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Environmental impact assessment of strawberry cultivation: The case study of Cyprus

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ABSTRACT

Strawberry cultivation possesses a significant role in Cyprus agricultural sector, yet its environmental impact remains a critical concern. This study employs a Life Cycle Assessment (LCA) methodology to evaluate the environmental burdens associated with three distinct strawberry production systems: (1) open-field cultivation in soil, (2) unheated high tunnel cultivation in soil and, (3) unheated high tunnel soilless (peat moss) cultivation. To identify the most relevant cultivation systems for analysis, we designed and distributed questionnaires to local farmers. Based on the responses received, we focused our study on these prevalent cultivation methods. The analysis conducted encompassed key impact categories, including global warming potential, terrestrial acidification, freshwater eutrophication, terrestrial ecotoxicity, human toxicity, and land use and water consumption. The findings indicated that the peat moss based soilless system exhibited the highest environmental burden, primarily due to the extensive use of inorganic fertilizers and fossil fuel consumption. Conversely, unheated high tunnel cultivation in soil emerged as the most environmentally sustainable method, demonstrating lower emissions and reduced consumption. Open- field systems, while widely practiced, they present significant challenges concerning water use efficiency and soil degradation. This research underscores the eminent need for sustainable agricultural practices tailored to Cyprus unique climatic and resource constraints. By optimizing irrigation strategies, minimizing synthetic input dependency and promoting resource-efficient cultivation methods, the environmental footprint of strawberry production can be significantly reduced. The insights from this study are expected to contribute to the development of best practices for eco-friendly strawberry cultivation.

Keywords: *Fragaria x ananassa, life cycle assessment, irrigation, sustainability,* global warming potential, terrestrial acidification, freshwater eutrophication, terrestrial ecotoxicity, human toxicity, land use

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1 Introduction

1.1 The agricultural sector in Cyprus

Cyprus, is located to the south East edge of Europe and thus to a relatively remote geographical position in relation to its European Union partners and its neighbouring states (Natos et al., 2014). Cyprus is the third largest island in the Mediterranean that experiences mild winters and hot dry summers (Cuenca-Garcia et al., 2024).The wet season is extended from November to March, with most of the rain falling between December and February.

Agriculture in Cyprus represents a significant component of the island nation's economy and agricultural heritage, although facing several challenges due to adverse climatic conditions and lack of resources. Cyprus's diverse agricultural landscape encompasses the cultivation of citrus, fruits, olives, grapes, potatoes and vegetables, alongside livestock farming. The sector contributes significantly to the country's economy, providing employment opportunities, supporting rural livelihoods and contributing to food security. It is characterized by small, fragmented farms. The island's total agricultural land is about 1.3 million hectares, but less than 15% is arable due to the island's rocky terrain and limited water resources (Adamides et al., 2020).

The main crops of the island, which are suggested to be vulnerable to climate change impacts are barley and wheat, tomatoes, potatoes, grapes and olives (Markou et al., 2020). These crops are considered to be important for the agricultural sector of Cyprus, as they contributed approximately 60% to the total revenues of the sector during period 2010-2015, while the area cultivated with these crops constituted 50% of the total cultivated area in Cyprus in 2015 (Papadaskalopoulou et al., 2020).

The primary crops cultivated are potatoes, citrus fruits including oranges, lemons, and grapefruits, vegetables such as such as tomatoes, cucumbers, and carrots, and grapes. Grapes, used for table consumption and wine production, highlight Cyprus's long tradition of viticulture, contributing to the island's unique wine offerings. All these contribute 35% of the total value added in agriculture.

However, contemporary agricultural practices in Cyprus must grapple with issues such as water scarcity, land fragmentation, and market competition. Despite these challenges, Cyprus's strategic location in the Mediterranean and its favourable climate offer opportunities for innovation and sustainable development within the agriculture sector.

The contribution of the agricultural sector to the overall Cypriot economy is quite significant. To be more specific the agriculture sector contributes 6,7 % to the Gross Domestic Product (GDP) of the country. Additionally, agriculture accounts for 10,3 % of the workforce in Cyprus. This means that a significant portion of the population is employed in agricultural industry such as farming, livestock production and related activities. Another one sector that Cyprus agriculture has a crucial role are the exports. Agriculture contributes to 37% of the total exports. This implies that agricultural products are substantial part of Cyprus international trade and export revenue.

Berry farming is a growing agricultural sector with significant possibility to diversify Cyprus' agricultural production. Although historically not a significant berry-producing region, Cyprus has drawn attention in berry farming particularly in mountainous regions where the microclimate provides ideal circumstances for these crops (Neocleous et al., 2005). Projects including berry growing currently focus the Troodos Mountain region, with a mesoclimate characteristics by temperature fluctuations and particular soil characteristics.

In the Pitsilia area, where farmers have modified sustainable agricultural methods to produce several berry crops including raspberries, blackberries, and blueberries, recent advancements in the berry industry have shown especially success. These agricultural initiatives show that, given suitable farming methods and variety selection, berry output can be feasible in Cyprus despite obstacles related to its Mediterranean temperature. With some facilities attaining daily yields of up to 50kg for raspberries and seasonal outputs of 500kg during peak harvest periods (Norman, 2023), current production levels show encouraging outcomes.

Certain berry crops can now be year-round thanks to the adoption of sophisticated farming techniques including protected cultivation in greenhouses and soilless culture systems. Studies carried out at the Agricultural Research Institute of Cyprus have indicated that under protected cultivation primocane-fruiting raspberries can be effectively cultivated, therefore creating new opportunities for off-season production (Neocleous et al., 2005). This development is especially important since it lets Cypriot growers aim for high-value market windows when imported berries are not available or are being sold for high prices.

Building on Cyprus's diverse agricultural landscape, strawberry (*Fragaria* x *ananassa* Duch.) has become an important crop displaying the island's opportunities for specialized fruit output (Odysseos et al., 2017). While citrus, fruits, olives, grapes and potatoes have long been the main focus of traditional agriculture, strawberry cultivation has grown to be a profitable sector appropriate for the agricultural growth plan of the country and initiatives at climate adaptation.

To solve environmental issues Cyprus's agriculture faces, strawberry growing has evolved to use both traditional and more advanced production protocols. While in high elevations planting takes place in the last ten days of November, in lowland and coastal areas it takes place from mid-September to late October. Modern agricultural systems blend open-field and protected cultivation techniques; recommended in lowland areas for early production to reach higher fruit quality and larger yields is protected cultivation in semi-tall greenhouses or low tunnels.

1.2 Environmental issues related to agriculture

Climate change affects many economic sectors, with agriculture being one of the most exposed, as it directly depends on climatic factors such as temperature, sunlight and precipitation for its viability (Papadaskalopoulou et al., 2020). Many Mediterranean regions face a range of environmental challenges that threaten the sustainability sector. Cyprus is one of the Mediterranean countries that has to handle these kinds of issues. Due to its unique geographical location, climatic conditions and socio-economic factors, Cyprus has to develop effective strategies to ensure the long-term viability of agricultural field.

The Mediterranean region is characterized by a unique set of environmental conditions, including hot, dry summers and mild, wet winters. The winters, from November to mid-March, are wetter and more variable. The autumn season is brief, occurring in October, and spring is also short, spanning April and May. Although the climate conditions might seem ideal in the past decades, Cyprus, just like every other part of the world, faces challenges related to climate change. As global temperatures rise, agricultural systems are increasingly stressed by heat and changing precipitation patterns (Cyprus Institute, "Climate Change Impact on Cyprus). Despite its significance, Cypriot agriculture faces several environmental challenges in particular, that impact the natural resources and ecological balance of the area. The issues related to agriculture in Cyprus are complex; they include encompassing water resource management, soil degradation, pesticide use, and the broader effects of climate change.

A crucial environmental challenge is the overuse of water resources. Agriculture in Cyprus relies heavily on irrigation due to the region's arid climate, which leads to the over-extraction of groundwater and depletion of water reserves (Papadopoulou et al., 2020). Water recourses are sources of water that are beneficial to living creatures. Conventional water is a renewable resource, but the global supply of clean and fresh water is steadily declining. It is only recently that awareness has emerged of global concern about conserving water for ecosystem services, as more than half of the world's wetlands have been lost along with their environmental services (Adamopoulos et al., 2024). Surface waters are naturally replenished by rainfall and lost naturally through discharge into the oceans, evaporation, and surface spillage (Adamopoulos et al., 2024). Over recent decades Cyprus has experienced a noticeable decline in rainfall, with droughts becoming more frequents and severe (Papadopoulou et al., 2020). The frequent droughts have reduced water resources considerably and Cyprus is already conformed to severe water deficit problems. In 2008 after four consecutive years of low rainfall, the available water reached a critical level and the government restored to importing water from Greece using ship tankers (Cleridou et al., 2014). In response to these challenges, Cyprus has invested in water management infrastructure, including the construction of over 100 reservoirs across the country. Additionally, non-conventional water sources such as desalinated and recycled water have been integrated into the water supply network (Papadopoulou et al., 2020).

Soil degradation in Cyprus is a critical environmental issue, driven by both natural factors and human activities. Due to the Mediterranean climate of Cyprus, the soil is particularly vulnerable to erosion (Zoumides et al., 2013). Agricultural practices, such as overgrazing, excessive use of chemical fertilizers and inefficient irrigation methods, exacerbate the problem leading to soil infertility, salinization and desertification in certain areas (Zoumides et al., 2013). Soil erosion caused by water is defined as the soil's structure break down and soil particles detachment due to failing raindrops and flowing water exceeding a critical threshold (Karydas & Panagos, 2016). Intensive methods, such as the use of heavy machinery and monoculture, contribute to soil compaction and erosion, which lead to the loss of soil fertility and productivity. The EEA (European Economic Area) report outlines these impacts, noting that soil degradation affects agricultural yield and ecosystem health (EEA, 2024).

