and agriculture systems are the major driver of climate change, because of the GHG emissions from human activity and livestock, determining the trapping heat in the earth's atmosphere and triggering global warming (FAO, 2022a). The transition towards a more sustainable food system is key to ensure sustainable use of renewable resources and increase resource efficiency in terms of chemical inputs, water, energy use, land use and waste generation, as stated by the European Environment Agency Report (EEA, 2018).

Science Advice for Policy by European Academies (SAPEA) consortium in the Evidence Review Report No. 7 defines a sustainable food system as "a food system that ensures food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition of future generations are not compromised."

A sustainable food system has three objectives:

- provide safe, nutritious, and healthy food without compromising the availability of and access to safe, nutritious, and healthy food for future generations.
- provide food security while ensuring a healthy environment using appropriate agricultural management practices.
- become a robust and resilient food system to produce food sustainably, including social and economic terms, resilient to price shocks and other crises and responsive to social inequalities and other forms of injustice (SAPEA, 2020).

1.2. Policy initiatives

The European Commission stated that "we need a comprehensive approach entailing a genuine change in the way we produce, transform, consume and distribute food by accelerating the transition to a sustainable food system based on circular economy principles and making innovative, healthy, environment and animal welfare-friendly, safe and nutritious food production one of our key European trademarks" (European Commission, 2019a).

Several initiatives have the objective to promote this transition both at global and European level.

1.2.1. Global level

The 2030 Agenda for Sustainable Development agreed in 2015 is a "soft" form of policy set at global level that have at its core 17 SDGs, many of which are related to food production and consumption.

Figure 1-2: Sustainable Development Goals.

For example, the SDG2: Zero Hunger aims to "end hunger, achieve food security and improved nutrition and promote sustainable agriculture" by 2030. Global organizations and institutions such as FAO and WHO, driven by their shared interests, produced norms and guidelines to achieve the 2030 Agenda for Sustainable Development (SAPEA, 2020). Furthermore, FAO is promoting the application of sustainable food and agricultural practices to meet the society's needs of present and future generations and hence to achieve the Zero Hunger SDG (FAO, 2022b).

1.2.2. European level

The EU proposed new policy frameworks and initiatives to support this sustainability transition. The European Green Deal is a set of policy initiatives aimed at turning the EU into the first climate neutral continent by 2050. To this end, the Commission proposed the first European 'Climate Law' entered into force in June 2021. This law enshrines the 2050 climate neutrality objective in legislation and ensures that all EU policies contribute to the climate neutrality objective and that all sectors play their part. The EU already achieved a significant reduction of GHG of 23% between 1990 and 2018. Now the EU wants to reduce emissions by at least 55% by 2030, compared to 1990 levels (European Commission, 2019b).

To achieve the climate and environmental objectives of the Green Deal, the Commission proposed two main strategies.

- *The Biodiversity Strategy for 2030*

This strategy aims to recover biodiversity by 2030 to protect the society from the threats of climate change, food insecurity and epidemics. The biodiversity strategy identifies specific measures to achieve these objectives, such as increasing the coverage of protected biodiversity-rich land, sea areas building on the Natura 2000 network and improve and restore damaged ecosystems to good ecological status, including carbon-rich ecosystems (European Commission, 2022a).

- *The Farm to Fork Strategy*

This strategy is at the heart of the European Green Deal, and it is designed to achieve a fair, healthy and environmentally friendly food system. The strategy sets out both regulatory and non-regulatory initiatives, with the common agricultural and fisheries policies as key tools to support this transition. The Commission's proposals for the Common Agricultural Policy (CAP) for 2021 to 2027 stipulate that at least 40% of the CAP's overall budget and at least 30% of the Maritime Fisheries Fund would contribute to climate action. The strategy objectives cover four main areas: sustainable food production, sustainable food processing and distribution, sustainable food consumption, and food loss and waste prevention. For example, it aims to significantly reduce the use and risk of chemical pesticides, as well as the use of fertilizers and antibiotics (European Commission, 2019b; European Commission, 2020).

The European Commission adopted the new Circular Economy Action Plan (CEAP) in March 2020. The EU's transition to a circular economy will reduce pressure on natural resources and will create sustainable growth and jobs. The Commission lists in the action plan 35 actions which aim to design sustainable products, empower consumers and public buyers, and circularity in production processes. The latter can deliver substantial material savings throughout value chains and production processes, generate extra value, and unlock economic opportunities (European Commission, 2022b).

1.3. Frozen vegetables

According to FAO technical manual, freezing is a food preservation method widely applied to better retain the food quality, in terms of sensory attributes and nutritive properties of agricultural products, such as taste, texture and nutritional value. The freezing process is the application of low temperatures, generally to -18 C° or below, to retard the microbial growth and slow down chemical changes which affect food quality or cause food spoilage. Therefore, it is used to extend the food shelf-life while ensuring food safety and quality. The packaging of frozen food is crucial to protect the product from contamination and damages during the transport from manufacturer to consumers and to preserve the qualitative characteristics. Furthermore, it is important to ensure the cold chain during transport to avoid food losses caused by spoilage or deterioration (FAO, et al., 2005).

Frozen vegetables are food products prepared by freezing fresh vegetables. The process consists in different operations such as washing, peeling, grading, cutting, and blanching/deactivating enzyme activity depending on the product type. The freezing operation must be carried out in such a way the temperature of maximum crystallization is passed quickly (CBI, 2020).

FAO stated that the frozen food market is one of the largest sectors of the food industry; in Europe frozen food consumption reached 11,1 million tons in the 2000 (FAO et.al., 2005). Future trend of the European market concerning frozen vegetables shows a stable growth of 1-3% annually. Most frozen vegetables are traded without any ingredients added; instead, in ready-to-cook mixtures herbs, salt, sugars or other ingredients may be added. According to the Centre for the Promotion of Imports from developing countries (CBI), Europe is the largest importer of frozen vegetables: imports have increased annually by an average of 4 % in volume in the period of

2014-2018, to a value of € 3,3 billion and a quantity of 3,4 million tons. This market growth is driven by the current consumption patterns of European consumers because of the easy preparation of frozen vegetables, which are perceived as healthy food.

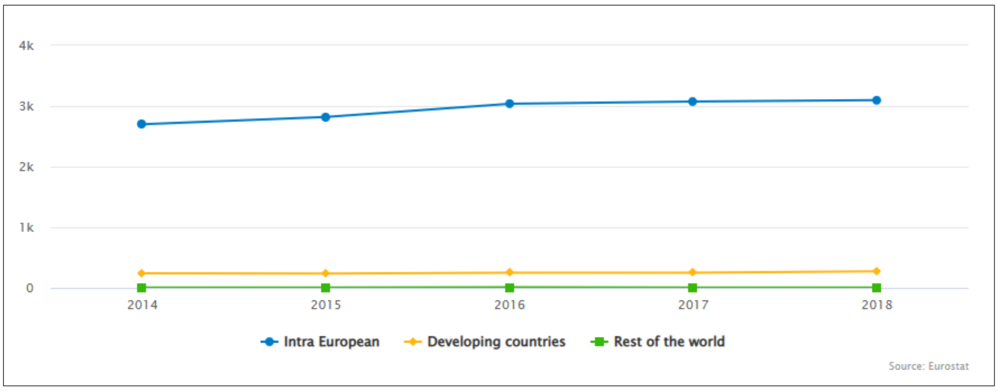

Figure 1-3: European imports of frozen vegetables.

The increasing demand for ready to eat food combined with the need for vegan and vegetarian food are driving the demand for frozen vegetables in Europe. Moreover, frozen vegetables are often promoted as richer in nutrition compared to fresh vegetables, due to better preservation of nutritional value than fresh.

Europe is the largest producer of frozen vegetables in the world. The total European production of frozen vegetables was estimated to have reached nearly 6 million tons in 2018. Belgium is the largest producer of frozen vegetables in Europe, accounting for 27 % of total European production, and around 90 % of production is exported. Spain and Poland are the second and the third-largest producer in Europe, respectively.

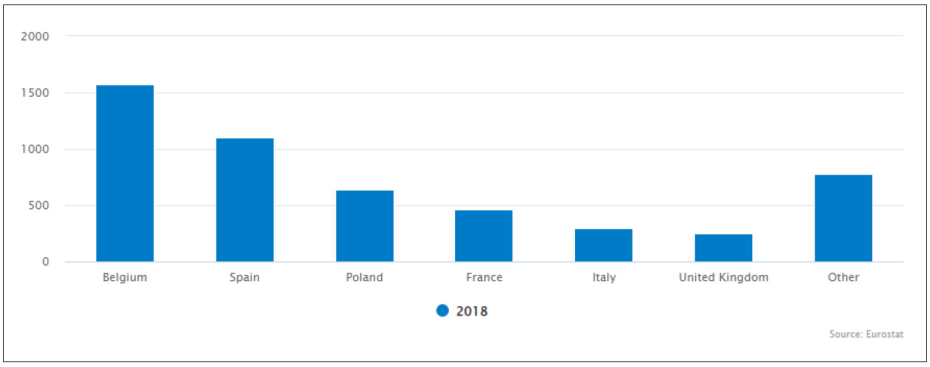

Figure 1-4: Production of frozen vegetables in Europe by country.

Consumption has increased by an average annual growth rate of 4 % between 2014 and 2018. France, Germany, Belgium, Spain, the United Kingdom, and Italy are the largest markets. In 2018, European consumption has reached 4,7 million tons.

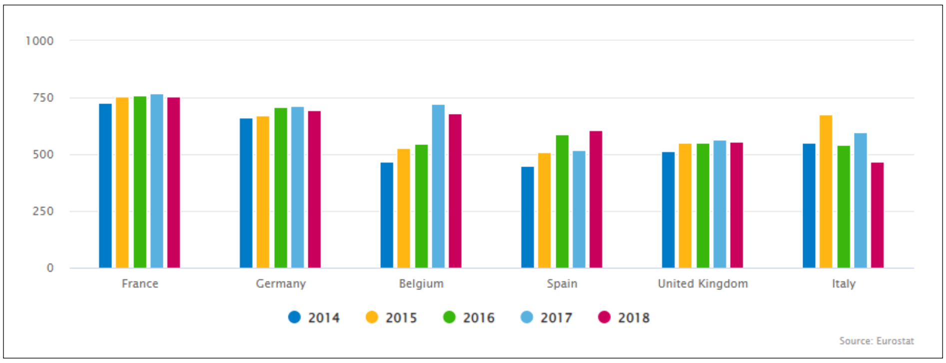

Figure 1-5: Consumption of frozen vegetables in Europe.

Italy is the fifth-largest importer and the sixth-largest market for frozen vegetables in Europe. In 2018, imports reached 213 thousand tons with consumption estimated at 300 thousand tons. Frozen peas account for the largest market share, followed by frozen mushrooms and frozen green beans.

Frozen vegetables to be marketed in Europe must comply with the requirements stated in the specific standard for quick frozen vegetables. All foods including imported products sold in the EU must be safe and all additives used must be approved. The presence of harmful contaminants, such as bacteria or viruses, pesticide residues and excessive levels of heavy metals is not allowed. Growing consumer awareness that their purchasing choices impact the environment has led to changes in consumer consumption patterns, thereby increasing the demand for organic frozen vegetables. To market frozen vegetables as organic in Europe, they must be grown using organic production methods according to European legislation. Growing and processing facilities must be audited by an accredited certifier before you will be allowed to use the EU's organic logo on your products.

Figure 1-6: EU organic certification logo.

Sustainability is a broad term with many aspects and there is still no internationally recognized sustainability certification covering all of them. The desire to achieve carbon neutrality and use recyclable packaging material are currently the most important aspects. One of the industry trends is the publication of CO_2 emission rates on products, but it is very difficult to reliably assess those claims (CBI, 2020).

2. LIFE CYCLE ASSESSMENT – STANDARDS AND FRAMEWORK

The LCT is an innovative and sustainable way of thinking that include environmental, social, and economic impacts of a product over its entire life cycle. The main objectives of the LCT are to optimize resources, reduce the use of the production materials of a product and consequently lower the polluting emissions for the environment that are released during its creation and transformation, thus contributing to the concept of circular economy.

The LCM is a management approach that provides the tools and methodologies of LCT into practice. The main operational and life cycle assessment tool of a product is the LCA.

LCA is an analytical and systematic methodology that allows to identify the key environmental issues associated with the product or service throughout its entire life cycle. The result is the environmental footprint value of a product or service associated to different impact categories, which represent all the different impacts that the product or service generates in the various environmental sectors. All the steps of a food production chain taken into consideration during the LCA analysis are described in the Figure 2-1.

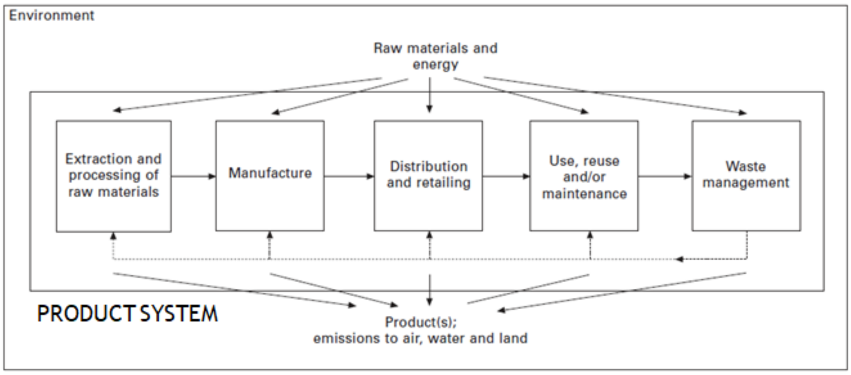

Figure 2-1: LCA framework.

One of the impact categories considered is the increase in the greenhouse effect, also known as GWP, measured as kg of CO_2 eq emitted into the atmosphere generated by the consumption of energy and matter within the life cycle of a product or of a service.

LCA methodology constitutes the technical basis for a wide range of actions aimed at increasing the sustainability of products and supply chains, since it helps to understand the impact generated on the environment by the products, services, economic systems, and production chains. Lastly, LCA objective is to be able to reduce and mitigate the impacts through an appropriate management of the calculated impacts. According to the LCT logic, comparative LCA assessments allows to identify the materials and production methods with a lower environmental footprint: therefore, the LCA allows to replace materials with a higher footprint with those with a lower footprint, to increase the environmental compatibility of products.

2.1. Life Cycle Assessment History

The environmental pollution and resource depletion acquired increasing importance in the recent decades. The increasing awareness of these issues led to the development of life-cycle-oriented approaches to assess the environmental sustainability of many products, since the impacts arise from their production, transportation, and disposal. The first life-cycle-oriented methods, precursors of today's LCA, were developed in the 1960s, as affirmed by M. Z. Hauschild et al. (M. Z. Hauschild, et al., 2018).

The first studies were focused on energy analyses, resource requirements, emission loadings and generated wastes because issues of broad public concern. During the 1970s and the 1980s, LCAs were performed using different methods but without a common theoretical framework. Consequently, LCA studies carried out on the same product led to significantly different results. From the early 1980s the interest for LCA studies increased. SETAC promoted collaboration among LCA practitioners, users, and scientists to improve and harmonize the LCA framework, terminology, and methodology. Along with SETAC, in the 1994, the ISO get involved in LCA for standardization of methods and procedures.

During the 1990s, LCA became part of policy documents and legislation. Several well-known life cycle impact assessment methods, still used today, evolved from methods developed in this period, such as the CML1992 environmental theme approach (J. B. Guinée, et al. 2011).

Since 2000, the attention towards LCA further increased. In 2002, the United Nations Environment Programme (UNEP) and the SETAC launched an International Life Cycle Partnership, known as the Life Cycle Initiative. The Life Cycle Initiative had the objective to formulate the LCT, to put it into practice and improving the supporting tools through better data and indicators. LCT became increasingly important also in the European Policy as underlined in the Communication on Integrated Product Policy (IPP). This Communication adopted by the

Commission on June 2003 concluded that LCA provides the best framework for assessing the potential environmental impacts of products currently available and announced that the Commission will provide a platform to facilitate communication and exchanges on life-cycle data. Accordingly, the European Platform on Life Cycle Assessment was established in 2005, mandated to promote the availability, exchange, and use of quality-assured life cycle data, methods, and studies for reliable decision support in EU public policy and in business.

In 2006, the European Commission commissioned the Co-ordination Action for innovation in Life Cycle Analysis for Sustainability (CALCAS) project to structure the varying field of LCA approaches and to define research lines and programs to further LCA where necessary. The result was the establishment of a framework for Life Cycle Sustainability Analysis (LCSA) which evaluate all environmental, social, and economic negative impacts and benefits in decision-making processes towards more sustainable products throughout their life cycle (J. B. Guinée, et. al. 2011).

2.2. ISO standards on Life Cycle Assessment

Different methodologies were developed, and harmonization of the evolving methods was required to ensure consistency of the studies. In the 1993, ISO developed a global standard for LCA, as the lack of a standardized methodology led to significantly different results in different studies of the same product. A first series of four ISO-LCA standards were published between 1997 and 2000: the ISO 14000 family. The ISO 14040 series standards address quantitative assessment methods for the assessment of the environmental aspects of a product or service in its entire life cycle stages (CTI, 2004).

2.2.1. Primary ISO standards

UNI EN ISO 14040:2021 and UNI EN ISO 14044:2021 standards are the leading international standards on LCA mainly focused on the process of performing LCA, following a product’s impact from cradle to grave. ISO 14040 describes the “principles and framework for LCA” while the ISO 14044 “specifies requirements and provides guidelines” for LCA, including definition of the goal and scope of the LCA, the LCI analysis phase, the LCIA phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, the relationship between the LCA phases, and conditions for use of value choices and optional elements (UNI, 2021; UNI, 2021a).

2.2.2. ISO standards on specific issues

- *UNI EN ISO 14067:2018 on the carbon footprint of products*

This standard "specifies principles, requirements and guidelines for the quantification and reporting of the carbon footprint of a product" addressing only a single impact category, that is climate change. The standard is consistent with ISO 14040 and ISO 14044. However, it also includes requirements on specific issues relevant to carbon footprint, including land-use change, carbon uptake, biogenic carbon emissions, and soil carbon change (UNI, 2018).

- *UNI EN ISO 14046:2016 on water footprint*

It sets out "principles, requirements and guidelines related to water footprint assessment of products, processes and organizations based on LCA." It is consistent with the international ISO 14044 LCA standard and only air and soil emissions that impact water quality is included in the assessment, and not all air and soil emissions are included (UNI, 2016).

2.2.3. ISO standards for results communication

- *UNI EN ISO 14020:2002 on environmental labels and declarations - General principles*

This International Standard establishes guiding principles for the development and use of environmental labels and declarations, but it is not intended for use as a specification for certification and registration purposes (UNI, 2002).

- *UNI EN ISO 14024:2018 on environmental labels and declarations - Type I environmental labelling - Principles and procedures*

This standard establishes the principles and procedures for developing Type I environmental labelling programs, including the selection of product categories, product environmental criteria and product function characteristics, and for assessing and demonstrating compliance. It also establishes the certification procedures for awarding the label (ISO 14024, 2018).

Figure 2-2: EU ecolabelling

- *UNI EN ISO 14021:2021 on environmental labels and declarations - Type II environmental labelling - Self-declared environmental claims*

It specifies requirements for self-declared environmental claims, including statements, symbols, and graphics, regarding products. It describes selected terms commonly used in environmental claims and gives qualifications for their use. It also describes a general evaluation and verification methodology for self-declared environmental claims and specific evaluation and verification methods for the selected claims in this International Standard (UNI, 2021b).

- *UNI EN ISO 14025:2010 on environmental labels and declarations - Type III environmental declarations - Principles and procedures*

It establishes the principles, specifies the procedures and the use of the ISO 14040 series of standards for developing Type III environmental declaration programs and Type III environmental declarations. Type III environmental declarations are primarily intended for use in business-to-business communication (UNI, 2010).

2.3. Life Cycle Assessment steps

The ISO 14040 standard establish the methodological framework of LCA, which is divided into four phases: Goal and scope definition, Inventory analysis, Impact assessment and Interpretation. In the Figure 2-3 the LCA phases are shown.

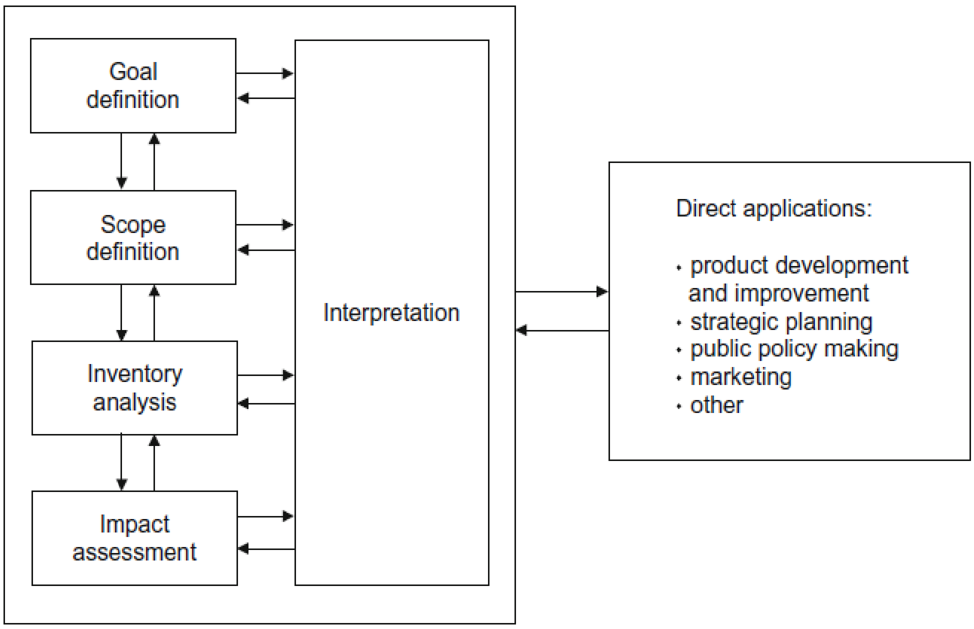

Figure 2-3: LCA phases from the ISO 14040 standard.

2.3.1. Goal and scope definition phase

The goal definition means to state the aim of the study, the intended application, the reason why the study is carried out, including who is the commissioner and the practitioner, and finally the target audience, that is the intended users of the study results.

The scope definition determines the main characteristics of the LCA study, by explaining which methodological choices are made and the reason of such choices. The aim of the scope definition is to ensure consistency throughout the study (M. Z. Hauschild et.al., 2018).

In detail, the scope must define the functional unit, the product system, the system boundaries, the allocation procedures, the studied impact categories, the LCIA models used, and data quality requirements (European Commission, 2022c).

The *function* is the use intended and the function provided by the product, while the *functional unit* defines the qualitative aspects and quantifies the quantitative aspects of the function; the functional unit provides the reference to which all the inputs and outputs are related, which is crucial when two or more products are compared with each other (M. Z. Hauschild et.al., 2018).

The *product system* description includes the components, manufacturing, distribution, use and disposal; transportation and energy used should be included as well (CTI, 2004).

The *system boundaries* determine which unit processes are included in the product system and which not. Depending on which unit processes are inside the system boundaries they can be classified as follow:

- *"cradle to grave"* allows a complete LCA since the system boundaries include all the phases of the product life cycle, starting from the extraction of raw materials to the use and disposal phase.
- *"cradle to gate"* includes the unit processes from the raw material extraction to the exit of the factory gate.
- *"cradle to consumers"* include the same unit processes of the "cradle to gate" approach along with the distribution phase.
- *"gate to gate"* is a very limited LCA because within the system boundaries are included only the unit processes from the entrance to the exit of the factory.

When the product system delivers more than one function the process is called multifunctional. The ISO 14044 standard recommends dividing the environmental impacts between the two functions by *system expansion* or by *allocation system*. The *system expansion* means to substitute the secondary product with a valuable alternative that provide the same function. The *allocation system* divides inputs and outputs between the two products, that is a division of the environmental impacts according to how much the products costs, contains energy or weights.

Data quality requirements are reliability, accessibility, and relevance. According to these requirements data are classified into primary, secondary, and tertiary data: *primary data* are obtained from direct measurements and represents the best option; *secondary data* are obtained from secondary sources such as national and international LCA databases; *tertiary data* are extrapolated by estimations and average values.

The goal and scope definition phase is one of the most important because the interpretation of the results is based on the defined methodological choices and then it strongly affects the validity of the conclusions and recommendations. (M. Z. Hauschild et.al., 2018).

2.3.2. Life cycle inventory analysis

The Inventory analysis consists in the collection of data for each life cycle phase included in the defined system boundaries and final calculations. Data should be preferably collected from the production site which should be real and verified or verifiable, also called *foreground data.* Otherwise, data can be collected from LCA software databases or from literature which are not closely related to the product and in the form of averages or ranges, also called *background data*. The collected input and output data are normalized to the chosen functional unit and then reported in the inventory table (CTI, 2004).

2.3.3. Impact assessment phase

The aim of the LCIA phase is to evaluate the environmental impacts of the product system. The ISO 14040/14044 standards provides the guidelines to perform the LCIA, which consists in different elements: classification and characterization that are mandatory elements, normalization, grouping and weighting that are optional elements. Different LCIA methods can be used such as CML 2011, ReCiPe, EDIP 2003, and Eco Indicator 99.

- *Classification*

Classification consists in dividing the inputs and outputs listed in the inventory table into different impact categories according to the expected types of impact on the environment. The impact categories often considered in LCIA are GWP, ozone depletion, acidification, eutrophication, land use, human toxicity, ecotoxicity, and solid waste. Furthermore, impact categories are divided into *midpoint impact category*, linked to a specific impact category such as climate change, acidification, and human toxicity, and *endpoint impact category*, linked to issues of concern such as human health, natural environment, and natural resources.

- *Characterization*

Following the classification, the inventory data are multiplied for the characterization factors which reflects their relative contribution to the environmental impact, quantifying how much impact a product or service has in each impact category. For example, kg of CO_2 equivalent is the measurement unit for GWP.

- *Normalization*

Normalization is applied to identify the most relevant impact category. This optional step is carried out by dividing the potential value of an impact category by a reference situation's scores. The normalized impact is the fractional contribution of the product system to a given impact category. For example, normalization can be used to determine the annual impact an average person has.

- *Grouping*

Grouping is an optional step of LCIA in which impact categories are grouped through two possible procedures: sorting the category indicators on nominal basis (e.g. by characteristics or global regional and local spatial scales); ranking of the category indicators on an ordinary scale (e.g. high, medium and low priority).

- *Weighting*

Weighting is a process that assigns relative significance to impact categories. In this step weighting factors are assigned to normalized indicator according to the relative importance of each impact category assessed. By multiplying these two values a weighted result is obtained. All weighted results have the same unit and can be added together to create a single score for the environmental impact of a product.

2.3.4. Interpretation phase

During this phase of the LCA the results are analyzed in terms of completeness, sensitivity, and consistency. The aim is to verify the fulfillment of the requirements defined in the goal and scope. ISO 14044 standard establishes three steps to perform the life cycle interpretation: the identification of the key issues, the evaluation by completeness, sensitivity and consistency analysis, and development of conclusions and recommendations. If the results do not fulfill the requirements, the analysis must be improved through the iteration of the four phases of LCA.

- *Identification of key issues*

The aim of this step is to identify key issues or weak point of the product system that mostly contribute to the environmental impact to improve the environmental aspects of the product. Different identification methods can be used:

- the *contribution analysis* consists in determining how much each life cycle step contribute to the total result, expressed in percentage of the total.
- the *dominance analysis* makes use of statistical tools or quantitative or qualitative ranking method to examine significant contribution.
- the *influence analysis* analyzes the possibility of the product system under study to influence the environmental issues.
- the *anomaly assessment* consists in the observation of unusual or surprising deviations from the expected results by comparing them with those obtained by previous analyst experience.

- *Evaluation*

The completeness, sensitivity and consistency of the results obtained must be evaluated through the following methods.

- *Completeness check* is an operation to ensure that all data and information required for the LCA are complete. If gaps are present and significantly affect the key issues identified, the goal and scope of the LCA study must be revised.
- *Sensitivity check* has the aim to assess the influence of varying assumptions on the results, then it determines the degree of reliability of the LCA results, especially related to identified key issues.
- *Consistency check* determines whether methods, procedures, data, and assumptions employed in the LCA study are applied with consistency throughout the entire LCA.

- *Conclusions and recommendations*

Conclusions and recommendation should include which environmental aspects of the product, possible areas for improvement or key environmental information to communicate to the consumer (CTI, 2004).

2.4. Product Environmental Footprint (PEF)

The PEF Guide was developed as one of the building blocks of the initiative of the Europe 2020 Strategy with the aim to "establish a common methodological approach to enable Member States and the private sector to assess, display and benchmark the environmental performance of products, services and companies based on a comprehensive assessment of environmental impacts over the life-cycle (environmental footprint)" (L. Zampori, 2019).

In April 2013 the Commission adopted Recommendation 2013/179/EU on the use of common methods to measure and communicate the life cycle environmental performance of products and organizations. It defines PEF as a multi-criteria measure of the environmental performance of goods or services throughout their life cycle, produced for the overarching purpose of helping to reduce the environmental impacts of goods and services.

The applications of PEF studies can be classified depending on in-house or external objectives:

- in-house applications include optimization of processes along the life cycle of a product, support to environmental management, identification of environmental hotspots, support for product design minimizing environmental impacts along the life cycle, environmental performance improvement and tracking,
- external applications cover a wide range of possibilities, from responding to customer and consumer demands, to marketing, benchmarking, environmental labelling, supporting eco-design throughout supply chains, green procurement and responding to the requirements of environmental policies at European or Member State level.

Each requirement specified in the PEF method were developed considering the recommendations of similar, widely recognized product environmental accounting methods and guidance documents, which are:

- ISO standards, in particular: ISO 14044, ISO 14067, ISO 14025, ISO 14020.
- ILCD (International Reference Life Cycle Data System) Handbook.
- Ecological Footprint.
- Greenhouse Gas Protocol (WRI/ WBCSD).
- General principles for an environmental communication on mass market products BPX 30-323-0 (ADEME).
- Specification for the assessment of the life cycle greenhouse gas emissions of goods and services (PAS 2050).

(European Commission, 2013)

2.4.1. Phases of a PEF study

The technical report by the Joint Research Centre (JRC) describes the four phases to carry out for conducting a PEF study:

- Goal Definition.
- Scope Definition.
- Resource Use and Emissions Profile, Environmental Footprint Impact Assessment
- Environmental Footprint Interpretation and Reporting.

(L. Zampori, 2019)

2.4.2. Product Environmental Footprint Category Rules (PEFCR)

According to the Recommendation 2013/179/EU, PEFCRs have the aim to provide detailed technical guidance on how to conduct a PEF study for a specific product category. They increase the reproducibility, quality, consistency, and relevance of PEF studies and help PEF experts to focus on the most important parameters, to reduce time, efforts, and costs required to conduct a PEF study.

PEFCRs provide further specification at the process and product level, in particular specification and guidance in:

- Defining the goal and scope of the study
- Defining relevant/irrelevant impact categories
- Identifying appropriate system boundaries for the analysis
- Identifying key parameters and life-cycle stages
- Providing guidance on possible data sources
- Completing the Resource Use and Emissions Profile phase
- Providing further specification on how to solve multi-functionality problems.

(European Commission, 2013)

2.4.3. Product Environmental Footprint's history

Four phases can be identified in the PEF history: the preparatory phase, the pilot phase, the transition phase, and the implementation phase.