The environmental impact of strawberry cultivation in Mediterranean regions like Cyprus is particularly significant in terms of water resource management. Strawberry farming is notably water-intensive, especially in regions with poor soil water retention, where growers often over-irrigate due to sandy soils with low water holding capacity (Martínez-Ferri et al., 2016). This intensive water usage compounds the existing water scarcity issues in Cyprus, where the agricultural sector already faces severe water deficit problems. Studies from similar Mediterranean climates have shown that strawberry cultivation can significantly affect groundwater levels due to high irrigation demands, leading to potential over-extraction and deterioration of aquifer health (Domingo-Pinillos et al., 2018).

In addition to water resource concerns, soil degradation presents another critical environmental challenge for strawberry cultivation in Cyprus. Long-term continuous cropping of strawberries has been demonstrated to alter the soil's bacterial community structure and reduce soil physicochemical properties and enzyme activities, which are crucial for maintaining soil fertility (LI et al., 2018). This impact is particularly concerning in the Mediterranean context, where soils are already vulnerable to erosion and degradation due to climatic conditions. The intensive methods used in strawberry cultivation, including the use of chemical fertilizers and inefficient irrigation methods, can exacerbate existing soil problems, potentially leading to further soil infertility and reduced agricultural productivity.

The extensive use of pesticides and fertilizers in strawberry farming poses additional environmental concerns for Cyprus's agricultural ecosystem. Studies have shown that runoff from fields treated with pesticides can significantly impact aquatic life, causing alterations in growth patterns and morphological changes in various organisms (Novelli et al., 2016). Furthermore, fertilizer use in strawberry farming has been identified as a major contributor to eutrophication potential, particularly in open field production systems, where nutrients can leach into water bodies and disrupt aquatic ecosystems (Romero-Gámez & Suárez-Rey, 2020). These impacts are especially relevant for Cyprus, where water resource protection is crucial due to the limited availability of freshwater resources.

Modern cultivation techniques, however, offer potential solutions to mitigate these environmental impacts. Hydroponic systems, for instance, allow for precise control over nutrient and water supply, significantly reducing waste and environmental pollution through optimized resource use (Maya Olalla et al., 2023). These systems have demonstrated increased yield and better fruit quality compared to traditional soil systems while minimizing environmental impact. Closed-loop hydroponic systems particularly enhance nutrient use efficiency by recirculating drainage and correcting nutrient solutions based on ion concentrations, which reduces the need for fresh inputs and minimizes waste (Lim et al., 2024). Such innovations could be particularly valuable for Cyprus's agricultural sector, where resource efficiency is paramount.

LCA studies from other Mediterranean regions provide valuable insights into the environmental footprint of strawberry cultivation that can be applied to Cyprus's context. Research from Italy and Spain has demonstrated that innovative systems like macrotunnel soilless integrated systems generally have lower environmental impacts compared to traditional open field systems (Romero-Gámez & Suárez-Rey, 2020). Studies in Southern Italy have particularly highlighted that organic systems using solarization and biological pest control show promising results for sustainability, although the use of plastic materials and zinc structures continues to pose environmental challenges (Pergola et al., 2023). These findings are particularly relevant for Cyprus as it seeks to develop more sustainable agricultural practices.

The implementation of sustainable practices and adaptation strategies is crucial for mitigating the environmental impacts of strawberry cultivation in Cyprus's changing climate. Cover crops like barley and vetch have been shown to enhance soil organic carbon and nitrogen sequestration, improve soil structure, and reduce nitrate leaching in irrigated lands (García-González et al., 2018). Additionally, the use of organic amendments, such as sheep manure, has demonstrated significant improvements in soil physicochemical properties and enhanced soil microbial diversity, which in turn promotes strawberry growth and yield (Zha et al., 2024). These practices, combined with efficient irrigation techniques and modern cultivation systems, offer a pathway toward more environmentally sustainable strawberry production in Cyprus.

1.3 Strawberry cultivation

1.3.1 General

Strawberries are widely appreciated for their vibrant red color, sweet flavor, and versatility in various dishes. Cultivating strawberries can be a gratifying experience for both home gardens and commercial growers, though it requires attention to specific conditions and practices to ensure a fruitful harvest. Understanding the fundamental aspects of strawberries farming, such as climate needs, soil conditions, watering, fertilization and pest management, is essential for growing healthy plants and achieving high yields (Eriksson et al., 2003).

The commonly cultivated strawberry known as the garden strawberry, is scientifically referred to as *Fragaria x ananassa*, a hybrid species derived from crossbreeding of two wild strawberry species: *Fragaria chiloensis and Fragaria virginiana*. Strawberries are considered as psychrophilic species, but due to the various genes inherited from their ancestors, they have the ability to adapt into diverse environments as a result of its cultivation all over the planet. They are non-climacteric fruit and characterized by a high softening rate, short post-harvest life and fast decay (Katel et al., 2022).

The common desert strawberry, *Fragaria x ananassa* Duchesne, is a regular part of the diet of millions of people and is cultivated in the arable regions of the globe. According to a recent publication of FAO, strawberry annual production, approximately, rise up to 9 million tone on an area 389,665 ha worldwide in 2021 (Wöhner & Höfer et al., 2023). The main producing countries are USA, Netherlands, Morocco, Spain and China.

1.3.2 Morphology and anatomy of strawberry

From a botanical point of view, strawberry is not a berry but an aggregate accessory fruit. That means that the fleshy part is derived not from the plant's ovaries but from the receptacle that holds the ovaries (Heide et al., 2013). The strawberry plant is an herbaceous perennial plant that propagates both sexually by seed and vegetatively by stolons (runners). The stem is a perennial rootstock with short internodes and leaves assembled in a rosette (Heide et al., 2013).

Strawberries are small, aggregate fruits, typically measuring between 30-40 cm in diameter and approximately 20-40 cm in height. The surface of the fruit is adorned with numerous tiny, brownish seeds that give characteristic texture. These seeds are not true seeds; they are individual achenes, a type of dry, one-seeded fruit. The achenes are arranged symmetrically on the fruit's surface, contributing to its distinctive appearance.

1.3.2.1 Roots

Roots are the underground part of the strawberry plant and are necessary for growth and fruit production due to the fact they are responsible for anchoring the plant and capturing water and nutrients from the soil (Poling et al., 2012). A healthy strawberry root system typically has 20 to 35 primary roots and thousands of small rootlets. The optimum soil temperature for rapid growth is 12-57 °C. Furthermore there are secondary roots that live for few days to few weeks and are constantly being replaced.

1.3.2.2 Stem

The strawberry plant has a short, thickened stem, commonly called a ‘crown’ which has a growing point at the upper end and forms roots at its base (Larson, K.D, 2018). New leaves and flower clusters emerge from ‘fleshy buds’ in the crown in early spring. The optimum temperature for stem growth and development is 10 °C, particular in month October.

1.3.2.3 Leaf

The leaves are borne along the stem on petioles arranged in a spiral fashion around the crown (Poling et al., 2012.). Strawberries have trifoliate compound leaves with serrated margins. These leaves are arranged alternately on the stem and play a crucial role in photosynthesis. They have relatively short petioles that emerges from the upper part of the rhizome. Leaves live one for three months and before the old ones die, and they are constantly renewed by new ones as the top part of the stem increases. Due to the fact that leaves have a large number of stomata, compared to other plants, large amounts of water are lost through transpiration.

1.3.2.4 Flower

The flowering process can be described in terms of three main phases of development, floral induction, initiation and differentiation (Taylor et al., 2000). The flowers are hermaphroditice and are formed in groups on inflorescences. They are generally white and occasionally reddish, borne in small clusters on slender stalks that arise from the axils of the leaves.

1.3.2.5 Fruit

The edible part of the strawberry, which is recognized as the fruit, is essentially a pseudocarp. This means that the flesh of the strawberry is not formed from the ovary of the flower but from the receptacle. The yellow spots attached to strawberries, often recognized as seeds, in reality, are actually the ovaries of the flowers. Inside each ovary, there is a seed (Taylor et al., 2000).

1.3.3 Strawberry Photoperiod and Temperature

Photoperiod and temperature are the major environmental factors influencing flowering in strawberry and they interact in the regulation of different stages of the process (Taylor et al., 2000). Understating how these factors impact strawberries is essential for successful cultivation.

The photoperiod of a strawberry plant refers to the number of hours of daylight it receives in a day and is crucial for the growth and flowering of many plants, including strawberries. Each cultivar has different requirements for daylength and temperature. Due to the interaction between photoperiod and temperature, floral initiation occurs in most cultivars under long day conditions, especially if the temperature is low (Sønsteby et al., 2009).

1.3.4 Strawberry varieties

Strawberries are classified into three main categories, based on their photoperiod requirements: June-Bearing, Day-neutral and Everbearing. It is worth noting at this point that Day-neutral and Ever-bearing are consider the same type of strawberries.

1.3.4.1 June-Bearing varieties

It is believed that the natural state of most strawberry species is that of June-bearing strawberries. These cultivars are commonly grown for winter production in glasshouses and are also referred to as short day plants (SD), meaning they require shorter daylight periods and are induced to flower in late summer (Konsin et al., 2001). In general, most June-bearing strawberries form flower buds under photoperiods of less than 14 hours (Stewart & Folta, 2010).

It is widely known that among strawberry growers that low temperatures govern flower bud formation in single-cropping cultivars. The optimum temperature for floral initiation in short day cultivars is 15-18 °C, while temperatures below 10 °C and above 25 °C are ineffective (Sønsteby et al., 2009).

1.3.4.2 EverBearing varieties

Everbearing strawberries are classified as long-day (LD) plants. They require longer photoperiods to initiate flowering. The initiation of flower buds in these strawberries, is inhibited at night-day temperatures of 25-30 °C under photoperiods of 13 hours or shorter, and is promoted under photoperiods of 14 hours or longer (Nishiyama & Kanahama, n.d.).

Long day strawberries produce fruit throughout an entire growing season. Beginning in spring, with intermittent crops throughout summer and early fall. Everbearing plants grown in higher temperatures had greater leaf growth and higher dry matter production than June-bearing plants grown in lower temperatures (Rivero et al., 2022).

1.3.5 Strawberry Cultivation Methods

Over the past decades, techniques of growing strawberries have changed dramatically to match technical developments and the growing demand for effective, sustainable production systems. From conventional soil-based systems to cutting-edge soilless farming technologies, modern strawberry production spans a wide spectrum of farming methods each meant to maximize yield while controlling available resources. The choice of farming technique greatly affects not only the output and fruit quality but also the resource needs, labor intensity, and whole environmental impact of the production system. These techniques have been created and polished to handle several issues in strawberry farming, including climate control, disease management, water use economy, and year-round output possibilities. Agricultural planning and execution depend on an awareness of these several farming techniques since every one of them offers unique benefits and drawbacks in terms of technical criteria, resource use, and environmental impact. The main farming techniques used in commercial strawberry production are investigated in this part together with their features, needs, and practical aspects.

1.3.5.1 Soil-Based Cultivation

Soil-based cultivation remains the most traditional and widely practiced method for strawberry production worldwide. This farming technique can be used in several ways each offering different degrees of control over environmental variables and growing conditions from open-field production to covered farming regions.

Traditional open-field farming is the most basic way to get strawberries when plants grown directly in the ground under natural conditions. More suited for environments with perfect growing circumstances, this method largely depends on local climate variables and seasonal rhythms (Hancock, 2008). Although open-field systems have cheaper initial cost than covered systems, they expose crops to environmental stresses and might yield less due to weather-related problems.

Rising as a significant enhancement in soil-based strawberry output, protected farming offers several degrees of environmental control using distinct structure styles. Made of plastic covers held up by wire hoops, low tunnels provide basic protection from poor weather and can extend the growing season by creating a more perfect microenvironment surrounding the plants (Rowley et al., 2011). Greater access for crop management and improved climate control features comes from larger walk-in buildings known as high tunnels. Especially beneficial for disease prevention, these systems can increase early output and fruit quality as well as provide protection against rains (Santos et al., 2010).

Greenhouse farming is the most advanced type of protected soil-based farming. Modern greenhouses with climate control systems provide accurate control of temperature, humidity, and ventilation, so enabling year-round cultivation in many different locations. Research has shown that greenhouse-grown strawberries can reach yields up to 2-3 times higher than open-field production, even if this comes with more running expenses and energy requirements.

Good soil-based farming mostly depends on proper management and preparation of the soil. Strawberries grow best in well-drained soils with high organic matter concentration and a pH range of 5.5–6.8. Prior to planting, soil preparation typically involves deep tillage, organic matter incorporation, and pH adjustment if necessary (Maas & Society, 1998). Adding organic matter improves soil structure, water retention, and nutrient availability usually at 25–50 tons per hectare.

In soil-based farming, planting patterns have evolved to maximize area usage and enable efficient management approaches. Usually 60–70 cm wide and 15–20 cm height, the raised bed technique has been accepted normal practice in commercial production. Plants are arranged single or double rows with 25–40 cm between each other depending on the variety and production technique (Conner et al., 2023). Black plastic is the most widely used variety in conventional farming; plastic mulch is usually used to control weed growth, save soil moisture, and keep soil temperature.

1.3.5.2 Soil-less Cultivation

Modern methods of producing strawberries that have drawn great attention are soilless farming because of their possibilities for higher yield, better resource economy, and better control overgrowth conditions. Especially attractive for intensive production systems (Giampieri et al., 2012), this method provides exact control over fertilizer input and eliminates soil-borne diseases.

Considered as the main method used in soilless strawberry cultivation, hydroponics offers numerous technical substitutes for plant production. Plants are hung under the Nutrient Film Technique (NFT) and nutrient solution is continuously poured via channels letting their roots receive nutrients straight from the flowing solution. NFT systems are unique in their water efficiency and perfect nutrition control, even if they must be carefully controlled in solution temperature and oxygen levels to reduce root stress (López-Aranda et al., 2011). Deep Flow Technique (DFT), where plants are kept above a deeper nutrient solution, provides greater buffer against system failures and temperature variations even if they need more significant water volumes.

For strawberries, substrate culture has been the most often employed technique combining system complexity with output dependability. Common growing mediums are coco coir, perlite, rockwool, and numerous combinations of these materials, each having special physical and chemical properties (Cantliffe et al., 2007). Coco coir has become somewhat well-known thanks in great part to excellent water-holding capacity and air-filled porosity, which provides the perfect root environment. Research on strawberries grown in coconut coir under optimum conditions has shown yields up to 40% higher than those produced in normal soil farming.

Vertical farming applications provide a novel way for soilless strawberry production that maximizes space consumption by vertical arrangement of growth systems. These technologies would be particularly suitable for urban and peri-urban agriculture since they could significantly increase output per square meter of floor area. Including advanced technologies as LED illumination and automatic watering (Zheng et al., 2019), modern vertical systems offer accurate control of development conditions at every level.

From simple bag culture to sophisticated gutter systems, container systems provide site flexibility and production scalability. Usually loading individual containers or bags with substrate, these techniques allow simple changing of growing medium and efficient disease management. Research indicating appropriate container volumes of 4-6 liters per plant for most commercial kind shows that container size and substrate volume (Camacaro et al., 2004) greatly affect plant development and fruit yield.

Operating parameters in soilless systems demand careful supervision to maximize fruit quality and plant development. While pH is maintained between 5.5 and 6.2 for maximum nutrient availability, the electrical conductivity (EC) of nutrient solutions normally falls from 1.2 to 1.8 dS/m. Maintaining root health and nutrient absorption efficiency depends on optimal ranges between 18-24°C, hence solution temperature regulation is essential important (Savvas et al., 2013).

2 Life Cycle Assessment (LCA)

2.1 Overview of Life Cycle Assessment

Environmental Life Cycle Assessment (e-LCA), normally referred to as Life Cycle Assessment (LCA), is a technique that aims at addressing the environmental aspects of a product and its potential environmental impacts throughout that product's life cycle. The development and application of LCA have played a crucial role in understanding the environmental impacts of various sectors, particularly in industry and agriculture (Sala et al., 2015). Companies use LCA to improve their sustainability strategies by identifying opportunities to reduce their carbon footprint and resource use. Initially introduced by the Coca-Cola Company in 1960, LCA was developed to evaluate the environmental burdens of beverage bottles from raw material extraction to final disposal. It was later formalized in 1993 by the Society for Environmental Toxicology and Chemistry (SETAC) as a comprehensive method to assess energy, material use and waste production (Benoît & Mazijn, 2009). While LCA is a powerful tool, it faces several challenges. Data collection can be difficult, as it requires comprehensive and accurate information for each stage of the product's life cycle. Additionally, the complexity of modern supply chains makes it challenging to track all inputs and outputs (Rebitzer et al., 2004).

The agricultural sector, which provides a large number of products and services, is vital to human beings. Research on agricultural LCA began in the mid-1990s. In 1998, Japan, initiated LCA methodology research for sustainable agriculture by organizing relevant research institutes affiliated with Ministry of Agriculture, Forestry and Fisheries which contributed to the rapid development of agricultural LCA (Fan et al., 2022).

LCA helps to assess the environmental impact of different types of crops and farming systems. For instance, comparisons between organic and conventional farming, or between monocultures and polycultures, can inform best practices to minimize environmental harm. Beyond the farm, LCA is used to assess the environmental footprint of food processing, packaging, transportation, and distribution. For example, it can reveal how much energy and water are used to process a product or how far food travels from farm to table (food miles)

Environmental burden can be assessed using input-relates indicators such as energy demand, land use, and water use and output related indicators such as climate change impact or carbon footprint, damage to water body, acidification of land and water, and human toxicity (Bosona & Gebresenbet, 2018). By analysing the full range of environmental impacts, from input production to farming practices and post-harvest processing, LCA provides valuable insights into the most significant environmental challenges and opportunities in the agricultural sector. Despites its complexity and challenges, LCA helps promote more sustainable practices, informing farmers, policymakers and consumers about the ecological footprint of agricultural products and food systems.

2.2 Key stages of LCA

The LCA framework operates with four distinct phases as defined by the International Organization for Standardization (ISO). These four phases are: Goal and Scope definition, Inventory analysis, Impact assessment and Interpretation which are illustrated in Figure 1 (Hauschild et al., 2018).

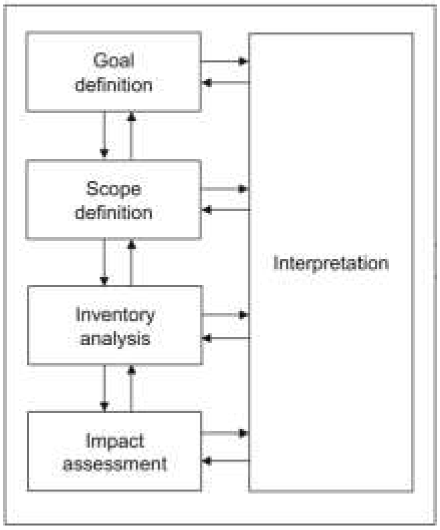

Figure 1: LCA framework based on the ISO 14040 standard.

2.2.1 Goal and Scope definition

Goal and Scope definition phase is essential for setting the foundation of an LCA. It defines the purpose, boundaries and the level of detail, ensuring that the study addresses the intended environmental questions in a meaningful and structured way. The goal definition sets the context for the LCA study and serves as the basis for the scope definitions where the assessment is framed and outlined in accordance with the goal definition (Hauschild et al., 2018). The goal and scope are defined at the outset of the study, before any data are collected. According to the ISO

14040 and 14044 this phase is often underestimated, as it is much more than a simple introduction to the LCA process ((Hauschild et al., 2018).