The *preparatory phase* began in 2008, when the European Commission was commissioned by the European Council to perform studies on carbon footprints. The European Commission observed that the GHG emissions were not the most important environmental aspect for all products and sectors, therefore, the same method couldn’t be applied to products regardless their differences.

DG Environment has worked together with the European Commission's Joint Research Centre (JRC) and other European Commission services towards the development of a harmonized methodology for the calculation of the environmental footprint of products and organizations. The final methods, called Product Environmental Footprint (PEF) and Organization Environmental Footprint (OEF), were published.

In 2013 began the *pilot phase*, which had three main objectives:

- test the process for developing product and sector specific rules.
- test different approaches to verification.
- test communication vehicles for communicating life cycle environmental performance to business partners, consumers, and other company stakeholders.

During this phase the PEF method and PEFCRs were tested using 25 PEF pilot studies to develop PEFCRs specifically designed for a specific group of products. At the end of the pilot phase, the European Commission released the PEFCRs to anyone who wanted to do a study on the PEF.

During the *transition phase* (2018-2021) anyone could test PEFCRs, so that companies that wanted to create PEF or a new PEFCR could do it.

The *implementation phase* began in 2021 when the Commission in December adopted the revised Recommendation on the use of Environmental Footprint methods. Today the EU decides where and when the PEF is required by law becoming mandatory to claim the environmental impact on products.

2.4.4. Differences between PEF and LCA

Both LCA and PEF are methods employed for the evaluation of environmental sustainability of goods and services, but they have few differences. Both LCA and PEF take a life cycle perspective, but PEF follows further product category specific requirements and standardized specifications, allowing better comparability of the results.

The PEF method covers the entire cradle-to-grave cycle of a product, while in LCA studies it is possible to choose which unit processes to include within the system boundary.

Finally, the PEF provides a formula for end-of-life processes and a concrete approach which can employs standardized LCIA methods, while in LCAs different variants can be identified, which in turn makes more difficult the comparison of LCAs.

3. CASE STUDY DESCRIPTION

3.1. Objective of the study

The objective of this LCA study is to assess the environmental sustainability of frozen peas production to identify hotspots along the supply chain and improve them. Moreover, the environmental sustainability of integrated, “sustainable”, and organic production systems is evaluated. This study is part of a project of Università Politecnica delle Marche in collaboration with Coltivatori Ortofrutticoli Valli delle Marche (C.O.VAL.M.) which provided real and verified data related to the production of frozen peas.

3.2. Coltivatori Ortofrutticoli Valli delle Marche and O.R.T.O. Verde

C.O.VAL.M. is an Italian agricultural cooperative society that produces and transforms vegetables mainly intended for the frozen market while a negligible part is destined for the fresh market. It was born in 2004 as a producer organization of 130 shareholders with the aim of ensuring protection to agricultural producers. In 2007 C.O.VAL.M. acquired a processing and freezing plant in Senigallia (AN). Today, more than 600 producers from Marche, Abruzzo, Puglia, and Emilia Romagna regions are members of the cooperative society.

C.O.VAL.M. manages an integrated and controlled supply chain, which includes raw material production, processing, transformation, packaging, and distribution. The raw materials production is classified according to the agricultural system adopted by farmers in integrated, sustainable, and organic. The short supply chain guarantees good quality products: vegetables cultivated in different Italian regions are harvested and then transported to production plants, where they are transformed in a very short time to ensure the conservation of all the organoleptic and taste properties for a healthy and genuine product. Their products are the following: garlic, basil, chard, broccoli, cauliflower, carrots, chicory, turnip greens and florets, onion, borlotti beans, green beans, broccoli, potatoes, peas, cherry tomatoes, tomato, leek, shallot, celery, spinach, snow peas, pumpkin, cabbage, and zucchini. Their production is mainly driven by peas, with 18,000 tons of peas per year produced.

C.O.VAL.M. is aware of environmental issues and then of the importance that achieving environmental sustainability. To this end, C.O.VAL.M. has adopted an integrated supply chain and enhances organic production, thus limiting the use of pesticides and optimizing the use of energy and water resources. Furthermore, C.O.VAL.M. is committed to measuring and progressively reducing its environmental impacts with a view to continually improving its performance to preserve the environmental resources.

Since 2007, the transformation activity is entrusted to the O.R.T.O. Verde s.c.a.p.a. The company produces and distributes frozen vegetables for industry, retail, and catering costumers both on behalf of third parties and with its own brand line; "I freschi di campo" are O.R.T.O. Verde products strictly cultivated in the Marche region in compliance with the short supply chain to guarantee good quality products.

The company pays attention to seasonality, ripening times for harvesting, and the rational use of agronomic and phytosanitary techniques to protect the environment, natural resources, and respect consumers health. The freezing process of the vegetables takes place within the shortest time possible of harvesting to keep all the nutritional properties, taste, authenticity, and freshness of the product.

O.R.T.O. Verde s.c.a.p.a. involves 500 members, 6.000 hectares of soil cultivated, 50.000 tonnes of frozen vegetables per year and 2 manufacturing plants placed one in Rotella (AP) and one in Cesano di Senigallia (AN). The company is the leading supplier of the biggest Italian brands of frozen vegetables; indeed, their products are chosen and sold by Findus and Orogel for the high quality and safety products they supply, and for the traceability and transparency ensured along the entire supply chain. Finally, the company carry out analysis on raw materials, production processes and finished products in their own laboratories for quality controls. In addition, C.O.VAL.M. carries out chemical and microbiological analysis on water and food matrices in the associated laboratory analysis placed in Rotella (AN) accredited by the Italian accreditation body Accredia.

3.2.1. C.O.VAL.M. O.R.T.O. Verde's certifications

The company bears the following certifications:

- *Integral production and supply chain certification*

The integrated production and supply chain is certified and accredited by Accredia in compliance with the UNI CEI EN 17065: 2012 standard, a specification that provides agronomic and phytosanitary technical indications for agricultural producers, technicians and all the players in the production chain of vegetables destined for industrial processing.

- *BRC (British Retail Consortium) international standard* with grade AA
- *Organic production certification*

Organic production is based on the adoption of the best environmentally friendly practices for the maintenance of a high level of biodiversity, the protection of natural resources, and the production suited to the preferences of consumers for products obtained from natural substances. The organic logo and the labeling system have the task of ensuring the consumer that the product they are buying has been obtained in compliance with the European regulation on organic farming and national legislation.

- *QM certification for peas, spinach, and green beans*

The QM quality brand guarantee quality, traceability, and completeness of information. Quality means rigorous compliance with the production regulations and all product controls. Traceability certifies the transparency of each phase of production and of all the subjects involved. The exhaustiveness of the information is ensured from information reported on the label to those available on the internet. The O.R.T.O. Verde products bearing the QM brand are *new peas*, *primizia peas*, *cubed leaf spinach* and *very fine green beans*.

- *Sustainable agriculture certification*

Companies producing frozen vegetables such as Findus adopt sustainable agriculture certification on voluntary basis to communicate to customers that the product comes from sustainable agricultural programs and sustainable food systems. Therefore, these companies ask O.R.T.O. Verde the compliance with specific criteria required for sustainability agriculture certification. Indeed, Findus has 90% of the total volumes of plants verified according to the Farm Sustainability Assessment (FSA) standard, a framework developed by the Sustainable Agriculture Initiative (SAI) platform. FSA is not the only framework available for agri-food products obtained with sustainable farming, but it is one of the most popular. FSA is a self-assessment used by farmers to assess and report on their farm's level of sustainability: it consists in answering to 112 questions covering social, environmental, economic, and general farm management practices for crop production. These questions are classified as essential, basic, and advanced. Depending on the final score obtained from the given answers, FSA assess the company performance level as bronze, silver, or gold.

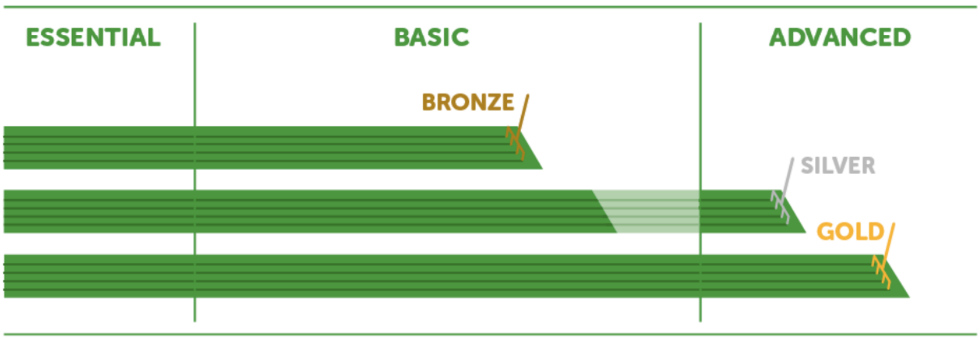

Figure 3-1: FSA scores required to achieve the different levels of performance.

As shown in Figure 3-1, to achieve the bronze performance level are required a minimum 100% coverage of essentials and 75% of basic; silver requires a minimum 100% coverage of essentials and 80% of basic and 50% of advanced; finally, gold requires a minimum 100% coverage of essentials, 100% of basic and 75% of advanced. The FSA will be revised and updated every three years.

Sustainable agriculture does not significantly differ from the integrated agriculture concerning the agronomic and phytosanitary technical indications for agricultural producers. Both approaches aim to reduce the use of chemical synthesis substances, to use low environmental impact products, to plan and implement suitable crop rotations and green manure, to use rationally water resources, to minimize the mechanical interventions on the soil and its compaction, to use energy from renewable sources, and to control greenhouse gas emissions and to implement systems for their reduction. Greater differences concern social, economic, and general farm management practices.

3.3. Frozen peas supply chain

Peas are small and spherical seeds of leguminous plants contained in the pod of the *Pisum sativum* plant species which belongs to the Fabaceae family. The pea plants have a life cycle of one year and withstand to low temperatures. The sowing period depends on the climate of the cultivation area: sowing is carried out in autumn and winter in the Italian central-southern regions, while in the northern regions it can begin at the end of winter and continue in the spring season.

Peas can be round or wrinkled: round peas contain amylose and have more flavor while wrinkled peas also contain amylopectin thus resulting sweeter and tastier. They have a high nutritional profile if compared to other vegetables; the nutritional profile referred to 100 gr of peas is shown in the Table 3-1.

Table 3-1: Peas nutritional profile referred to 100 gr.

Product component	Unit	Quantity
Energy	kcal	81
Carbohydrates	g	14,45
Protein	g	5,42
Fat	g	0,4
Vitamin A	% of DRI*	5
Vitamin K	% of DRI	24
Vitamin C	% of DRI	48
Thiamine	% of DRI	23
Folate	% of DRI	16
Manganese	% of DRI	20
Iron	% of DRI	11
Phosphorus	% of DRI	15

*DRI: Daily Recommended Intake
(U.S. Department of agriculture, 2019)

About 70% of those calories come from carbohydrates and the rest are provided by protein and a small amount of fat. In addition, peas contain significant quantity of vitamins, iron, and dietary fibers.

At O.R.T.O. Verde, the supply chain steps, which includes cultivation, transport, and processing, are described below.

3.3.1. Cultivation

In 2020, O.R.T.O. Verde associated farmers had 457 fields for a total of 4.558,50 hectares. Farmers manage three cultivation systems: integrated, sustainable, and organic. The Table 3-2 shows the number of fields and the respective hectares divided per cultivation system.

Table 3-2: Fields number and hectares per cultivation system.

Cultivation system	Fields number	Hectares
Integrated	253	1.910,30
Sustainable	176	2.245,20
Organic	28	403
Total	457	4.558,50

Cultivation includes soil preparation, sowing, fertilization, weed control, pest management and harvest.

Weather conditions, pest and disease attacks can significantly affect the yield of pea production due to the open field production system adopted. Therefore, proper soil management is essential to break any disease chain or pest buildup and excessive depletion of specific soil nutrients. One of the most common practices used by farmers is *crop rotation*. Producers often cultivated wheat or grain before peas cultivation. Sometimes sunflower and rapeseed are used as substitutes, or horticultural crops such as tomato and zucchini. Legumes such as field beans and chickpea are cultivated as the penultimate crop and mostly wheat, grain, or alfalfa as the initial crop. Furthermore, operations such as *soil ploughing*, *harrowing*, *manure* and *slurry distribution* were performed.

The *sowing* of early, medium, and late *cultivars* was planned in order to guarantee a continuous harvest. In fact, sowing took place between the end of November 2019 and mid-April 2020 using an average of 200 kg / ha of seeds. The main cultivated varieties are the following: Azarro, Cargo, Ebba, Extasia, Madison, Maurice, Sherwood, Stampede, Style, Tomahawk and Wolf.

A tenderometer was used to measure the tenderometric degree (i.e. the effort required to compress and extrude a standard quantity of peas through a grid) in order to decide the right ripeness degree for harvesting. The *harvesting* was performed from the beginning of April to the end of June 2020 and the collected peas were loaded onto the transport truck.

3.3.1.1. Integrated approach

The integrated approach includes the use of synthetic chemical fertilizers, fungicides, insecticides, and herbicides. It differs from the other approaches for the high input levels to achieve a high yield agriculture.

Fertilizers

Fertilizers are natural or synthetic materials applied to the soil or plant tissue to provide nutrients for supporting plant growth and development. Fertilization is performed to provide mainly 3 macro nutrients: Nitrogen (N), Phosphorus (P), and Potassium (K). Each fertilizer has different NPK chemical content, which indicate the quantity of each macro nutrient contained within it. Fertilizers can be either solid or liquid and their application requires the use of agricultural equipment. The Table 3-3 shows the fertilizers used in fields under integrated system and their relative NPK content.

Table 3-3: Fertilizers used in fields with an integrated approach.

Fertilizers	NPK content
Ammonium nitrate	26 (N)
Fertiactyl Gz	13(N) 00 (P) 05(K)

In addition to nitrogen fertilizers, biostimulants such as *Kendal Te* were also used. It contains substances for supporting and stimulating the plant growth and development throughout the life cycle of the crop.

Pesticides

A pesticide is a substance used to prevent, destroy, or control a harmful organism or disease, or protect plants or plant products during production, storage, and transport. The term includes herbicides, fungicides, insecticides, acaricides, nematicides, molluscicides, growth regulators, repellents, rodenticides, and biocides (European Commission, 2022d). Pesticides can be liquid or solid and are diluted or dissolved in water for application to the soil or to the plant tissues. Pesticides available on the market may contain the same active principle but sold under a different commercial name. The following Table 3-4 reports the names of the active principles of the pesticides used classified as insecticides and fungicides, each associated to the specific pest or disease for which they were applied.

Table 3-4: Insecticides and fungicides used in fields with an integrated approach.

Insecticides	Pest/disease	Fungicides	Pest/disease
Pirimicarb	Aphids	Cimoxanil	Downy mildew
Lambda-Cialotrina	Aphids	Bordeaux mixture	Colletotrichum spp
Deltametrina	Aphis fabae		
Tau-Fluvalinate	Aphis fabae		

The pesticide interventions were performed mainly for the treatment of *aphids* and *downy mildew*. The integrated approach is to distribute the pesticide only when the intervention threshold is exceeded. The Table 3-5 reports the active principles of herbicides used for weeding control.

Table 3-5: Herbicides used in fields with an integrated approach.

Herbicides
Pendimetalin
Quizalofop-P-Etile
Aclonifen
Imazamox
Bentazone
Cicloxidim
Propaquizafop

3.3.1.2. Sustainable approach

The sustainable approach consists in reduced use of chemical synthesis substances, rational use of water resources, and minimization of mechanical interventions on the soil. However, this approach does not significantly differ from the integrated approach for the types of fertilizers and pesticides used. The Table 3-6 shows the fertilizers used.

Table 3-6: Fertilizers used in fields with a sustainable approach.