2.2.2 Inventory Analysis

Life Cycle Inventory (LCI) is a crucial phase in Life Cycle Assessment that involves comprehensive data collection and quantification of inputs and outputs throughout a product's life cycle. The development of LCI has faced several challenges, particularly in agricultural systems, including difficulties in data collection due to the complexity of modern supply chains and the need for accurate, comprehensive information at each stage of the product's life cycle. These challenges are further complicated by the variability in agricultural practices, soil types, and climatic conditions, which significantly affect the accuracy of environmental impact assessments (Bellon-Maurel et al., 2015).

To address these challenges, various tools and databases have been developed to support LCI analysis in agriculture. Key databases include Ecoinvent, which provides comprehensive datasets for agricultural processes, Agri-footprint, which focuses specifically on the agriculture and food sector, and AGRIBALYSE, a French database for agricultural products. These databases offer methodologically consistent datasets for a wide range of crops and animal products, making them valuable resources for LCA practitioners (Corrado et al., 2018). Additionally, the emergence of precision agriculture technologies, including Information and Communication Technologies (ICT) and Internet of Things (IoT), has enhanced the accuracy and efficiency of LCI data collection by enabling detailed and site-specific data gathering (Demestichas & Daskalakis, 2020).

A significant consideration in agricultural LCI studies is the management of regional variations and their influence on results. Studies have shown substantial differences in environmental impacts across different geographical locations. For example, research on strawberry production across four major U.S. states demonstrated significant variations in global warming potential per kilogram of strawberries: California at 1.75 kg CO_2-eq, Florida at 2.50 kg CO_2-eq, North Carolina at 5.48 kg CO_2-eq, and Oregon at 2.21 kg CO_2-eq. These variations are attributed to differences in yield and management practices influenced by geographic location and climate (Tabatabaie & Murthy, 2016).

Managing uncertainties in agricultural LCI studies requires various methodologies and sensitivity analyses to ensure accurate environmental assessments. A multilevel modelling (MLM) approach has proven effective in characterizing uncertainty by linking geographical and temporal characteristics with material and energy inputs, providing more accurate estimates than traditional aggregation methods. This is particularly important when dealing with spatial disparities that can lead to substantial differences in environmental impact assessments (Dai et al., 2020; Yang et al., 2018). The integration of traceability data and Information and Communication Technologies (ICTs) has also emerged as a valuable approach for streamlining LCI generation while improving accuracy. These technological solutions help reduce data collection efforts and better account for variations in crop yield and soil type, ultimately contributing to more reliable and comprehensive life cycle inventories (Bellon-Maurel et al., 2015).

2.2.3 Life Cycle Impact Assessment (LCIA)

Life Cycle Impact Assessment (LCIA) is a critical phase in evaluating the environmental impacts of agricultural activities by translating emissions and resource extractions into environmental impact scores. In agricultural systems, particularly for crops like strawberries, several key impact categories are commonly considered to understand the environmental burdens. These categories include Global Warming Potential (GWP), which measures the contribution of greenhouse gases to climate change, eutrophication potential related to nutrient enrichment of water bodies from fertilizer use, acidification potential measuring contributions to acid rain, land use impacts, ecotoxicity potential assessing impacts of toxic substances on ecosystems, and photochemical oxidation potential evaluating the formation of photochemical smog (Khoshnevisan et al., 2013; Romero-Gámez & Suárez-Rey, 2020).

The LCIA process employs both midpoint and endpoint approach to provide a comprehensive understanding of environmental impacts. The midpoint approach focuses on specific environmental problems or impact categories that are directly linked to environmental mechanisms, making them more straightforward to calculate and interpret. For instance, the ReCiPe2016 method includes 17 midpoint impact categories such as climate change and water use. In contrast, the endpoint approach translates these midpoint impacts into broader areas of protection, such as human health, ecosystem quality, and resource scarcity, providing a more comprehensive view of potential environmental damage (Huijbregts et al., 2017).

The characterization phase in LCIA links inventory data to environmental impacts through comprehensive methodologies that evaluate the environmental burdens associated with agricultural activities. This phase employs LCA tools like ENVIAM (Environmental Inventory of Agricultural Machinery operations), which incorporates local variables such as soil texture and machinery characteristics for accurate impact assessments. The integration of other methods, such as Material Flow Analysis (MFA) and artificial intelligence techniques, enhances the assessment process by evaluating material flows and predicting environmental impacts with greater precision (Lovarelli et al., 2017; Nabavi-Pelesaraei et al., 2018).

Managing uncertainties in LCIA for agricultural systems involves various methodologies and sensitivity analyses to ensure accurate environmental assessments. A MLM approach has proven effective by linking geographical and temporal characteristics with material and energy inputs, providing more accurate estimates than traditional aggregation methods. This is particularly important when dealing with spatial disparities that can lead to substantial differences in environmental impact assessments. Geographic variability significantly impacts LCIA results, with sector-specific approaches recommended to address these uncertainties, as conventional methods often underestimate them (Dai et al., 2020; Yang et al., 2018).

A significant challenge in applying LCIA to agricultural systems lies in their inherent diversity and complexity, which makes it difficult to implement standardized assessment approaches. Agricultural systems are characterized by wide variations in production conditions, regional and site-specific characteristics such as climate and soil type, and varying management practices. These variations necessitate the use of regionalized LCIA methods, which can be challenging to implement due to the need for detailed geospatial data. Additionally, accurately estimating field emissions, particularly reactive nitrogen emissions, remains a major challenge as current methods often extend beyond their validity domain. The assessment of pesticide impacts presents unique challenges, especially in tropical regions where higher kinetic rates of environmental processes like degradation and volatilization require adaptation of existing LCIA models that are typically based on temperate conditions (Gentil et al., 2020; Perrin et al., 2014).

2.2.4 Data interpretation

The interpretation phase of LCA employs several key methodologies to analyse and understand environmental impacts in agricultural systems. One crucial methodology is contribution analysis, which breaks down the total environmental impact into contributions from different processes or inputs within the system. For example, in studies of wheat and maize production, contribution analysis has identified that the agricultural phase, particularly the use of fertilizers and pesticides, represents a major hotspot across multiple impact categories. This method helps practitioners understand the environmental burdens associated with different stages of agricultural production (Fantin et al., 2017).

Sensitivity analysis serves as another critical methodology in the interpretation phase, assessing how variations in input parameters affect overall environmental impact results. This approach is particularly valuable for understanding the robustness of LCA outcomes and identifying key parameters that significantly influence the results. For instance, in studies comparing different farming systems, sensitivity analysis has been used to evaluate the impact of crop yields, biogas yields, and nitrous oxide emission factors on energy and greenhouse gas balances. This helps ensure that conclusions drawn from the LCA are reliable and well-supported by data (Tuomisto et al., 2012).

Spatial differentiation has emerged as a significant method in LCA interpretation, particularly relevant for agricultural systems due to their dependence on local environmental conditions. This approach allows for more accurate assessments by considering the geographic distribution of environmental impacts. For example, spatialized territorial LCA (STLCA) has been developed to study land-use planning in agricultural territories, incorporating spatial differentiation to provide more precise results and guide efforts to reduce environmental impacts. The inclusion of spatially explicit characterization factors in LCA studies has also proven valuable for improving the accuracy of environmental assessments by considering site-specific data (Antón et al., 2014; Nitschelm et al., 2016).

The identification of environmental hotspots represents another crucial aspect of LCA interpretation in agricultural systems. Studies have revealed several key hotspots in agricultural production, such as soil sterilization and fertilization practices. For instance, research in Switzerland identified soil sterilization as a major environmental hotspot, significantly impacting various environmental categories except for toxicity-related impacts and resource consumption. Similarly, studies in Spain highlighted fertilizers as a critical stage, contributing significantly to acidification, eutrophication, and ecotoxicity across different production systems. The identification of these hotspots helps guide improvements in agricultural practices and supports more sustainable farming approaches (Romero-Gámez & Suárez-Rey, 2020; Valiante et al., 2019).

The translation of LCA findings into actionable recommendations plays a vital role in shaping sustainable agricultural practices. One effective approach is the use of participatory eco-design, as demonstrated in vineyard management, where LCA results are made accessible to stakeholders through workshops and interactive tools. For example, the implementation of "serious games" and simplified calculation tools has enabled winegrowers and extension officers to better understand and manipulate LCA data, leading to improved technical management routes. This approach has proven successful, with studies showing improvements in four out of five case studies. The development of customized LCA tools tailored for agriculture has also enhanced the accessibility and usability of results, particularly when these tools focus on relevant life cycle phases and practice variables that align with the wider decision-making context (Renouf et al., 2018; Rouault et al., 2020).

2.3 International Organisation for Standardisation (ISO 1404/14044)

Designed by the International Organisation for Standardisation (ISO), standards were developed as a means of aggregating LCA procedures and approaches under ISO's environmental management requirements. Published between 1997 and 2000, four ISO standards—ISO 14040-14043—were replaced in 2006 by two standards: ISO 14040 (2006) and ISO 14044 (2006). These two standards provide guidance and requirements for performing a Life Cycle Assessment, therefore ensuring reliability, consistency, and openness in the LCA process.

ISO 14040:2006 defines four essential phases – Goal and Scope Definition, Life Cycle Inventory Analysis, Life Cycle Impact Assessment, and Life Cycle Interpretation – that reflect the fundamental concepts and approach for Life Cycle Assessment. These connected and iterative phases allow feedback loops to focus the research as necessary (Hauschild, 2018). The framework ensures systematically and comprehensively under well-defined standards for system constraints, transparency, consistency, and stakeholder issues LCA investigations are conducted under.

Especially in key areas including the review process, interpretation phase, and resolution of multifunctionality issues, ISO 14044:2006 supports ISO 14040 by providing comprehensive methodological standards and guidance. One significant development in ISO 14044 is the required critical assessment process for LCA studies with comparison statements exposed to the public that demand minimum of three experts to ensure the validity and credibility of such studies (Klöpffer, 2012). Emphasising the need of time-related coverage, geographic coverage, technical coverage, precision, completeness, and representativeness in data collecting and analysis, the standard also specifies data quality standards (Cooper & Kahn, 2012).