Fertilizers	NPK content
Ammonium nitrate	26 (N)
Fertiactyl Gz	13 (N) 00(P) 05(K)
Urea	46(N)
Megafol fogliare	03(N) 00(P) 08(K)

As in the integrated approach, biostimulants are used such as *Kendal Te* and *Impulsive premium*. The Tables 3-7 and 3-8 shows the pesticides used.

Table 3-7: Insecticides and fungicides used in fields with a sustainable approach.

Insecticides	Pest/disease	Fungicides	Pest/disease
Pirimicarb	Aphids	Cimoxanil	Downy mildew
Lambda-Cialotrina	Aphids	Bordeaux mixture	Colletotrichum spp
Deltametrina	Aphis fabae		

Table 3-8: Herbicides used in fields with a sustainable approach.

Herbicides
Pendimetalin
Quizalofop-P-Etile
Aclonifen
Imazamox
Bentazone
Cicloxidim
Propaquizafop

3.3.1.3. Organic approach

The organic agricultural system is based on the application of biological fertilizers and ecologically based pest control products. Compared with integrated agriculture, organic agriculture foresees reduced application of fertilizers and pesticides, agricultural practices to reduce soil erosion, decreased nitrate leaching into groundwater and surface water, crop rotation, and the recycle of animal manure back into the farm. These benefits are counterbalanced by higher food costs for consumers and generally lower yields.

Fertilizers

Pea plants cultivated with an organic approach were fertilized with *Propolis*, that is a natural extract used to activates and enhances the natural resistance of plants against adversity. Thanks to its fraction of flavonoid compounds, it also stimulates the fundamental physiological functions, and promotes the rapid healing of tissues and wounds caused by injuries.

Pesticides

The insecticides allowed for application on pea plants with an organic approach are:

- *Pyrethrins*, that are compounds of natural origin extracted from *Chrysanthemum cinerariaefolium* flowers, used against aphids.
- *Azadiractina* used against aphids.
- *Spinosad* used against the moth *Mamestra brassicae*: this insecticide is obtained from the bacterium *Saccharopolyspora spinosa* which occurs naturally in the soil.

Bordeaux mixture (mixture of copper sulphate and calcium hydroxide) is the only fungicide applied against *Downy mildew*.

3.3.2. Transport

The transport of bulk peas is carried out through trucks with a maximum capacity of 9 tons. The vehicles are open trucks to avoid product microbial spoilage and overheating. They are diesel powered and 80% loaded. In addition, they are equipped with hermetic containers in steel to contain the leachate produced during transport and avoid getting lost on the street. The environmental class of the truck is EURO 3. The truck on the return journey is empty because they are only intended for the transport of food products.

3.3.3. Processing

In *Table 3-9,* the quantities of peas provided to O.R.T.O. Verde in 2020 are reported.

Table 3-9: Pea's quantity provided to O.R.T.O. Verde in 2020.

Cultivation system	Quantities at the gate (kg)
Integrated	3,26E+06
Sustainable	3,39E+06
Organic	1,05E+06
Total	*7,70E+06*

The flow chart of the peas processing carried out in O.R.T.O. Verde company is shown in Figure 3-2.

Once harvested, peas must be processed as quickly as possible to prevent them from warming up, which might cause the peas to be affected by bacteria. At the *receipt of raw materials,* freshly harvested peas undergo to the required registrations and checks while waiting to be sent to the processing lines. The raw materials are then poured from the truck directly into the bunker where a feeding belt move peas slowly to the subsequent phase.

The *cleaning* is carried out in 6 steps in the following order: pneumatic air separation, water stone removal, vibrating screening, belt stone removal, washing and vibrating screening.

A first separation of the product from light plant materials is carried out by means of a *pneumatic air separator*. The product is brought to the cleaner hopper by means of a bucket elevator and during the fall into the cleaning chamber is hit at variable speed, by an ascending current of air. In this step the first waste is generated, consisting mainly in plant leaves and grass.

Coarse and heavy dirt particles are removed through *water stone removal*. The peas are fed into the machine where they are immersed in drinking water and moved by water circuits to favor peas separation from heavier materials exploiting their different density, such as stones and animals (insects). Then, peas are moved by a *vibrating screen*, for further removal of foreign materials, to the *belt stone removal.* It is performed on an inclined plane for removal of residues such as branches and bark.

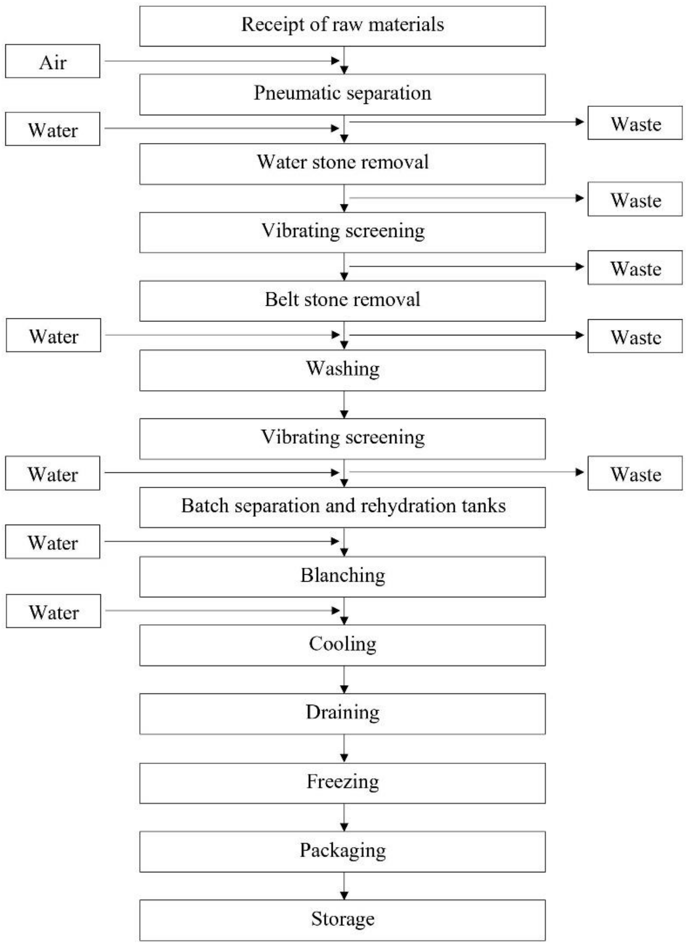

Figure 3-2: Frozen peas processing flow.

To make sure no debris from the field is left over, *washing* is then carried out by means of a rotating drum using drinking water. Washing with water has the purpose of removing any impurities still present such as earth, pesticide residues, and any other washable materials. The cleaning process ends with a *vibrating screen* for the removal of any remaining foreign materials.

Once thoroughly cleaned, peas are sent to *batch separation* tanks by means of water channels. The tanks load capacity is of 9 tons, equal to the quantity of peas transported by a truck. *Batch separation* is required to temporarily stock peas before blanching separating the different batches to ensure perfect product traceability. This phase is essential considering that the harvesting of the different fields is often contemporary and different productions tend to overlap.

Blanching is performed to inactivate enzymes by immersing the product in boiling water. This phase is crucial, and many aspects must be considered: a uniform distribution of heat to the individual units of the product, to ensure an identical duration of treatment; do not damage the product during the blanching and cooling phases; allow high product yields and a high degree of quality; have limited consumption of water and energy; ensure satisfactory reliability. The blanching machine uses methane to generate high temperature steam (92°C). This step represents the only critical control point of the entire production chain, and the critical limit is established at a temperature of 94°C +- 2°C for 75'' of time.

After blanching, the product must be quickly *cooled* to a temperature below 15°C, to stop the action of heat, which could further damage product quality, and to prevent the growth of thermophilic microorganisms. A rotating cylinder immersed in a tank containing drinking water is used for cooling.

A step of *draining* is performed. The excess water is drained off (and sent to a treatment plant) by means of a belt moved by a vibrator, at the same time a manual sorting is carried out.

Peas are frozen at -20°C through a rapid *freezing* process which allows to obtain the micro crystallization of the ice and to achieve the following advantages:

- maintain the structural characteristics of the products almost equivalent to those of the original fresh products and therefore the biochemical and nutritional stability of frozen foods is higher over time.
- reduce liquid losses upon thawing.
- make online processing possible and the transformation process cheaper.

The products at the end of the freezing are mechanically *packaged*. During the various steps of the cold chain, if they are not adequately protected, they can be subjected to oxidation, weight loss and contamination by chemical and microbial agents. It is, therefore, essential to protect the products with suitable packaging and remove the air from the packaging as much as possible, to ensure correct and prolonged storage.

The production process ends with *storage* of packaged frozen peas in freezing cells.

3.4. Materials and methods

The environmental sustainability of the frozen peas production was evaluated using the Life Cycle Assessment methodology. The LCA was carried out using the SimaPro (version 9.1) software, based on the ISO 14040 and 14044 standards. This software is a tool that allows to analyse the sustainability performance of a product or service.

SimaPro allows the creation of projects customized on the product studied and to model the product life cycle stages according to the goal of the study. Before starting the LCA, the libraries required for the product study must be selected. These libraries contain LCI databases that provide information about the inputs, outputs, and emission of industrial, agricultural, transport, and household processes.

SimaPro includes the following LCI databases:

- *Agri-footprint*

Agri-footprint is an agriculture-oriented LCI database that was developed by Blonk Consultants. This database is especially suited for sensitivity analyses, and it finds application for agricultural LCAs, carbon footprinting, and comparative product life cycle assessment (LCAs). Agri-footprint database contains approximately 5,000 products and processes strictly related to agricultural LCA, such as crops, food products, and background processes such as transport, energy, pesticides, and fertilizers.

- *Ecoinvent 3*

It was developed by the Ecoinvent center and finds application for many life cycle assessment projects, carbon footprint assessment, water footprint assessment, environmental performance monitoring, product design and eco-design. It consists of more than 15,000 datasets on energy supply, agriculture, transport, biofuels and biomaterials, bulk and specialty chemicals, construction materials, packaging materials, basic and precious metals, metals processing, ICT and electronics, dairy, wood, and waste treatment. Currently, it is the most complete and well-documented LCI database.

- *ELCD*
- *EU & Danish Input Output Database*
- *Industry data 2.0*

This database contains data collected by industry associations and processes from PlasticsEurope, worldsteel, and ERASM (European Detergents and Surfactants Industries).

- *USA Input Output Database*
- *USLCI*

This database was created by NREL and its partners. It provides individual gate-to-gate, cradle-to-gate, and cradle-to-grave accounting of the energy and material flows into and out of the environments that are associated with producing a material, component, or assembly in the U.S.

These libraries contain inventory databases which provide data and processes for the collection in the inventory table of information related to material, energy, transport, processing, use, waste scenario and waste treatment. When selecting the process needed for the LCI phase, it is important to verify the information contained in the selected process such as the unit, the type of allocation, eventually included emissions, and other additional information to choose the most appropriate for the study.

SimaPro measures the environmental impact across all life cycle stages of the product according to the LCIA method selected. In SimaPro is possible to choose the most appropriate impact assessment method, which are classified as global and European methods. Global methods are IMPACT World+ Endpoint and Midpoint, LC-IMPACT, and ReCiPe 2016 Endpoint and Midpoint. European methods are CML-IA baseline and non-baseline, Ecological Scarcity 2013, EF 3.0 Method, EN 15804 + A2, Environmental Prices, EPD (2018), and EPS 2015d and dx. Finally, SimaPro allows to identify the hotspots in every link of your supply chain, from extraction of raw materials to manufacturing, distribution, use, and disposal.

The CML_IA baseline is the method used for the LCIA of frozen peas production.

This LCIA methodology was developed in 2001 by a group of scientists under the lead of CML (Center of Environmental Science of Leiden University). This methodology is based on the midpoint approach; it foresees normalization but not weighing and addition. According to the CML_IA methodology, the following impact categories are included:

- *Depletion of abiotic resources*

This impact category is referred to the consumption of non-renewable sources such as minerals and fossil fuels for energy production, thus affecting human welfare, human health, and ecosystem health. The Abiotic Depletion Factor (ADF) is a value that measure the scarcity of such resources that depends on the quantity of the resource and the extraction rate. Indeed, the abiotic depletion potential is the quantity of depleted resources expressed as kg antimony equivalents, kg of minerals or MJ for fossil fuels.

- *Climate change*

The increasing release of GHG caused by human activities has a noticeable effect on climate, that is the raise of global temperature. This raise is expected to cause climatic disturbance, desertification, rising sea levels and spread of disease. the UN's Intergovernmental Panel on Climate Change (IPCC) developed Environmental Profiles characterisation model based on factors expressed as Global Warming Potential over the time horizon of different years, being the most common 100 years (GWP100). GWP measures the heat absorbed by any GHG in the air, including carbon dioxide, methane, sulphur hexafluoride, and dinitrogen monoxide. Carbon dioxide is used as reference unit to measure GWP, expressed as kg CO_2 equivalent.

- *Ozone Layer Depletion*

Ozone-depleting gases cause damages to stratospheric ozone, also known as the "ozone layer". CFCs, halons and HCFCs are the major causes of ozone depletion, thus reducing its ability to prevent ultraviolet (UV) light entering the earth's atmosphere, increasing the amount of carcinogenic UVB light reaching the earth's surface. Ozone Depletion Potential (ODP), therefore, has harmful effects upon human health, animal health, terrestrial and aquatic ecosystems, biochemical cycles and on materials. The World Meteorological Organisation (WMO) defined the ozone depletion potential of different gases relative to the reference substance chlorofluorocarbon-11 (CFC-11), expressed in kg CFC-11 equivalent.

- *Human toxicity*

This impact category is related to the potential harm of toxic substances released in the environment, not including the working environment. These by-products, mainly arsenic, sodium dichromate, and hydrogen fluoride, are mainly caused by electricity production from fossil sources. These are potentially dangerous chemicals to humans through inhalation, ingestion, and even contact. The Human Toxicity Potential (HTP) is a calculated index that reflects the potential harm of a unit of chemical released into the environment, and it is based on both the inherent toxicity of a compound and its potential dose. This potential is measured in 1,4-dichlorobenzene equivalents.

- *Eco-toxicity*

This impact category is referred to the impact that emissions of toxic substances (i.e. heavy metals) to air, water and soil have on freshwater ecosystem. Eco-toxicity Potentials describe the fate, exposure, and effects of toxic substances on the environment. Environmental toxicity is measured as three separate impact categories which examine freshwater, marine and land. Characterisation factors are expressed using the reference unit, kg 1,4-dichlorobenzene equivalents and are measured separately for impacts of toxic substances on *Fresh-water aquatic ecosystems*, *Marine aquatic ecosystems*, *Terrestrial ecosystems*.

- *Photochemical oxidation*

Ozone on the ground-level it is toxic to humans in high concentration. Its formation is due to the reaction of volatile organic compounds and nitrogen oxides in the presence of heat and sunlight, which are injurious to human health and ecosystems, and which also may damage crops. Photochemical Ozone Creation Potential (POCP) for emission of substances to air is expressed using the reference unit, kg ethylene (C_2H_4) equivalent.

- *Acidification*

Acidic gases such as ammonia (NH_3), nitrogen oxides (NOx) and sulphur oxides (SOx) react with water in the atmosphere to form acid rain, which cause a wide range of impacts on soil, groundwater, surface water, organisms, ecosystems, and materials. Acidification Potential (AP) is expressed as kg SO_2 equivalents/ kg emission.

- *Eutrophication*

Eutrophication is the increasing concentration of chemical nutrients in an ecosystem which impacts are caused by emissions of these nutrients, such as ammonia, nitrates, nitrogen oxides and phosphorous, to air, water, and soil. Eutrophication potential (EP) is expressed as kg PO_4 equivalents.

4. LCA OF CASE STUDY

4.1. Goal and scope phase

The *goal* of this attributive LCA study is to assess the environmental impact of the production and processing of 1 kg of packaged frozen peas. The study was carried out also to evaluate the environmental aspects of sustainability of peas grown by three different agricultural systems (integrated, sustainable, and organic). The results of this study will be used to identify potential hotspots of improvement and to determine the environmental performance of the three agricultural systems. The following study involves the researchers of Università Politecnica delle Marche, O.R.T.O. Verde and C.O.VAL.M. Interested parties can be companies involved in the production and processing of frozen peas, legislators, and LCA researchers interested about the potential environmental impact of frozen peas.

The *product system* is the frozen peas production starting from the agricultural cultivation.

The *system function* is to provide packaged frozen peas, no co-product or by-product were produced, then it is not a multifunctional process.

The *functional unit* (FU) selected, on which the inventory data are normalized for the LCIA, is 1 kg of packed frozen peas cultivated in Italy adopting the integrated, sustainable, or organic agricultural system.

The *system boundary* includes the part of the supply chain that start from peas cultivation and ends with frozen peas packaging (*"cradle to industry gate"* approach), as described in the Figure 4-1 below.

Primary data collected for the LCA analysis were directly provided by O.R.T.O. Verde company and taken from farmers' official documents. *Secondary data* were derived from the SimaPro database or literature sources.

No *allocation procedures* have been performed. The product life cycle studied does not produce co-products. In addition, the data were provided allocated to the production of peas.

The LCIA methodology selected for this study is CML_IA baseline v 3.01 with eleven impact categories.

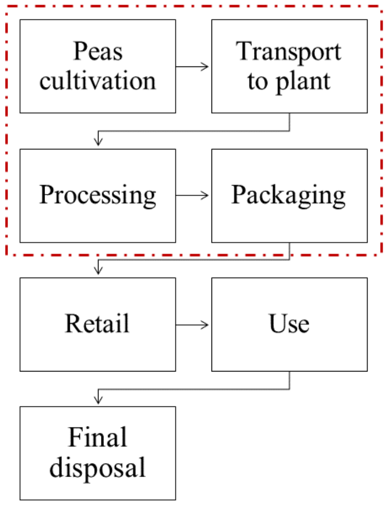

Figure 4-1: System's unit processes and system boundary of the packaged frozen peas production chain (the processes considered are those bonded by the dotted line).

4.2. Life Cycle Inventory analysis phase (LCI)

In this phase of the study, data were collected and then reported in the inventory table. All inputs were normalized to the defined FU: 1 kg of packaged frozen peas.

O.R.T.O. Verde company provided *primary data* regarding field characteristics, agricultural operations, fertilizers, and pesticides applied, transport characteristics, and processing plant data covering transformation efficiency, packaging materials, electricity, and natural gas consumption. *Secondary data* regarding seed quantity, manure and slurry quantity and water used for dilution and dissolution of pesticides were indirectly obtained from scientific literature sources.

4.2.1.Cultivation

The LCA study was carried out on a sample of the entire frozen peas production. Farmers' fields were selected according to the following criteria:

- Agricultural system: 18 fields were selected for each agricultural system, being integrated, sustainable and organic, for a total of 54 fields.
- Field surface: ranging from 2,5 to 28 ha.
- Field location: 13 of the 18 fields selected for each agricultural system are in the Marche region and the remaining 5 fields are in the Puglia region.

The main characteristics of selected fields for this LCA study are listed in the Table 4-1.

Table 4-1:Main characteristics of the selected fields concerning the agricultural system adopted, field location, total field surface and sowing and harvesting period.

Field number	Cultivation system	Field location	Sowing period	Harvesting period	Total surface
13	Integrated	Marche	11-12-2019/16-03-2020	29-04-2020/04-06-2020	145,1
5	Integrated	Puglia	01-12-2019/08-12-2019	15-04-2020/25-04-2020	34
13	Sustainable	Marche	05-12-2019/20-03-2020	23-04-2020/08-06-2020	169,5
5	Sustainable	Puglia	01-12-2019/08-12-2019	15-04-2020/25-04-2020	33
13	Organic	Marche	16-12-2019/16-03-2020	04-05-2020/05-06-2020	110,3
5	Organic	Puglia	01-12-2019/06-12-2019	15-04-2020/24-04-2020	101

The information related to the cultivation step reported in the inventory table are the following:

- land surface
- operations
- seed quantity
- manure and slurry quantity
- mineral fertilizer quantity
- pesticide (herbicides, insecticides, and fungicides) quantity
- fertilizer and pesticide emissions
- water for fertilizers and treatments

LCI data related to peas cultivation for each agricultural system are listed in the Table 4-2.

Table 4-2: Total Pea's cultivation inputs for integrated, sustainable, and organic system.

Process/material	Unit	Integrated system	Sustainable system	Organic system
Land surface	ha	1,79E+02	2,03E+02	2,11E+02
Seed quantity	kg	3,58E+04	4,05E+04	4,23E+04
Water for fertilizers	l	7,87E+04	1,10E+05	2,80E+04
Water for pesticides	l	5,09E+05	5,94E+05	2,08E+05
Operations				
Soil preparation	ha	5,67E+02	6,30E+02	6,61E+02
Sowing and harvesting	ha	3,58E+02	4,05E+02	4,23E+02
Distribution of fertilizers	ha	1,64E+02	2,44E+02	3,15E+01
Distribution of pesticides	ha	1,00E+03	1,23E+03	2,23E+02

Distribution of manure and slurry	ha	3,58E+02	4,05E+02	4,23E+02
Fertilizers				
Ammonium nitrate	kg	9,17E+03	9,25E+03	
Urea	kg		3,10E+03	
Fertiactyl Gz	l	1,71E+01	2,20E+01	
Biostimulants	l	1,92E+02	2,29E+02	
Manure	t	1,00E+04	1,13E+04	1,18E+04
Slurry	t	1,41E+04	1,59E+04	1,66E+04
Propolis	l			6,30E+01
Herbicides				
Pendimetalin	l	2,19E+02	2,32E+02	
Quizalofop-P-Etile	l	1,40E+01	1,60E+01	
Aclonifen	l	1,59E+02	1,67E+02	
Imazamox	l	5,20E+00	1,12E+01	
Cicloxidim	l	1,08E+01	1,80E+01	
Propaquizafop	l	6,90E+00	1,33E+01	
Bentazone	kg	8,80E+00	2,61E+01	
Bentazone/Imazamox	l	3,21E+01	5,17E+01	
Insecticides				
Pirimicarb	kg	1,37E+02	1,46E+02	
Lambda-Cialotrina	l	6,47E+00	1,44E+01	
Deltametrina	l	1,50E+00	3,00E+00	
Tau-Fluvalinate	l	1,35E+00		
Piretrine	l			1,08E+02
Azadiractina	l			5,60E+01
Spinosad	l			8,00E-01
Mineral Oil	l			2,55E+01
Fungicides				
Cimoxanil	kg	1,89E+02	2,15E+02	
Bordeaux mixture	kg	3,55E+02	5,37E+02	1,38E+02

The land surface is given by the sum of the hectares of the 18 producers' field for each agricultural system. Seed quantity was derived from scientific literature: an average of 200 kg of seeds per hectare were sowed (F. Sodi, 2021). The water required for dissolving and diluting fertilizers, herbicides, insecticides, and fungicide was calculated according to indications declared on the product labels. Operations are referred to those for soil preparation such as ploughing, harrowing, sowing, and harvesting and those for fertilizer, pesticide, manure, and slurry distribution. The quantities of fertilizers and pesticides were directly obtained from farmers' documents.

Manure and slurry quantities were calculated as an average of the minimum and the maximum amount / ha of manure and slurry that can be distributed considering first fields as zones vulnerable to nitrates (ZVN) areas and then not ZVN areas. Pig slurry nitrogen content derived from literature sources was considered as a reference for calculations (A. Bordoni, 2021).

Once all inputs were reported in the inventory table, the emissions of fertilizers and pesticides were estimated and reported in SimaPro as well. On the other hand, emissions of operations were already included in the background processes chosen in the software.

- *Pesticides*

Pesticide's fate and relative emission were calculated following Margni et al., 2002 considering that 85% of the total active ingredient is emitted in the soil, 10% in the air and 5% in water (Margni et al., 2002).

Pesticides used by farmers can contain one or two active principles. To calculate the emissions of pesticides containing two active principles, its composition declared on the label was considered; indeed, the emissions of herbicides containing both Bentazone and Imazamox were calculated considering the 43,1 % and 2% respectively. In the Table 4-3, the emissions of herbicides used by farmers adopting the integrated and sustainable system are listed. No herbicides were applied to pea plants grown under the organic system.

Table 4-3: Emissions of herbicides applied to pea plants grown under integrated and sustainable system.

Herbicides	**Unit**	**Integrated system**	**Sustainable system**
Pendimetalin			
Soil	kg	2,12E+02	2,24E+02
Air	kg	2,50E+01	2,64E+01
Water	kg	1,25E+01	1,32E+01
Quizalofop-P-Etile			
Soil	l	1,19E+01	1,36E+01
Air	l	1,40E+00	1,60E+00
Water	l	7,00E-01	8,00E-01
Aclonifen			
Soil	kg	1,64E+02	1,71E+02
Air	kg	1,93E+01	2,01E+01

Water	kg	9,63E+00	1,01E+01
Imazamox			
Soil	kg	5,02E+00	1,05E+01
Air	kg	5,91E-01	1,23E+00
Water	kg	2,96E-01	6,17E-01
Cicloxidim			
Soil	kg	8,45E+00	1,41E+01
Air	kg	9,94E-01	1,66E+00
Water	kg	4,97E-01	8,28E-01
Propaquizafop			
Soil	l	5,87E+00	1,13E+01
Air	l	6,90E-01	1,33E+00
Water	l	3,45E-01	6,65E-01
Bentazone			
Soil	kg	2,05E+01	4,32E+01
Air	kg	2,41E+00	5,08E+00
Water	kg	1,21E+00	2,54E+00

The same considerations were done for fungicides containing two active principles: Cymoxanil and Copper emissions were calculated considering the 4,2% and 39,75% respectively. In the Table 4-4, the emissions of fungicides used by farmers adopting the integrated, sustainable, and organic system are listed.

Table 4-4: Emissions of fungicides applied to pea plants grown under integrated, sustainable, and organic system.

Fungicides	Unit	Integrated system	Sustainable system	Organic system
Cimoxanil				
Soil	kg	5,92E+00	7,68E+00	
Air	kg	6,96E-01	9,03E-01	
Water	kg	3,48E-01	4,52E-01	
Copper				
Soil	kg	5,60E+01	7,27E+01	
Air	kg	6,59E+00	8,55E+00	
Water	kg	3,29E+00	4,27E+00	
Bordeaux mixture				
Soil	kg	3,02E+02	4,56E+02	1,17E+02
Air	kg	3,55E+01	5,37E+01	1,38E+01
Water	kg	1,78E+01	2,69E+01	6,90E+00

In the following Table 4-5 and 4-6, the emissions of insecticides used by farmers adopting the integrated, sustainable, and organic system are listed.

Table 4-5: Emissions of insecticides applied to pea plants grown under integrated and sustainable system.

Insecticides	Unit	Integrated system	Sustainable system
Pirimicarb			
Soil	kg	1,16E+02	1,24E+02
Air	kg	1,37E+01	1,46E+01
Water	kg	6,84E+00	7,29E+00
Lambda-Cialotrina			
Soil	l	3,39E+00	1,26E+01
Air	l	3,99E-01	1,48E+00
Water	l	2,00E-01	7,40E-01
Deltametrina			
Soil	l	2,55E-01	2,55E+00
Air	l	3,00E-02	3,00E-01
Water	l	1,50E-02	1,50E-01
Tau-Fluvalinate			
Soil	l	2,55E-01	
Air	l	3,00E-02	
Water	l	1,50E-02	

Table 4-6: Emissions of insecticides applied to pea plants grown under organic system.

Insecticides	Unit	Organic system
Piretrine		
Soil	kg	9,14E+01
Air	kg	1,08E+01
Water	kg	5,38E+00
Azadiractina		
Soil	l	4,69E+01
Air	l	5,52E+00
Water	l	2,76E+00
Spinosad		
Soil	l	6,80E-01
Air	l	8,00E-02
Water	l	4,00E-02
Mineral Oil		

Soil	1	2,17E+01
Air	1	2,55E+00
Water	1	1,28E+00

- *Fertilizers*

The *emissions and fate of fertilizers* were calculated following the Product Category Rules (PCR) for arable and vegetable crops (Product Category Rules, 2020).

Only nitrogen fertilizers were used for peas cultivation. In details, the emission factors for ammonium nitrate fertilizers are 0,037 for ammonia (NH_3), 0,008 for dinitrogen oxide (N_2O), and 0,006 for nitrogen monoxide (NO) which directly emits to air. The emission factor for nitrates (NO_3^-) to groundwater is 0,3. Furthermore, N_2O is indirectly emitted to air from NH_3 and NO_3^-, considering emission factors 0,01 and 0,0075 respectively. In the Table 7-7 below, the total emissions of nitrogen fertilizer are listed.

Table 4-7: Emissions of nitrogen fertilizers applied to pea plants grown under integrated and sustainable system.

Emission type	**Unit**	**Integrated system**	**Sustainable system**	**Sub compartment**
Direct emissions				
N_2O	kg	6,00E+01	1,10E+02	Air
NH_3	kg	1,08E+02	5,31E+02	Air
NO	kg	3,07E+01	5,24E+01	Air
NO^{3-}	kg	3,17E+03	5,09E+03	Groundwater
Indirect emissions				
N_2O from NH_3	kg	2,79E+00	1,37E+01	Air
N_2O from NO^{3-}	kg	1,69E+01	2,71E+01	Air

Propolis was applied as fertilizer to pea plants grown under organic systems and bio stimulants such as Kendal Te and Impulsive Premium to those under integrated and sustainable system, but they do not emit, therefore they are not considered when calculating emissions.

The overall peas production from the cultivation step is reported in the Table 4-8.

Table 4-8: Fresh peas production.

Agricultural system	**Fresh peas quantity (tons)**
Organic	7,33E+02
Sustainable	8,10E+02
Integrated	7,16E+02
Total	2,26E+03

Peas production from two fields under organic system was not harvested and then wasted because damaged by adverse climatic conditions. The impact of these fields has not been considered as in SimaPro it is not possible to model a process without a production, however in the general framework the distributed inputs are part of an overall evaluation of the entire company production.

4.2.2. Transport

The transport-related information required are:

- loading factor
- distance covered by the truck
- fuel type
- environmental class
- empty return
- the peas quantity

In the reference year, the 39 fields in the Marche region are located in an area between 13 and 127 km, with a mean distance of about 72 km. While the 15 fields in the Puglia region are located in an area 315 and 345 km, with a mean distance of about 325 km.

As previously mentioned, once fresh peas are harvested, they are unloaded directly into the truck. This vehicle transports the raw materials from the fields to the company's gate. The maximum truck load is 11 tons but an average quantity of 7 tons to a maximum of 9 tons of peas are loaded on the truck. Then, the loading factor considered for the study is of 80 %. Trucks are open to avoid food losses caused by spoilage or deterioration. In addition, it is equipped with hermetic containers in steel to contain the leachate, which weigh 0,07 tons, released during the transport. The average weigh of the leachate is 0,2 tons. The truck is diesel powered and belongs to the EURO 3 environmental class. For the study, it was assumed an efficiency of the 100%, that means absence of transport losses. The emissions of this step are included in the input chosen in SimaPro. The Table 4-9 shows a summary of the main transport characteristics.

Table 4-9: Main transport characteristics.