Though these standards have substantially improved the uniformity and dependability of LCA studies, they have certain negative effects particularly in agricultural applications. The lack of major modifications in the criteria in recent years has led to various inconsistencies and outdated recommendations. Particularly in sectors of bioeconomy where manufacturing techniques are sometimes complex and interrelated, problems including multifunctionality and co-product allocation remain challenging (Moretti et al., 2020; Schaubroeck, 2022). Notwithstanding these challenges, ISO 14040 and 14044 remain the principal frameworks for doing valid Life Cycle Assessments.

The criteria give high weight on uncertainty and sensitivity analysis to ensure the reliability and robustness of LCA outcomes. While uncertainty analysis is advised to highlight probable effects on result dependability, sensitivity analysis is specifically needed to uncover significant assumptions and facts that considerably influence the outcomes. This is particularly crucial when addressing multi-functionality problems in LCA as choices between allocation strategies can greatly affect outcomes (Jung et al., 2014). Although in fact practitioners occasionally ignore these uncertainties, the guidelines encourage at least a qualitative discussion of uncertainty (Ross et al., 2002).

Moreover separating two distinct LCA methods are ISO 14040 and 14044: consequential and attributional approaches. Usually used to assess existing environmental footprints, Attributional LCA (ALCA) stresses on using average data to characterise the environmental effects of a product's life cycle. Consequential LCA (CLCA) evaluates the environmental effects of system changes including policy or demand variations by means of marginal data and more complex modelling techniques (Schaubroeck et al., 2021). For practitioners selecting the appropriate technique depending on their study objectives, this difference is quite crucial.

The criteria also provide comprehensive directions for LCA study reporting and communication. These principles provide openness and comparability by way of extensive documentation of the complete LCA process. Extra standards apply, including required critical examination by a panel of experts, when studies make comparative assertions meant for public publication. This emphasis on thorough documentation and review processes helps to maintain the credibility and dependability of LCA results especially when LCA findings assist decision-making (Koffler et al., 2020). The criteria motivate participation of stakeholders all during the LCA process, therefore enhancing the acceptance and value of study results.

2.4 LCA studies on strawberries cultivation

LCA research on strawberry farming have been carried out all over different geographical areas and reveal obvious differences in environmental impacts depending on production techniques and geographical location. Research from Italy, Spain, Iran, and the United States shows that local climate variables, management practices, and farming methods as well as each other greatly affect environmental effects. For example, studies of mulched soil tunnel and soilless tunnel systems in Italy revealed that environmental impacts per kilogramme of strawberries produced were the same, and most of the variability depended on crop input variations and technical use (Ilari et al., 2021). On the other hand, studies carried out in Spain concluded that although organic systems showed lower impacts per hectare, although with lower production, the macrotunnel soilless integrated systems showed lower environmental impacts per tonne than other systems (Romero-Gámez & Suárez-Rey, 2020).

Comparative study of diverse manufacturing environments exposes quite evident geographical variations in environmental effects. Research shown in Iran indicated that open-field strawberry production was generally more environmentally friendly than greenhouse production, except in acidification and eutrophication categories, where significant environmental burdens are attributed to electricity, natural gas, and N-based fertilisers in greenhouse systems (Khoshnevisan et al., 2013). Conversely, studies on California, Florida, North Carolina, and Oregon in the United States revealed notable variations in environmental effects by location; California displays the best sustainability metrics due of superior yields (Tabatabaie & Murthy, 2016). Furthermore, a comparison between Switzerland and Italy exposed further environmental effects in Swiss industry, largely connected to soil sterilising techniques (Valiante et al., 2019).

Through their different environmental implications, LCA studies have investigated diverse agricultural methods including plasticulture, hydroponics, and soil-based, hydroponics. Rising usage of fertilisers, petrol and water has resulted in soil-based systems displaying often more environmental effects, which significantly contribute to terrestrial ecotoxicity, human non-carcinogenic toxicity and global warming (Wimmerova et al., 2022). Although hydroponics offer innovative concepts, their environmental load is much worsened by their challenge with conventional energy use. Still, these systems show promise for less environmental consequences should renewable energy sources be embraced (Wimmerova et al., 2022). Particularly cold-climate plasticulture (CCP), reduced soil disturbance and mulch use under plasticulture systems shows less soil erosion and runoff than more conventional soil-based systems (Stevens et al., 2009).

Water use and efficiency have become relatively major factors in LCA studies of strawberry producing systems. Studies have shown that although improved irrigation scheduling can increase water use efficiency without losing production, soil-based systems usually show high water consumption due of ineffective irrigation practices (Lozano et al., 2016; Martínez-Ferri et al., 2016). On the other hand, due to more controlled water application, soilless systems – hydroponics, for example – usually exhibit superior water usage efficiency, therefore conserving a lot of water and producing more fruit than in regular soil systems (Rizk & Seidhom, 2009). While there is considerable variation in technique, the precision irrigation-most notably sensor-based systems-can reach dramatic gains in use efficiency of water with significant savings in resources without sacrificing yield (Bonelli et al., 2024).

LCA studies have gone into much detail on the GHG emissions from various methods of strawberry farming. Distinct differences in the emission from the different production systems are evident; for instance, the GHG emissions from Iranian greenhouse production are far higher than that from open field production, at 35,083.5 kg CO_2eq/ha and 803.4 kg CO_2eq/ha, respectively (Khoshnevisan et al., 2014). Studies published in organic production systems under high tunnels in Kentucky revealed a Global Warming Potential (GWP) of 0.57 kg CO_2-eq per kg of strawberries, with major contributions coming from the manufacture of aluminium and plastic materials used in tunnel construction (Clark & Mousavi-Avval, 2022). Nitrogen fertilizers and machinery use being described as the main determinants, the GHG emissions of drip irrigation systems per hectare were higher compared to the GHG emission of furrow irrigation systems. It was estimated as 1,284.19 kg CO_2 equivalent/ha in case of drip irrigation systems, as compared to furrow irrigation systems, which showed an emissions total of 764.28 kg CO_2 equivalent/ha (KAZEMI & ZARDARI, 2018).

Comparative analysis of organic and conventional strawberry farming techniques has exposed fascinating environmental effects trends. Studies have shown that conventional strawberry farming methods typically show less environmental effect than organic methods, largely due to higher productivity and lower input transportation requirements. One study in California showed that organic strawberries generate 46% more carbon equivalent emissions than their conventional cousins - due to the transport of organic amendments such as compost and manure, which are applied in greater volume (Chiu & Gomez, 2023). While an organic strawberry farming system generally had lower impacts across a range of indicators compared with conventional and integrated strawberry production per hectare, yield per hectare in this production system was typically much lower in the studied Spanish examples. Particularly macrotunnel soilless integrated systems, the creative conventional systems showed lower environmental effect per tonne of strawberries grown (Romero-Gámez & Suárez-Rey, 2020).

Energy efficiency and use have become relatively crucial factors in LCA assessments of strawberry producing systems. Studies on greenhouse systems have found that, with large usage from diesel fuel, chemical fertilisers, and electricity, they are especially energy-intensive. In extreme circumstances, studies have revealed that diesel fuel can account for up to 80% of energy use (Banaeian et al., 2011; Hosseini-Fashami et al., 2019). The energy consumption pattern in tropical regions is different; air cooling for 64% of the total electricity used and lighting for 36% (Wai et al., 2022). Even so, studies have indicated possible answers by making use of solar technologies. From such studies, PV systems installed on greenhouses have indeed achieved great reduction in both energy consumption and environmental impact. This is depicted more specifically by those who attain great efficiency from exergy demand, lowering up to 50% with regard to conventional systems (Hosseini-Fashami et al., 2019).

LCA studies also identify packaging and postharvest handling as one of the main determinants in the whole environmental impact of strawberry production. Compared to a traditional polyethylene use, which produced 260 kg/ha of waste, a study showed that biodegradable packaging material can generate zero wastes; thereby, this reduces by about 20% GWP and non-renewable energy under (Girgenti et al., 2014). Specifically Equilibrium Modified Atmosphere Packaging (EMAP), Modified Atmosphere Packaging (MAP) methods have been shown to reduce food losses while preserving product quality. Studies underline, however, the need of striking an ideal balance between food loss reduction and environmental burden since too aggressive post-harvest operations may not always produce minimum environmental impacts (Sasaki et al., 2022).

Several major data gaps and uncertainty in strawberry growing assessment found by LCA research compromise the quality and dependability of environmental effect assessments. Important sources of uncertainty include the variation in farming methods, including as cycle length and soil management, which cause significant variations in environmental impacts. Studies have revealed that yield variability is very important since low yields, particularly in long-term crop cycles, can greatly compromise environmental results (Valiante et al., 2019). Moreover, studies on data source choice and model accuracy have shown uncertainty, especially in categories of toxicity-related impact; so, more uniform data collecting techniques are suggested to be necessary. Data on the long-term benefits of technologies, such as integrated agricultural production and renewable energy consumption, shows a significant difference in their efficiency in reducing environmental impact, which is not well recognize (Romero-Gámez & Suárez-Rey, 2020).

Geographic and regional differences in LCA studies have shown how important local variables are for influencing environmental effects of strawberry farming. Studies conducted in the United States have revealed notable differences between different states; California shows the lowest global warming potential (1.75 kg CO_2-eq) due to high yields, while North Carolina shows the highest (5.48 kg CO_2-eq) due to different management practices and lower yields (Tabatabaie & Murthy, 2016). European research has similarly pointed out geographical differences: Italian open field production without soil sterilization presents much lower environmental impact compared to Swiss production, which, due to the applied techniques of soil sterilizing, has more significant impacts (Valiante et al., 2019). This evidence of geoclimatic and cultivation practices conditions between geographical variations strengthens the importance of considering local conditions and practices when evaluating and enhancing environmental performance in strawberry farming.