Process/material	Unit	Value
Transport mean	type	truck (useful payload 9 tons)
Fuel	diesel	
Average distance (Marche)	km	72
Average distance (Puglia)	km	325
Transported peas	tons	2,26E+03

4.2.3. Processing

Peas produced with different agricultural systems are processed in the same way, but in different periods to avoid the mixing of the different batches. The information required for this step are:

- raw material quantity
- packaged frozen peas produced
- transformation efficiency
- processing steps
- plant powering (energy and fuels)
- packaging

The quantity of frozen peas produced by the company in 2020 is 6.576,645 t from 7.698,960 t of fresh peas; then, 1.122,315 t of peas during the transformation is wasted. The total production has and efficiency of 85%. The quantities of fresh, frozen, and wasted peas for each cultivation system are listed in the Table 4-10.

Table 4-10: Fresh, frozen, and wasted peas quantity.

Product typology	Fresh peas (tons)	Frozen peas (tons)	Efficiency (%)	Wasted peas (tons)
Integrated production	3,26E+06	2,91E+06	89%	3,43E+05
Sustainable production	3,39E+06	2,76E+06	81%	6,38E+05
Organic production	1,05E+06	9,08E+05	87%	1,41E+05
Total	7,70E+06	6,58E+06	85%	1,12E+06

The company further provided data of the processing steps; in the Table 4-11 all the inputs to produce frozen packaged peas are listed.

Table 4-11: Inputs of packaged frozen peas processing.

Process/material	Unit	Value
Peas	tons	7,70E+03
Electricity	kWh	1,97E+06
Methane	m3	1,38E+05
Packaging		
Bags (plastic)	kg	3,53E+02
Box covering (plastic)	kg	7,74E+03
Sheets 90 g (paper)	kg	8,26E-02
Sheets 120 g (paper)	kg	9,35E+02
Dividers (cardboard)	kg	2,53E+03

The *emissions* of the whole processing are already included in the inputs chosen in SimaPro.

4.3. Life Cycle Impact Assessment phase (LCIA)

Impact assessment method selected is the CML_IA Baseline version 3.01: the method includes eleven impact categories based on the midpoint approach for 1 kg of packaged frozen peas, and then nor normalization nor weighting was performed.

4.3.1. Classification

The classification assigns to all substances listed in the inventory table an impact category according to the potential effects on human and environment that they have. Depending on the LCIA method chosen different sets of impact categories are considered in the study; CML_IA baseline method has eleven environmental impacts:

- Abiotic Depletion Potential (ADP) elements (E)
- Abiotic Depletion Potential (ADP) fossil fuel (FF)
- Global Warming Potential (GWP 100 year)
- Ozone Layer Depletion Potential (ODP)
- Human Toxicity Potential (HTP)
- Fresh Water Aquatic Ecotoxicity Potential (FAETP)
- Marine Aquatic Ecotoxicity Potential (MAETP)
- Terrestrial Ecotoxicity Potential (TETP)
- Photochemical Oxone Creation Potential (POCP)
- Acidification Potential (AP)
- Eutrophication Potential (EP)

4.3.2. Characterization

Once classified, the inventory data are automatically converted by the SimaPro software into impacts expressed with the same unit to quantify the potential environmental effects of the examined system. The software multiplies the LCI data for the characterization values present in the CML_IA baseline database, thus obtaining impact scores for the mid-point environmental impact categories referred to FU.

The results of the LCIA about the environmental impact of peas through all the steps included in the system boundaries referred to the FU for each impact category are showed in the Table 4-12.

Table 4-12: Environmental impact of packaged frozen peas production for each impact category.

Impact category	Unit	Value
Abiotic Depletion Potential (ADP - elements)	kg Sb eq.	2,46E-05
Abiotic Depletion Potential (ADP - fossil fuel)	MJ	9,31E+00
Global Warming Potential (GWP - 100 year)	kg CO2 eq.	1,08E+00
Ozone layer Depletion Potential (ODP)	kg CFC-11 eq.	2,36E-07
Human Toxicity Potential (HTP)	kg 1,4-DB eq.	6,99E-01
Fresh water Aquatic Ecotoxicity Potential (FAETP)	kg 1,4-DB eq.	1,30E+00
Marine Aquatic Ecotoxicity Potential (MAETP)	kg 1,4-DB eq.	6,14E+02
Terrestrial Ecotoxicity Potential (TETP)	kg 1,4-DB eq.	3,73E-02
Photochemical Ozone Creation Potential (POCP)	kg C_2H_4 eq.	2,36E-04
Acidification Potential (AP)	kg SO_2 eq.	6,95E-03
Eutrophication Potential (EP)	kg PO_4^{3-} eq.	3,77E-03

4.4. Interpretation phase

The Life Cycle Interpretation was accomplished to identify the key issues, that is the identification of those elements that significantly contribute to each impact category, and to evaluate the LCI and LCIA results in terms of completeness and consistency. During this phase, the assumptions made in the goal and scope definition must be considered; if the results do not fulfil the requirements defined in the goal and scope, the analysis must be improved through the iteration of the four phases of the LCA. Interpretation starts with understanding the accuracy of the results, and ensuring they meet the goal of the study.

- *Evaluation*

The *completeness check* was accomplished to ensure that all data and information required for the LCA are complete. If gaps are present and significantly affect the key issues identified, the goal and scope of the LCA study must be revised.

Some of the pesticides, fertilizers and biostimulants used for cultivation were absent in SimaPro databases, therefore general processes were chosen. The company did not provide the amount of water used when processing the peas. However, it does not significantly affect the impact categories considered. A huge amount of water is expected to be used, as most operating units in the process consume it; then, it would be critical to provide such data if a water footprint analysis were to be carried out. It wasn’t possible to allocate the electricity consumption of the industrial transformation step to each process unit. If these data were available, the study would have been more accurate and complete.

Some inputs related to the cultivation step, such as seed quantity per hectare for sowing, manure and slurry quantity per hectare distributed were not provided by the company, therefore they were derived from data found on the available scientific literature. Peas produced in two fields under the organic system weren't harvested because damaged by adverse climatic conditions, thus affecting the representativeness of the organic sample. These limitations of the study further affect the completeness and accuracy of the study.

All the identified gaps represent the starting point for future improvement of this LCA study.

- *Identification of key issues*

The identification of key issues or weak points of the product system that mostly contribute to the environmental impact was performed for future improvement of the environmental aspects of the product. The identification methods used was the *contribution analysis*. It consists in determining how much each life cycle step contribute to the total product impact, expressed in percentage of the total. The contribution analysis was accomplished establishing the cut-off at 0,5 %, meaning that all the elements contributing less than 0,5 % were not considered.

4.4.1. Case study contribution analysis

As it is possible to observe in the Figure 4-1, the cultivation step contributes the most in almost all the impact categories because of fertilizer and pesticide emissions. Processing contributes more than other phases to ODP (72,79 %), significantly contributes to ADP (FF) (37,86 %), to POCP and GWP (12,43 % and 10,41 % respectively) because of the large use of energy for product handling and thermal treatment. On the other hand, transport has a very low impact because of the short distances covered and the high loading factor. Considering the lack of availability of similar research on frozen peas production in the literature, the results are compared with those of other agricultural crops produced.

The results obtained for this case study are confirmed in the study of A. Ilari et al., where the impact of frozen green beans was evaluated (A. Ilari, et al., 2019) and the study of E. F. Pedretti et al., about the sustainability of spinach production, which affirmed that in general the cultivation step is the most impacting (E. F. Pedretti, et al., 2021).

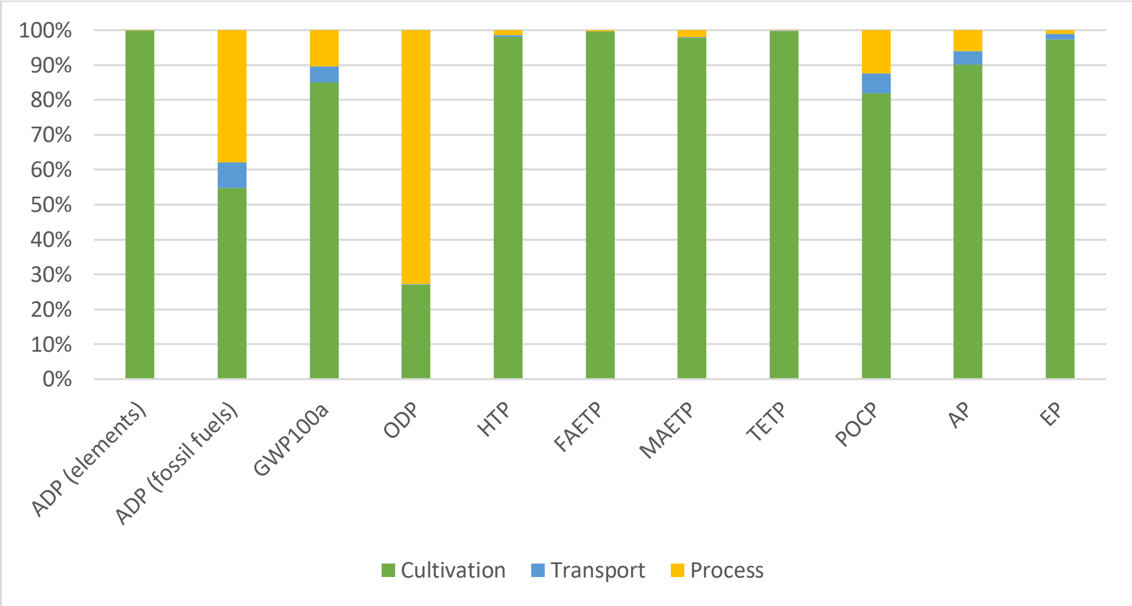

Figure 4-2: Contribution analysis of the frozen peas production referred to the FU.

By focusing on the impacts of the three different agricultural systems adopted by farmers, results show that the organic system is the most environmentally preferable. The study of A. Ilari et al. (A. Ilari, et al., 2019) confirmed that organic agriculture is preferable especially in terms of the freshwater aquatic toxicity and abiotic resources depletion, such as minerals and fossil fuels, because of the reduced consumption of fertilisers and plant protection substances.

Instead, the sustainable system seems to be the responsible of the major impacts in all the categories. However, the Figure 4-3 shows that the sustainable system follow the same impact trend of the integrated one. Therefore, it is possible to state that the sample of "sustainable" fields contribute to the same impact categories as the sample of integrated fields in a similar way, but with a relatively lower environmental efficiency. These results confirmed that the sustainable and the integrated system do not significantly differ from each other in terms of agricultural management.

Figure 4-3: Contribution analysis of peas cultivation under organic, sustainable, and integrated system referred to the FU.

4.4.2. Abiotic Depletion Potential (ADP) elements (E)

Cultivation is the main contributor for ADP (E) because in this phase the most relevant amount of resources is consumed, as affirmed also in the A. Ilari et al. study (A. Ilari, et al., 2019).

The Figure 4-4 shows that zinc mine operation is the most contributor to the ADP (E) impact category, accounting for 87,24 %, while pesticide production accounts only for the 5,45 %. According to A. Alengebawy et al. (A. Alengebawy, et.al., 2021), heavy metals arise from many sources in the agricultural sector, which can be categorized into fertilization, pesticides, and livestock manure. Fertilizers, including organic and inorganic elements, and bio-fertilizers are responsible for releasing heavy metals in the soil and then taken up by plants. Zinc concentration in livestock manure can range from 15 to 250 mg/kg. Accordingly, the huge amounts of manure and slurry distributed for soil fertilization by farmers highly contribute to ADP (E).

According to R. Parajuli et al. (R. Parajuli, et al., 2019) the cultivation impact is also caused by the metals used for agricultural machinery. B. Elhami et al. further stated that the production of agricultural machineries highly contributes to ADP. Then, it will be necessary to increase the sizes of the farms by integration and to perform different agricultural operations with combined machineries, such as combined equipment for ploughing and seed bed preparation, to reduce the impact to ADP (B. Elhami, et.al., 2017).

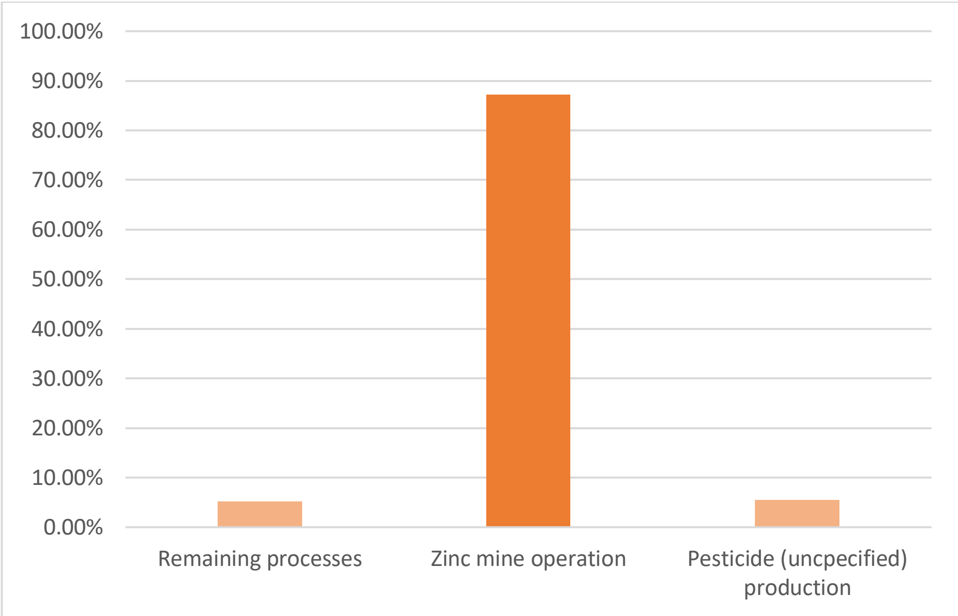

Figure 4-4: ADP contribution analysis.

As already mentioned before, the organic system is the most preferable for the environment due to the reduced quantities of pesticides and fertilizers used and therefore the reduced agricultural interventions carried out for their distribution. However, the distribution of huge amount of manure and slurry significantly contribute to the release of zinc in soil.

4.4.3. Abiotic Depletion Potential (ADP) fossil fuel (FF)

The process step is the major contributor for ADP (FF) because of the large use of energy in form of natural gas. In fact, it is possible to observe in the Figure 4-5, that natural gas production mostly contributes to this category, accounting for the 26 %, since methane is employed during the industrial transformation of peas for blanching. However, part of emissions related to natural gas production derive from the cultivation step. In fact, T. Nemecek et al. stated that the demand for non-renewable energy resources by the farming systems is dominated by the use of machinery and of mineral fertilizers. Soil cultivation and harvest were the two mechanization processes consuming most energy resources. Nitrogen fertilizers contributed most to the energy demand since the process of ammonia synthesis requires a high amount of fossil fuels, particularly natural gas (T. Nemecek, et.al., 2011).

Emissions deriving from petroleum and gas production on shore and offshore (23 % and 12 % respectively) are linked to both cultivation for agricultural interventions such as harvesting and process, as supported by E. F. Pedretti et al. (E. F. Pedretti, et al., 2021) who stated that "*combine* *harvesting tillage, and pesticides were the main impact contributors due to the extraction and use of fossil fuel in the manufacturing and operation associated with these materials and processes."*

Then, energy production is clearly linked with the consumption of non-renewable sources, which usually are hard coal, lignite, and crude oil, besides natural gas. Hard coal production contributes for the 11,28 % to ADP (FF).

T. Nemecek et al. further confirmed that the use of machinery should be restricted to the necessary interventions and the infrastructure needs to be used efficiently, either by sharing machinery between farms or by combining different interventions in one pass in order to reduce impacts related to petroleum consumption and hard coal for energy production for agricultural machines (T. Nemecek, et.al., 2011).

The electrical mix contributes 9.56% to the total impact due to the supply of energy required to power machines used for processing peas. Similar results were obtained by A. Frankowska et al., who demonstrated that processing contribution was significant for peas especially because of the freezing step, as the main contributor to the processing stage for peas (A. Frankowska, et al., 2019).

The small contribution deriving from diesel emissions, instead, is related to transport.