The particular climatic difficulties of the Mediterranean Basin—warming and drying trends—have important effects on strawberry farming in Cyprus. From the case studies related to LCA about water scarcity influence on Mediterranean agriculture, the future water reserves may be arguably short of agricultural needs under the climate change scenarios causing lower inflows and higher irrigation demand (Claro et al., 2024). The research shows that solving these problems in Cyprus, and thus improving the current practices of water and land management, should be based on integrated modeling platforms and decision-support systems. In particular, Decision Support System-based irrigation or smart irrigation systems have already shown their potential to substantially reduce water and energy consumption; thus, they could become one of the ways for sustainable intensification of agriculture in this area (Fotia et al., 2021).

The local energy mix and infrastructure in Cyprus are quite decisive for the environmental impact assessment of different strawberry farming methods. Greenhouse production usually causes higher environmental impact in areas where most of the electricity is produced from fossil fuel, due to higher emissions related to heating and lighting (Khoshnevisan et al., 2013). Previous preliminary research seemed to indicate, however, that the environmental influence of greenhouse strawberry production would indeed be significantly reduced the wider the renewable energy sources become part of Cyprus's electric mix. This obviously creates different conditions, particularly for high-tech greenhouse systems, where strawberry cropping's overall environmental impact really stood to gain from infrastructure and energy economy, among other factors (Khoshnevisan et al., 2013.

2.5 Aim of the study

The current study aimed to assess the environmental implication of different strawberry production systems in Cyprus, focusing on the variations in cultivation methods and growing media. The examined systems were categorized based on their approach to production: open filed farming versus protected cultivation and their use or either soil or soilless growing techniques. The study was driven by two primary objectives. The first was to develop a comprehensive Life Cycle Inventory (LCI) that documented all the inputs, outputs and operational processes integral to strawberry production and the second was to pinpoint the specific practices and methods that contribute most significantly to the overall environmental footprint of these systems. The analysis focused exclusively on the production phase of strawberries, with system boundaries extending from the initial input stage through to the point at which the strawberries were ready to leave the farm, commonly referred to as “cradle-to-farmgate”. By concentrating on the production stage, this study aimed to provide actionable insights into the environmental performance of different farming systems in order to be adapted more sustainable approaches to strawberry cultivation in Cyprus.

3 LCA Methodology

3.1 Goal and Scope Definition

The study aimed to evaluate the environmental effects associated with various strawberry production systems in Cyprus. These systems were distinguished by their production methods (open-filed versus protected cultivation) and the type of growing media (soil or soilless). The systems analysed were chosen to represent typical strawberry farming practices in Cyprus are outlined in **Table 1.**

The research had two main goals: firstly, to create a Life Cycle Inventory (LCI) that captures all the inputs, outputs and processes involved in strawberry cultivation, and secondly, to identify the practises and procedures that contribute most significantly to environmental impact.

The main interest of the study was restricted to the production phase of the crop with the system boundaries defined from the initial input stage to the point where the strawberries leave the farm (cradle-to-farmgate). The assessment included field operations such as land preparation, planting, fertilization, pesticide application, irrigation and harvesting. Activities following the harvest were presumed to be uniform across the systems and were therefore excludes from the study’s scope.

Table 1: The various systems studies, distinguished by cultivation method.

Country	Production Systems	Growing Media	Acronym
Cyprus	Open Field	Soil	COFS
	Protected in high tunnel	Soil	CPS
		Peatmoss/Cocopeat	CPSs

Each cultivation system reflects the practices employed by farms producing fresh strawberry using the specified methods. Any waste generated during the cultivation process, such us pruning residues and discarded fruits, was assumed to decompose naturally within the field. This practise effectively completes the biogenic carbon cycle, as the CO_2 absorbed by the plants during their growth is returned to the soil through the breakdown of organic matter, leading to a carbon-neutral outcome for this aspect of the process.

The layout of the product systems is depicted in **Figure.2**. The analysis accounted for all inputs, including fuel, fertilizers, pesticides, water and materials used for constructing the irrigation setup, while also considering the manufacturing process of these inputs. The chosen functional unit (FU) was 1 kilogram of marketable strawberries produced at the farm gate during the 2023 growing season. Within the field, all data references were standardized to an area of 1 hectare (ha). For the Life Cycle Impact Assessment (LCIA), all necessary Life Cycle Inventory (LCI) data resulting calculation were aligned with the defined FU.

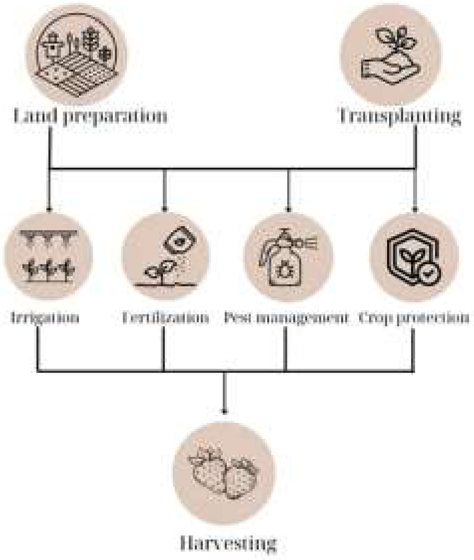

Figure 2: Product System-System boundaries of the LCA of Strawberry cultivation.

The LCI data for the product system were based on data collected from the representative farms. Data for upstream activities, such as the supply of raw materials (e.g., fertilizers, fuels, nursery plants, and polyethylene) and the treatment of waste, are sourced from Ecoinvent 3.10, Agri-footprint 6.3 and/or Agribalyse 3.1 databases.

3.2 Life Cycle Inventory

The study focused on strawberry production systems in Cyprus, analysing three cultivation methods: soil-based protected high tunnel systems, soilless protected high tunnel systems and open-filed systems. Data for the Life Cycle Inventory (LCI) were gathered regionally during the 2023-20224 growing season through questionnaires and in-person interviews with farmers and local experts.

The questionnaire was consisting of 48 questions about strawberry cultivations. In total we gather 11 responses from Cyprus farmers, 7 farmers used the Protected in high tunnel soilless cultivation, 3 farmers used the Protected in high tunnel in soil and 1 farmer used the open field in soil cultivation.

This data represents typical practices in the region. Calculations for fertilizers and pesticide use, water needs, energy consumption and strawberry yields across the systems were derived from responses to customized surveys. These surveys captures input flows, including plant density per hectare, irrigation volumes, chemical inputs, cultivated land area, electricity for irrigation and machinery, diesel for equipment and materials such as polyethylene. Outliner data points were excludes, and averages were calculated to represent each system and region reliably.

For irrigation infrastructure in open-field systems, the study utilized the “Irrigation | Irrigation, drip | Cut-off, U” dataset from the Ecoinvent database. Protected systems employed the “Plastic tunnel | Plastic tunnel construction | Cut-off, U” dataset, representing unheated galvanised steel structures with EVA (ethylene vinyl acetate) copolymer covers replaced every four years. These tunnels, designed to last 25 years, incorporate a fertigation system using polyethylene pipes, alongside other auxiliary facilities. Polyethylene coverage assumed complete coverage, with raised beds 40 cm high and covered externally. Two planting rows per bed were modelled, with uncovered pathways for worker movement (40-50 cm wide). Pesticide application was confined to planting rows. Tunnels in protected systems were modelled as 7m wide and 100m long. In soilless systems each polyethylene bag accommodated five plants.

Supplementary information was sourced through an extensive review of relevant literature. Environmental impacts of inputs, including raw material extraction, production, and market activities, were assessed using Ecoinvent 3.10, AgriFootprin 6.3 and Agribalyse 3.1 databases. Farming operations such as soil preparation, fertilization, pest management, irrigation, and harvesting were analysed. Emissions, both direct and indirect, were estimated based on the active components in products and the quantities of consumed fuel, water and energy, Diesel emissions were modelled using SimaPro's LCI databases, while the embodies emissions for electricity, diesel, fertilizers, pesticides and materials like polyethylene were analysed using the international Ecoinvent 3 database.

Life Cycle Inventory data for the studies systems are detailed in Tables 1, 2 and 3. For pesticide emissions, the Pest LCI Consensus Model was applied, categorizing strawberries under the "Berries" archetype with the "Herbaceous fruits and vegetables" class (Nemecek et al., 2022). The emissions from fertilizers were calculated according to the IPCC guidelines (IPCC, 2019). Table1, 2 and 3 summarizes the emissions distribution for each system.

Table 1: Inventory for the Open Field system, Cyprus

Input/output	Type	Amount	Unit	Source
Material input	**Strawberry plantlets**	50000	**pcs**	Representative farm in Cyprus
	Insecticides	80	**kg**	
	Fungicides	40	**kg**	
	Inorganic nitrogen fertiliser	122	**kg**	
	Inorganic phosphorus fertiliser	30	**kg**	
	Inorganic potassium fertiliser	500	**kg**	
Energy	**Diesel**	500	**kWh**	
Land	**Annual crop**	1	ha	
Infrastructure	**Drip irrigation**	6000	**m^3**	
Main output	**Strawberries**	22.5	**ton**	
Emissions to air	**Insecticides**	8	**kg**	(Nemecek et al., 2019)
	Fungicides	4	**kg**	
	Ammonia, from fertilizers	14.81	**kg**	(IPCC, 2019)
	Dinitrogen monoxide, from fertilizers	1.92	**kg**	
Emissions to water	**Insecticides**	0.056	**kg**	(Nemecek et al., 2019)
	Fungicides	0.028	**kg**	

	Phosphate, from fertilizers	2.1	**kg**	(IPCC, 2019)
	Nitrate, from fertilizers	54.03	**kg**	
Emissions to soil	**Insecticides**	40.81	**kg**	(Nemecek et al., 2019)
	Fungicides	11.76	**kg**	
	Nitrate, from fertilizers	36.6	**kg**	(IPCC, 2019)
Waste	**Landfill**	4.5	**ton**	Representative farm in Cyprus