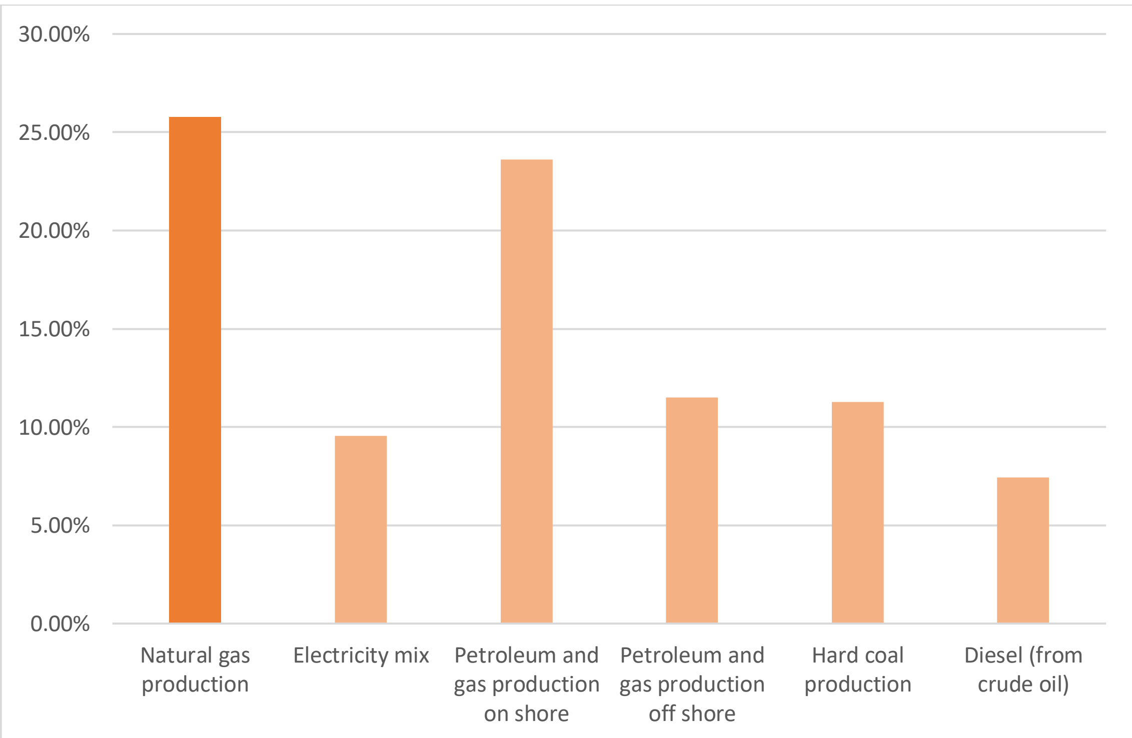

Figure 4-5: ADP (FF) contribution analysis.

The organic system is still confirmed as the least impacting system for the environment. In fact, T. Nemecek et al. stated that since almost no mineral fertilisers are used, large quantities of fossil fuels that otherwise would have been needed to manufacture nitrogen fertilisers are saved, thus having clearly positive effects on pollutant-driven impacts (T. Nemecek, et.al., 2011).

4.4.4. Global Warming Potential (GWP)

CO_2, CH_4, and N_2O come from different processes, mainly the combustion of fossil fuels and the natural emissions of the soil.

Emissions from cultivation mainly contribute to GWP, accounting for the 53,11 % (Figure 4-6). Field operations (22,44 %) and direct and indirect emissions from fertilizer (55,03 %) (including synthetic N fertilizer, manure, and slurry) gave the highest contribution. Pesticides contribute to emissions and global warming as well.

On the other side, the impact caused by processing (Figure 4-7) that accounts for 10,41 % is due to the energy requiring processes for freezing. The electricity mix contributes to GWP for 8,02 %. B. Atilgan et al. demonstrated that the majority of the GWP is from fuel combustion for energy generation, ranging from 97% for lignite to 83% for hard coal and 74% for gas. The second largest contributor for the latter is gas distribution (17%) because of its leakage during the long-distance pipeline transport (B. Atilgan, et.al., 2015).

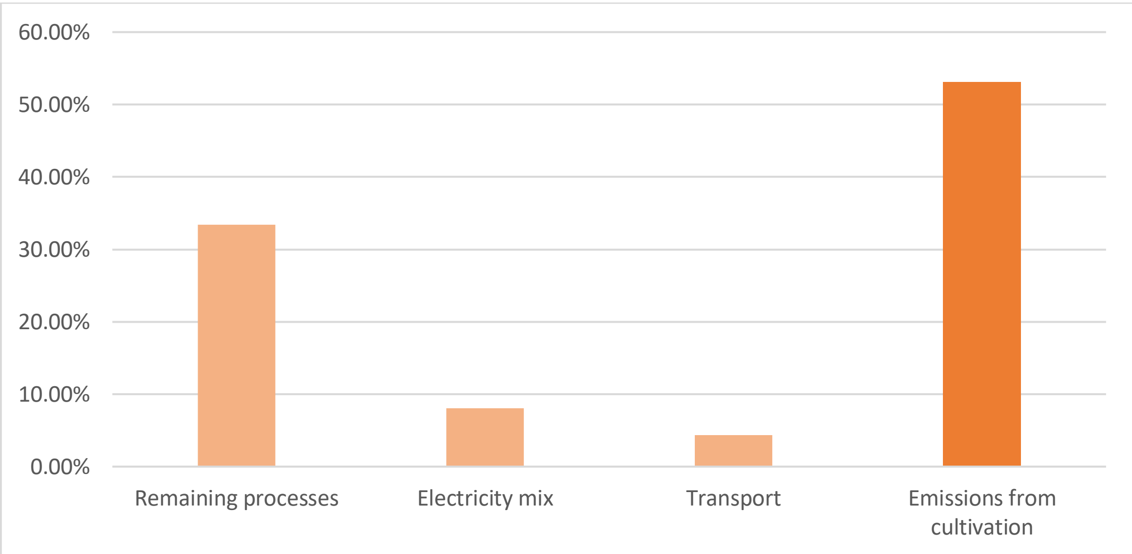

Figure 4-6: GWP contribution analysis.

The organic agriculture system contributes for 25,11 %, the integrated for 28,73 %, while the sustainable for 32,83 %, being the most impacting agricultural system, as shown in Figure 4-7.

E. F. Pedretti et al. reported that the GWP results based on the cultivation system revealed that integrated agriculture had a higher impact than organic agriculture because of the use of inorganic fertilizer in the integrated system which directly emits N_2O (E. F. Pedretti, et. al., 2021).

T. Nemecek et al. reported similar results, affirming that organic system had a lower global warming potential because of the ban of the use of synthetic nitrogen fertilizers whose manufacture and application cause the emissions of N_2O (T. Nemecek, et.al., 2011).

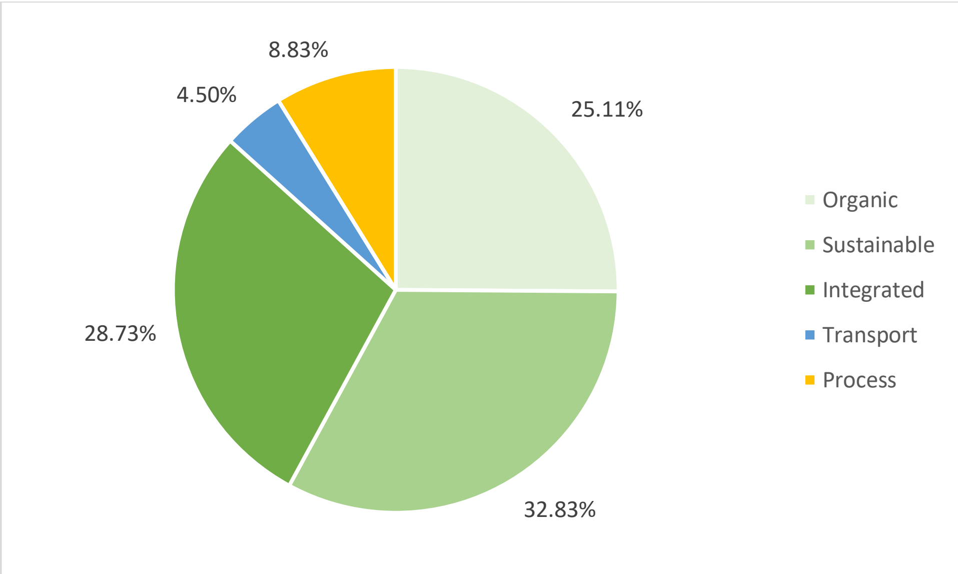

Figure 4-7: GWP contribution analysis related to each step of peas production.

4.4.5. Ozone Layer Depletion Potential (ODP)

The ozone layer is gradually destroyed by ozone-depleting substances, including chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and halons.

The Figure 4-8 shows that electricity consumption mostly contribute to the production of these substances, accounting for the 60,27 %; indeed, the most impacting step is the industrial transformation that require energy. Secondly, the petroleum production contributes to 14,91 % and finally the transport of natural gas pipeline contributes to 13,03 %.

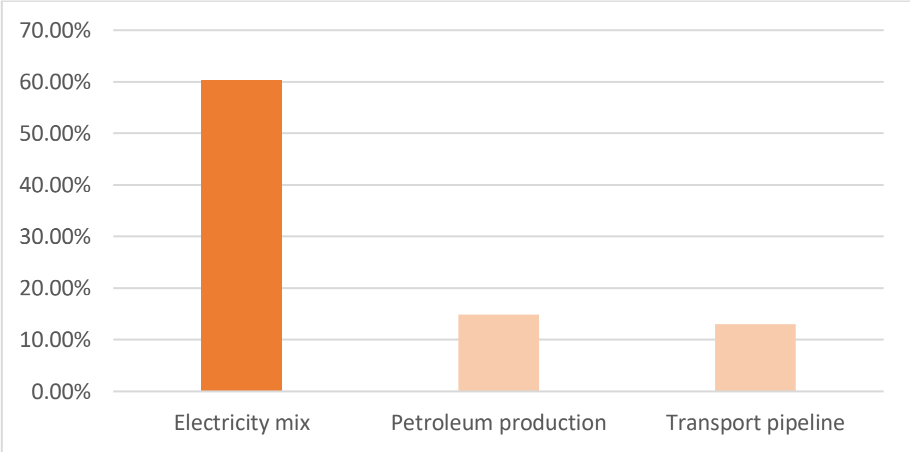

Figure 4-8: ODP contribution analysis.

4.4.6. Human Toxicity Potential (HTP)

HTP is concerned with the toxic effects of chemical substances especially used for cultivation, such as arsenic, sodium dichromate, and hydrogen fluoride on humans when emitted into air or water. The treatment of sulfidic tailing contributes to the 52,84 %, followed by ferrochromium and copper production, accounting for the 15,22 % and 5,07 % respectively.

Since the emissions of these harmful substances are caused from the use of fertilizers and pesticides, as stated by A. Frankowska et al. (A. Frankowska, et.al., 2019), the organic system of this case study impact less because of the reduced fertilizers and pesticides used. In fact, the study of T. Nemecek et al. further stated that the organic system shows low impacts related to human toxicity impact category explained by the ban of synthetic pesticides (T. Nemecek, et.al., 2011).

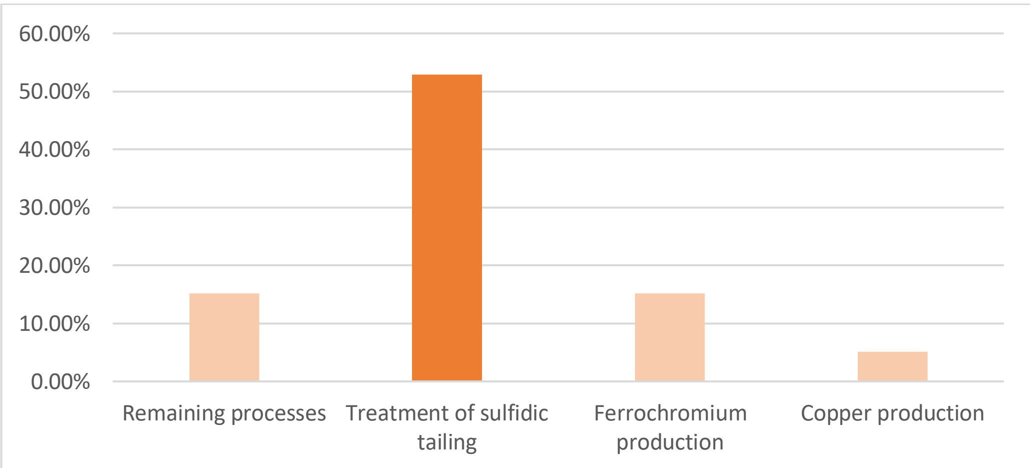

Figure 4-9: HTP contribution analysis.

4.4.7. Fresh Water Aquatic Ecotoxicity Potential (FAETP)

The impact in freshwater is due to emissions of toxic substances, such as heavy metals, to water. These substances are mainly produced from treatment of sulphidic tailings for the synthesis of inorganic fertilizers, accounting for the 52,06 %. Hence, the cultivation step contributes the most to this impact category, if compared to the other production steps, but the organic system is the least contributor because of the reduced use of fertilizers.

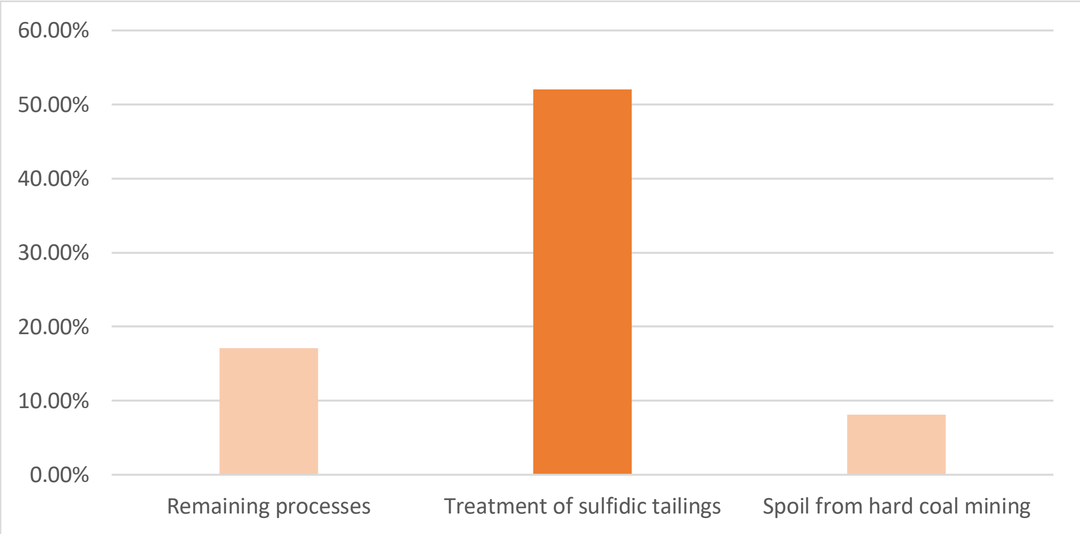

Figure 4-10: FAETP contribution analysis.

4.4.8.Marine Aquatic Ecotoxicity Potential (MAETP)

The same of FAETP is for this impact category where toxic substances are mainly produced from treatment of sulphidic tailings to produce inorganic fertilizers. Accordingly, the organic system is again the most environmentally preferable.