Table 2: Inventory for the protected cultivation in soil, Cyprus

Input/output	Type	Amount	Unit	Source
Material input	**Strawberry seedlings**	40000	**pcs**	Representative farm in Cyprus
	Insecticides	30	**kg**	
	Fungicides	20	**kg**	
	Inorganic nitrogen fertiliser	243.9	**kg**	
	Inorganic phosphorus fertiliser	130	**kg**	
	Inorganic potassium fertiliser	533.3	**kg**	
	Manure	20	**ton**	
Energy	**Diesel**	1602.4	**kWh**	
Land	**Annual crop**	1	ha	
Water	**Water**	2500	**m^3**	
Infrastructure	**Tunnel infrastructure**	11775	**m^2**	
	HDPE, mulch	570	**kg**	
	HDPE, mulch (forming)	570	**kg**	
Main output	**Strawberries**	32.5	**ton**	
Emissions to air	**Insecticides**	3	**kg**	(Nemecek et al., 2019)
	Fungicides	2	**kg**	
	Ammonia, from fertilizers	29.62	**kg**	(IPCC, 2019)
	Dinitrogen monoxide, from fertilizers	108.01	**kg**	
Emissions to water	**Insecticides**	0.021	**kg**	(Nemecek et al., 2019)
	Fungicides	0.014	**kg**	
	Phosphate, from fertilizers	9.1	**kg**	(IPCC, 2019)

	Nitrate, from fertilizers	108.01	**kg**	
Emissions to soil	**Insecticides**	14.87	**kg**	(Nemecek et al., 2019)
	Fungicides	5.88	**kg**	
	Nitrate, from fertilizers	73.17	**kg**	(IPCC, 2019)
Waste	**Landfill**	3.25	**ton**	Representative farm in Cyprus

Table 3: Inventory for Protected cultivation, soilless, Cyprus

Input/output	**Type**	**Amount**	**Unit**	**Source**
Material input	**Strawberry seedlings**	68600	**pcs**	Representative farm in Cyprus
	Insecticides	55.4	**kg**	
	Herbicides	10.7	**kg**	
	Fungicides	32.7	**kg**	
	Inorganic nitrogen fertiliser	396.3	**kg**	
	Inorganic phosphorus fertiliser	250	**kg**	
	Inorganic potassium fertiliser	1083.3	**kg**	
	Peat moss	1.5	**m^3**	
Energy	**Diesel**	14373.2	**kWh**	
Land	**Annual crop**	1	ha	
Water	**Water**	4065	**m^3**	
Infrastructure	**Tunnel infrastructure**	11775	**m^2**	
	HDPE, mulch & polyethylene bags	1352	**kg**	
	HDPE, mulch & polyethylene bags (forming)	1352	**kg**	

Main output	**Strawberries**	35.17	**ton**	
Emissions to air	**Herbicides**	1.07	**kg**	(Nemecek et al., 2019)
	Insecticides	5.54	**kg**	
	Fungicides	3.30	**kg**	
	Ammonia, from fertilizers	48.12	**kg**	(IPCC, 2019)
	Dinitrogen monoxide, from fertilizers	6.23	**kg**	
Emissions to water	**Herbicides, unspecified**	0.008	**kg**	(Nemecek et al., 2019)
	Insecticides, unspecified	0.039	**kg**	
	Fungicides, unspecified	0.023	**kg**	
	Phosphate, from fertilizers	17.5	**kg**	(IPCC, 2019)
	Nitrate, from fertilizers	175.5	**kg**	
Emissions to soil	**Herbicides, unspecified**	6.87	**kg**	(Nemecek et al., 2019)
	Insecticides, unspecified	27.75	**kg**	
	Fungicides, unspecified	9.61	**kg**	
	Nitrate, from fertilizers	118.89	**kg**	(IPCC, 2019)
Waste	**Landfill**	1.76	**ton**	Representative farm in Cyprus

3.2.1 Open filed cultivation in soil

Open filed cultivation of strawberries is a traditional and widely practiced method for producing this popular fruit, offering simplicity and cost effectiveness for large-scale operations. Strawberries growing directly in prepared soil under natural environmental conditions, making it suitable for regions with favourable climates. Ideal selection is critical, with well-drained sandy loam soils and pH between 5.5 and 6.5 being optimal (Liu et al., 2024). This cultivation method requires raised beds to ensure proper drainage, frequent irrigation and balanced fertilization. Using mulch is benefit to control weeds and retain soil moisture. Despites its vulnerability duo to whether fluctuations, open-field cultivation allows for natural pollination and remains an effective approach for producing high-quality strawberries in large quantities (Garza-Alonso et al., 2022).

3.2.2 Protected in high tunnel in soil

Protected high tunnel cultivation of strawberries is an advanced farming technique that enhances yield, extends the growing season and improves fruit quality by providing a controlled environment. There are unheated, plastic-covered, usually polyethylene films, structures which traps heat and maintains favourable growing conditions. At this type of method the soil should be well-aerated, fertile and well drained with pH of 5.5-6.5. For drainage and root development improvement, raised beds (15-30 cm high) are commonly used. The drip irrigation method is preferred in high tunnel due to the fact it provides precise water delivery to the root zone (Guan et al., 2022).

3.2.3 Protected in high tunnel soilless

The cultivation of strawberries in protected high tunnels using soilless systems is an innovative approach that enhances productivity, improves fruit quality and reduces disease pressure. Strawberries are growing without traditional soil, using alternative growing media such as coconut coir, peat moss, pertile or hydroponic solutions. One of the most commonly used growing system is substrate bags or containers where plants are grown in bags filled with substrate providing excellent aeration and drainage (Claire et al., 2018). Coconut coir is the most popular substrate due to its water retention capacity, good drainage and sustainability (Claire et al., 2018). High tunnels, as already described earlier, are unheated greenhouse structures covered with polyethylene plastic creating a microclimate that enables early planting and prolonged fruiting (Wortman et al., 2016).

4 Results

4.1 Life Cycle Impact Assessment

The environmental impacts of strawberry cultivation were assessed using the ReCiPe2016 methodology, specifically adopting the midpoint approach. The ReCiPe2016 midpoint (Hierarchist) framework was chosen for this analysis as it is a modern and widely accepted tool for impact assessment, frequently utilized in contemporary agricultural life cycle studies (Parajuli, Matlock and Thoma, 2022). The midpoint indicators employed in the study, as defined by the ReCiPe2016 methodology are outlined in Table 4

Table 4: ReCiPe2016 – Midpoint Impact Indicators

Impact Category	Impact	Unit
Global Warming Potential	GWP	kg CO2,eq
Ozone depletion	ODP	Kg CF-11eq
Ionising radiation	IRP	kBq U-235eq
Photochemical ozone formation	PCOP	Kg NMVOCeq
Particulate matter	PM	Disease
Human toxicity, non-cancer	HTPNC	CTUh
Human toxicity, cancer	HTPC	CTUh
Acidification	AP	Mol H+eq
Eutrophication, freshwater	FEP	Kg Peq
Eutrophication, marine	MEP	Kg Neq
Eutrophication, terrestrial	TEP	mol Neq
Ecotoxicity, freshwater	ETP	CTUe
Land use	LU	Pt
Water use	WDP	m3
Resource use, fossils	ADPF	MJ

The Systems were modelled, and the environmental impacts assessed using SimaPro software version 9.6.0.1 (PRé Sustainability B.V., 2024), in accordance with the classification and characterization phases outlines in ISO-14040 (2006).

4.2 Life Cycle Impact Assessment Comparison of 3 Cultivation Systems

4.2.1 Global Warming

The results of Global warming midpoint are demonstrated in **Figure 3**. The greatest environmental effect is exhibited by the peat moss cultivation system, primarily due to the use of inorganic fertilizers, diesel fuel and high density Polyethylene. In contrast unheated in high tunnel cultivation in soil system exhibits the lowest impact and this reduction is mainly efficiency and reduce excessive fertilizer applications.

[redacted]

Figure 3: Comparison of global warming potential among the different cultivation protocols of strawberry cultivation.

4.2.2 Terrestrial acidification

The results for terrestrial acidification are demonstrated in **Figure 4**, were the peat-moss based system emerges again as the most important, with inorganic potassium and nitrogen fertilizers and diesel consumption being the main contributors factors. Acidification occurs as a result of ammonia (NH_3) and sulfur dioxide (SO_2), emissions, which contribute to soil and water degradation. In contrast cultivation with unheated tunnels in soil has comparatively less effect largely due to its reduced dependency on synthetic fertilizers and the improved efficiency of nutrient uptake in protected cultivation environments.

[redacted]

Figure 4: Comparison of terrestrial acidification among the different cultivation protocols of strawberry cultivation.

4.2.3 Freshwater eutrophication

In **Figure 5**, illustrated the results for the freshwater eutrophication midpoint. Peat moss cultivation impacts the most, owing to large contributions from inorganic potassium and nitrogen fertilizers and extrusion of plastic sheets. The open field system has an inferior environmental effect, which is dominated by drip irrigation, insecticide and inorganic potassium fertilizers use.

Figure 5: Comparison of freshwater eutrophication among the different cultivation protocols of strawberry cultivation.

4.2.4 Terrestrial ecotoxicity

The results for terrestrial ecotoxicity are demonstrated in **Figure 6**, were the peat moss system has the highest environmental contribution and it is largely due to inorganic fertilizers and diesel consumption. The open field in soil has relatively lower impact but still has a significant contributions from the drip irrigation system that it used.