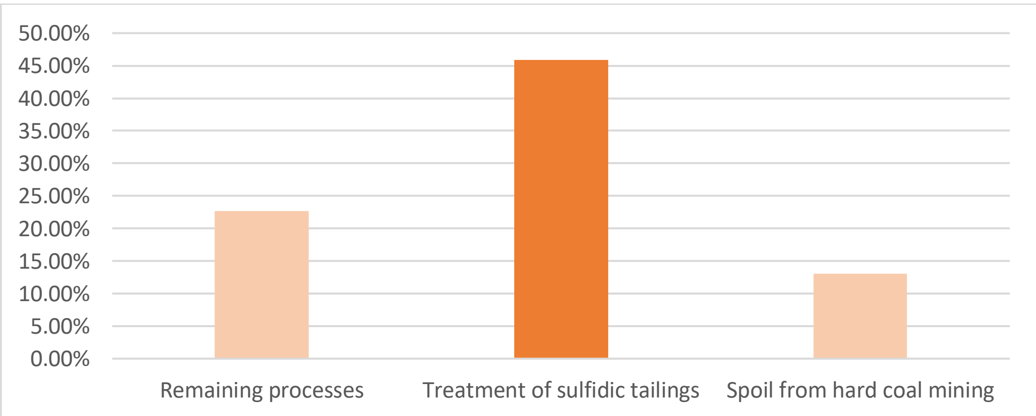

Figure 4-11: MAETP contribution analysis.

4.4.9. Terrestrial Ecotoxicity Potential (TETP)

Emissions of toxic substances such as heavy metals to soil are dominated by coconut husk production, which accounts for 38,04 %, followed by emissions from soybean production, which accounts for 35,30 %. Coconut husk is used to produce fertilizer, which can sometimes be created by burning the coconut husk. The ashes produced by burning them are a natural fertilizer.

Since the production of fertilizers are the main contributor to MAETP and TETP, B. Elhami et al. demonstrated that the use of right amount of chemical fertilizers at different growth stages of lentil cultivation have a significant impact in reducing direct emissions associated with these inputs (B. Elhami, et.al., 2017). In this way, it would be possible to reduce the impacts of the integrated and sustainable agricultural system to the three sub-categories of the ecotoxicity impact category (FAETP, MAETP and TETP).

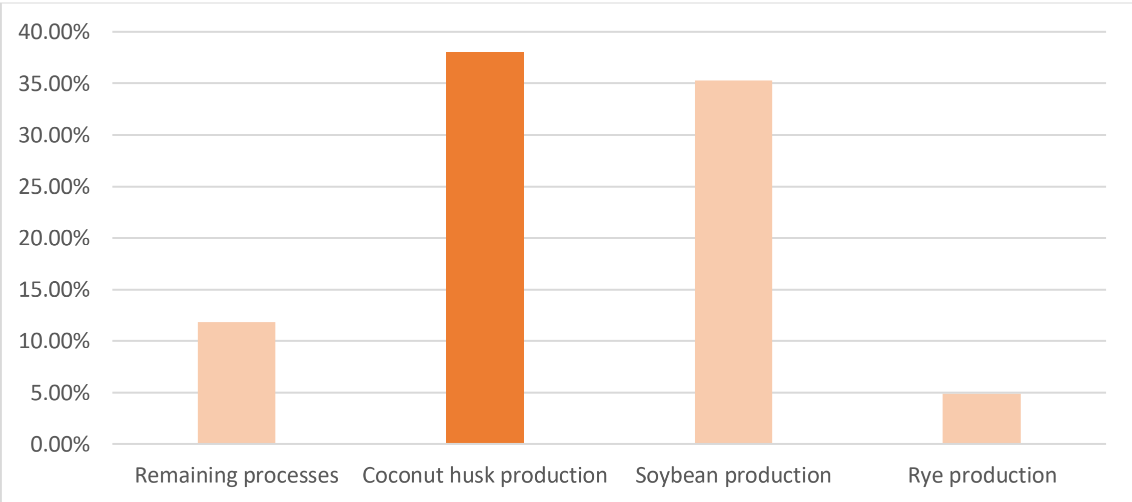

Figure 4-12: TETP contribution analysis.

4.4.10. Photochemical Oxone Creation Potential (POCP)

Photochemical ozone is formed by the reaction of volatile organic compounds and NOx in the presence of heat and sunlight and is harmful to human health and ecosystems. CO, SO2, NO, NH_3, and non-methane volatile organic compounds (NMVOC) are responsible for developing ozone at the atmosphere level.

Emissions from cultivation mainly produced these substances, accounting for the 43,72 %, followed by heat production and electricity, accounting for the 12,93 % and 7,10 % respectively.

Fertilizer use in cultivation were most impacting. According to E. F. Pedretti et al. urea is the most impacting substance because reactive nitrogen from urea can form harmful substances responsible for developing ozone at the atmosphere level (E. F. Pedretti, et. al., 2021).

Moreover, the study conducted by A. Frankowska et al. showed that farm production caused from 6% to 46% of the impact. The main contributors were mechanized field operations, such as fertilizing, tillage, manure spreading and irrigation, the latter being the main source of POCP in the farming stage for Spanish peas and Peruvian asparagus (A. Frankowska, et.al., 2019).

Results related to the environmental performance of the three different agricultural systems revealed that the integrated system was more impacting than organic system. Similar results were obtained by E. F. Pedretti et al. study: in this case study, the POCP scores for the organic system was 3,51 x 10^{-5} kg C_2H_4 eq., while integrated system obtained 3,75 x 10^{-5} kg C_2H_4 eq; in the E. F. Pedretti et al. case study POCP scores for the organic system was 2,71 x 10^{-5} kg C_2H_4 eq., while integrated system obtained 4.31 x 10^{-5} kg C_2H_4 eq./FU (E. F. Pedretti, et. al., 2021).

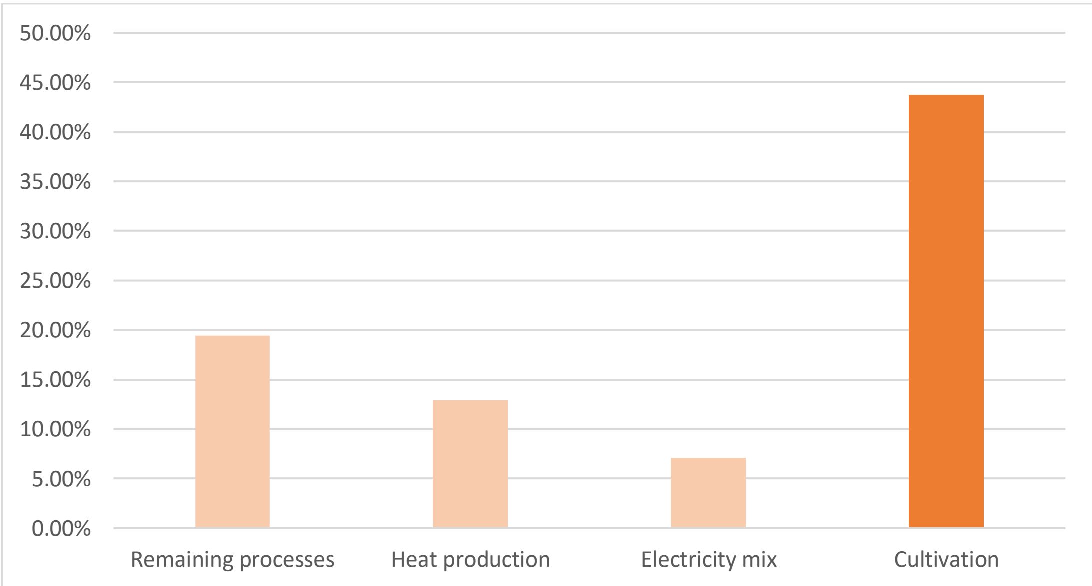

Figure 4-13: POCP contribution analysis.

4.4.11. Acidification Potential (AP)

Gases including NH_3, NO, and SO are acidifying substances responsible to cause a wide range of impacts on soil, groundwater, surface water, organisms, ecosystems, and materials consequently, decreasing biodiversity and damaging the quality of ecosystems.

Emissions from cultivation mainly contribute to acidification potential, accounting for the 63,34 %, as shown in the Figure 4-14. The nitrogen fertilizers heavily contribute to soil acidification. These results are widely supported by other studies.

E. F. Pedretti et al. demonstrated that nitrogen-based fertilizers are the major contributor to AP. The ammonium-N in fertilizers undergo nitrification, which releases hydrogen thus increasing acidity. Hence, as the percentage of ammonium increases in a given fertilizer, the acidifying potential increases as well (E. F. Pedretti, et. al., 2021).

Concerning the environmental performance of the different agricultural systems, the organic system had the lowest AP. Similar results were obtained by E. F. Pedretti et al., which supports that the direct and indirect emission of NH_3 and NO from the fertilizer applied in integrated system significantly contribute to AP (E. F. Pedretti, et. al., 2021).

Manure and slurry application also contribute to AP, hence, the environmental impacts related to the use of manure and slurry should not be undervalued.

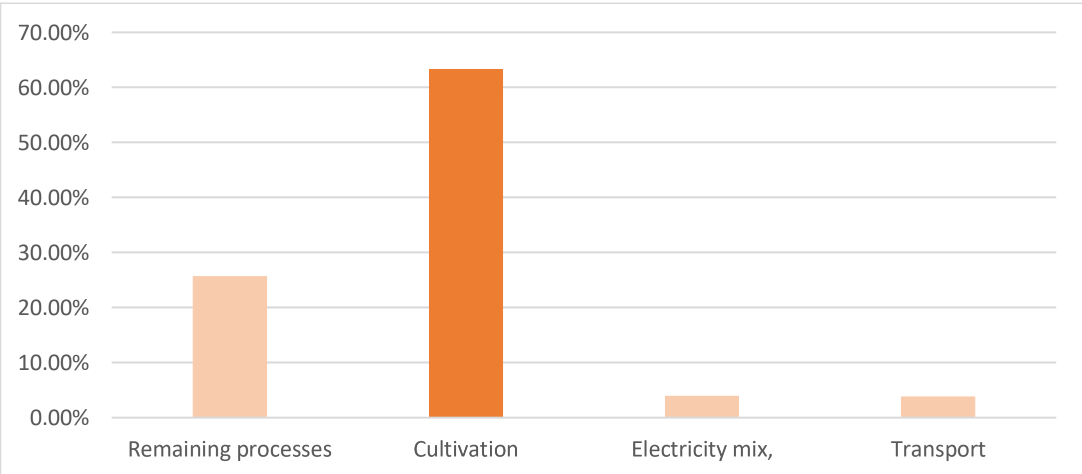

Figure 4-14: AP contribution analysis.

4.4.12. Eutrophication Potential (EP)

As it is possible to observe in graphic in the Figure 4-15, the eutrophication is mainly due to the emissions derived from the cultivation (74,19 %). According to E. F. Pedretti et al., direct emissions of nitrogen into both air and water from the fertilizers used accounted for about 90% of the total impact EP scores (E. F. Pedretti, et. al., 2021). Moreover, as for acidification, the increasing N content in a given fertilizer, the higher the eutrophication potential.

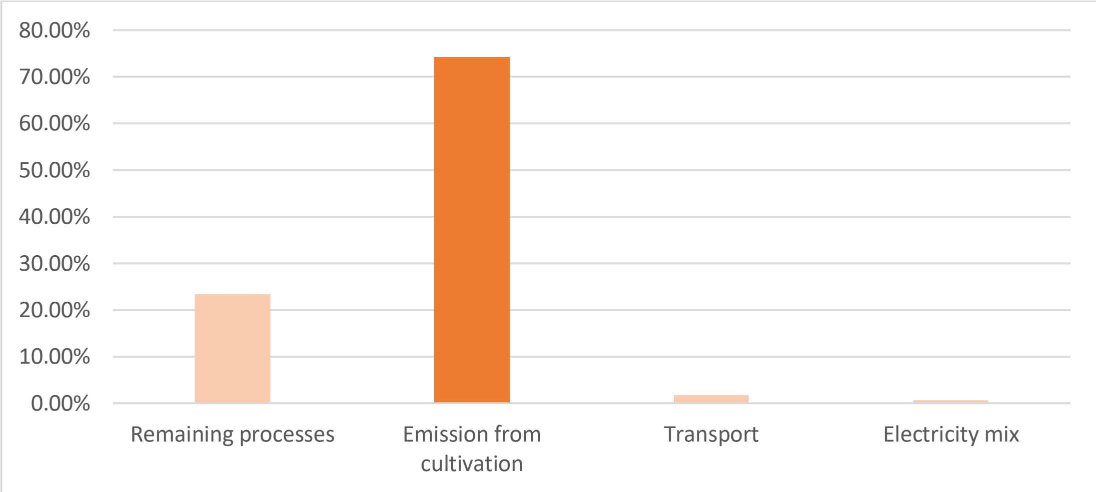

Figure 4-15: EP contribution analysis.

The are no significant differences among the three agricultural systems, as shown in the Figure 4-16. Similar outcomes were obtained by T. Nemecek et al., who reported that the emissions of NH_3 were at a similar level for both integrated and organic system, due to the high amount of slurry applied to the organic system (T. Nemecek, et.al., 2011).

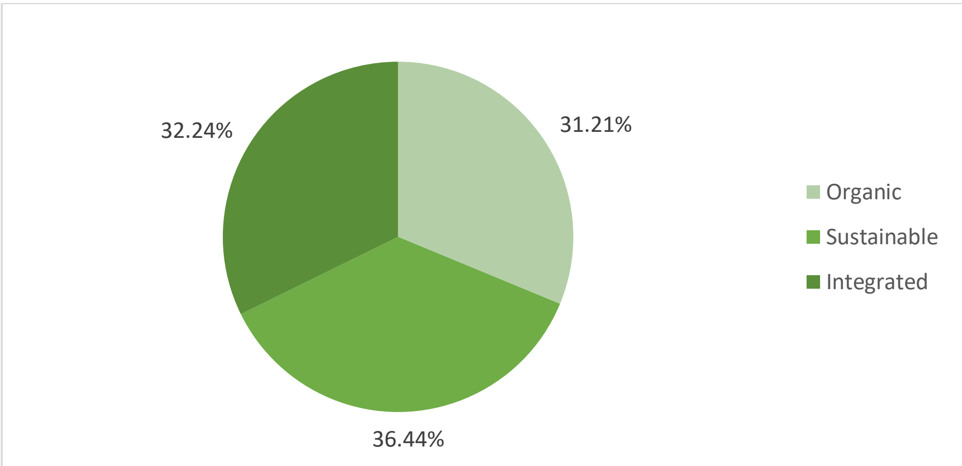

Figure 4-16: EP contribution analysis for organic, sustainable, and integrated system.

5. CONCLUSIONS

The aim of this LCA study is to assess the environmental impact of the production and processing of 1 kg of packaged frozen peas and to evaluate the environmental aspects of sustainability of peas grown by three different agricultural systems (integrated, sustainable, and organic).

Although not many similar studies are available in the scientific literature, this analysis can be considered representative of frozen peas, thanks to the primary data provided by the company, in addition to the O.R.T.O. Verde leadership as a supplier of frozen peas for many important Italian brands in the frozen sector. However, further LCA studies should be carried out to improve the results consistency and completeness.

Results of the LCA analysis showed that the cultivation is the most impacting step in almost all the impact categories examined, while the processing impact is particularly important for ODP and ADP (FF) impact categories. Finally, the transport less contributes to the total impact because of the reduced distances covered by the company, concerning the selected fields for this study.

Climate change represent an imminent threat for the world which can affect food and water availability for the present and future generations. The World Health Organization calls climate change the greatest threat to global health in the 21st century. Climate change includes global warming, which can potentially alter biological systems; hence, the reduction of GHG emissions is of greatest interest nowadays. Outcomes of the study related to the GWP, showed that the cultivation step strongly contribute to this impact category accounting for the 53,11 % of the total impact derived from the production of frozen peas, which generates 1,08 kg CO_2 eq. / kg product.

The organic agricultural systems showed significantly different environmental performance compared to the other two for some impact category, such as Ecotoxicity impact categories (FEATP, MAETP, and TETP), HTP and ODP. While the integrated and sustainable system showed similar environmental performances, as it was expected. Therefore, an additional study covering the social and economic aspects taken into account by the sustainability certification should be carried out to effectively assess the sustainable production of frozen peas.

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