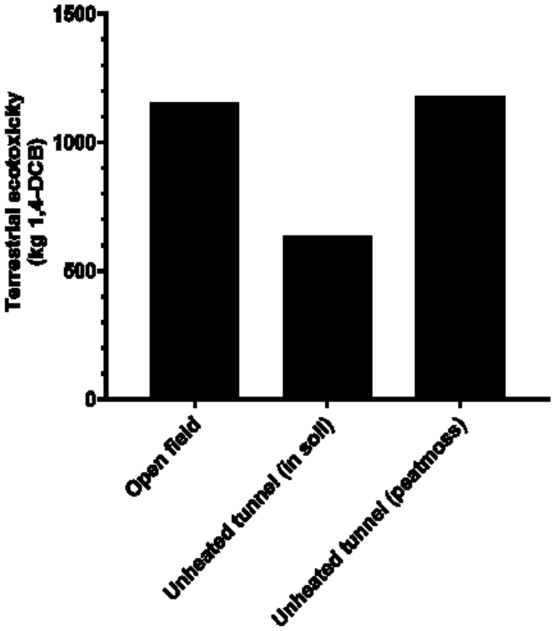

Figure 6: Comparison of terrestrial ecotoxicity among the different cultivation protocols of Strawberry cultivation

4.2.5 Freshwater ecotoxicity

Results for freshwater ecotoxicity illustrated in **Figure 7** with the open field system being the most environmentally harmful, dominated by irrigation, insecticide and fungicide applications. The unheated in high tunnel in soil and soilless exhibits intermediate impacts with fertilizers and insecticides application being the significant contributors.

Figure 7: Comparison of freshwater ecotoxicity among the different cultivation protocols of strawberry cultivation.

4.2.6 Water consumption

Figure 8, presents the outcomes for water consumption. The highest impact occurs in open filed systems where irrigation is defined as the primary contributing factor. The lowest water usage is observed in high tunnel systems where strawberry pants exhibits the highest rates of water use.

[redacted]

Figure 8: Comparison of water consumption among the different cultivation protocols of strawberry cultivation.

4.2.7 Land use

Figure 9, demonstrates the impact in land use. The greatest impact appears in open filed in soil system, followed by the unheated high tunnel systems in soil and peat moss and this is due to the fact that in open filed farmer use more land for the production of 1Kg of marketable strawberries than in the protected cultivations were farmers use raised bags and they have better yields.

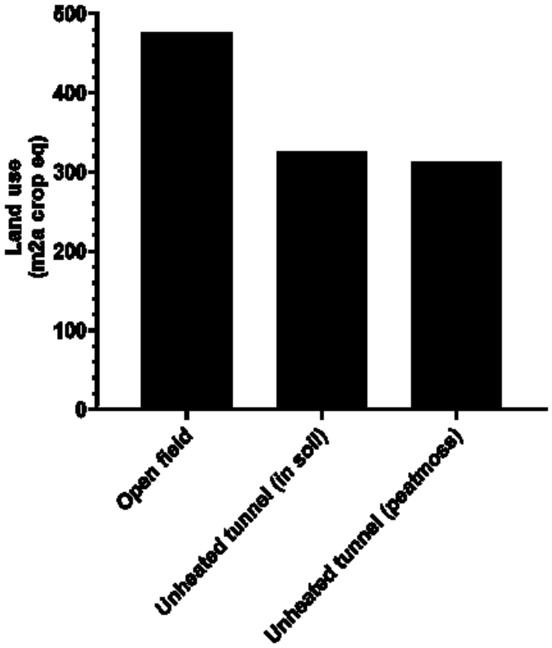

Figure 9: Comparison of land use among the different cultivation protocols of strawberry cultivation.

4.2.8 Human non-carcinogenetic toxicity

Figure 10, demonstrate the results of Human non-carcinogenetic toxicity impact with the most significant environmental contribution derived from peat moss based cultivation system mainly due to diesel combustion in agricultural machinery and the use of nitrogen and potassium fertilizers which release heavy metals and other toxic compounds into the environment.

[redacted]

Figure 10: Comparison of human non-carcinogenic toxicity among the different cultivation protocols of strawberry cultivation.

5 Discussion

This study evaluates the environmental impact of different strawberry cultivation systems in Cyprus, focusing on various categories, including global warming, terrestrial acidification, freshwater eutrophication, terrestrial ecotoxicity, human non- carcinogenic toxicity, land use and water consumption. The cultivation methods analysed include the open-field system and the unheated high tunnel cultivation, both soil-based and soilless.

The findings indicated that the peat moss based cultivation system has the highest environmental impact across multiple categories, primarily due to the use of inorganic fertilizers (nitrogen and potassium), use of high density polyethylene (HDPE) and diesel fuel consumption by the farm machinery. The high dependency on synthetic fertilizers leads to significant emissions of greenhouse gases, such as nitrous oxide (N_2O), contributing to global warming. Additionally, diesel fuel combustion in agricultural machinery further exacerbated the carbon footprint of this system. In contrast, the unheated high tunnel cultivation in soil presents the lowest environmental burden, with similar contributing factors to the open-field systems but with lower overall emissions. This reduction is mainly efficiency and reduce excessive fertilizer applications.

Terrestrial acidification is also most pronounced in the peat moss system due to the extensive use of inorganic fertilizers and diesel fuel. Acidification occurs as a result of ammonia (NH_3) and sulfur dioxide (SO_2), emissions, which contribute to soil and water degradation. Conversely, unheated high tunnel cultivation in soil demonstrates a comparatively lower impact largely due to its reduced dependency on synthetic fertilizers and the improved efficiency of nutrient uptake in protected cultivation environments.

Regarding freshwater eutrophication, the peat moss system again emerges as the most environmental harmful, largely due to its high reliance on inorganic fertilizers and plastic-based materials. The open-field system, while exhibiting a lower effect, still has significant contributions from drip irrigation and insecticide application, which introduce additional pollutants into freshwater ecosystems. In contrast, the unheated high tunnel soil-based system demonstrated a more sustainable approach, with reduced nutrient leaching and optimized water management.

Similarly, in the category of terrestrial ecotoxicity, the peat moss-based system shows the greatest impact, followed by the open-field system and the unheated high tunnel cultivation in soil. The widespread use of synthetic fertilizers and pesticides contributes to soil degradation and the accumulation of harmful chemicals, which pose risks to both terrestrial and aquatic ecosystems. Long-term exposure to these contaminants can disrupt biodiversity, reducing soil microbial activity and affecting pollinators and other beneficial organisms. The unheated high tunnel soli-based system minimizes these effects by reducing chemical inputs and implementing more sustainable pest management strategies.

In terms of human health, the open-field system exhibits the highest human carcinogenic toxicity impact, with drip irrigation, inorganic fertilizers, and insecticides being major contributors. Pesticide residues and nitrate contamination in groundwater pose serious health risks, including increases susceptibility to cancer and other chronic illnesses. The peat moss system contributes the most to human non-carcinogenic toxicity, mainly due to diesel combustion in agricultural machinery and the use of nitrogen and potassium fertilizers which release heavy metals and other toxic compounds into the environment. Land use is highest in the open-field system, with strawberry plants serving as the main contributing factor across all systems.

Water consumption is found to be the highest in open-field systems, driven primarily by irrigation needs. Compared to unheated high tunnel soilless and soil-based systems water consumption in open-field cultivation is 110% and 360 % higher, respectively. The high water demand is exacerbated by evaporation and inefficient irrigation techniques, which lead to excessive water loss. The unheated high tunnel systems (both soil-based and soilless) exhibit the lowest water consumption, with strawberry plants and seedlings accounting for the highest water use within these systems. The controlled environment of high tunnels helps conserve water by reducing evaporation and improving irrigations efficiency, making it a more sustainable option in water-scare regions such as Cyprus.

Overall, this comparative analysis underscores the varying environmental implications of different strawberry production systems in Cyprus. The findings highlight the importance of adopting sustainable agricultural practices, particular the benefits of unheated high tunnel cultivation in soil, which presents a lower environmental burden across multiple impact categories. Reducing reliance on inorganic fertilizers, optimizing irrigation methods, and minimizing diesel fuels use are key strategies for mitigating the adverse environmental effects of strawberry production.

6 Conclusions

The environmental impact of strawberry cultivation in Cyprus varies depending on the production system, with soil-based unheated high tunnel cultivation being the most sustainable option, reducing emissions, nutrients runoff and resource waste through controlled growing conditions, improved nutrient efficiency, and optimized inorganic fertilizers, irrigation practices, use of HDPE, pesticide application and diesel fuels use.

To mitigate the adverse environmental effects of strawberry production, several key strategies should be implemented. Reducing reliance on inorganic fertilizers by incorporating organic alternatives, such as compost and biofertilizers, can significantly decrease nutrient runoff and soil degradation. Optimizing irrigation methods, such as implementing precisions irrigation and rainwater harvesting, can enhance water efficiency and reduce excessive consumption. Additionally, minimizing diesel fuel use by transitioning to more energy-efficient machinery or adopting renewable energy sources can help lower greenhouse gas emissions and reduce overall environmental impact.

Future research should focus in further improving the sustainability of strawberry cultivation by exploring alternative growing media that reduce dependency on peat moss while maintaining crop productivity. The implementation of integrated pest management (IPM) strategies and the adoption of agroecological approaches can further reduce pesticide usage and enhance ecosystem resilience. Policymakers and stakeholders should promote incentives for farmers to transitions toward environmentally friendly cultivation methods, ensuring the long-term sustainability of strawberry production in Cyprus and beyond.

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APPENDIX I

Questionnaire (English Version)

A. General

1. What is the location that you grow strawberries? Your country/region (e.g Verona, Italy)

   Free Text

2. Your climate region is characterised as:
   - a. *Temperate*
   - b. *Mediterranean*
   - c. *Mountaneous*

3. What is the predominant type of strawberry you grow?
   - a. *Day Neutral (e.g Albion)*
   - b. *Short day (e.g Fortuna)*
   - c. *Long day (e.g Elsanta)*

4. What are the strawberry cultivars you grow? (Provide percentage, i.e. Victory (80%), Fortuna (20%)

   Free Text

B. Cultivation info

5. What is your cultivation system?
   - a. *Open field*
   - b. *Open field with low tunnel*
   - c. *Unheated Greenhouse or tunnel*
   - d. *Heated Green house or glasshouse*
   - e. *Net protection*

6. Your cropping method is:
   - a. *Integrated management – Without Certificate*
   - b. *Organic Certified*
   - c. *IPM certified (GLOBAL GAP)*
   - d. *Low residues – Certified for European supermarket (IFS, BRC)*

7. Which is the duration of the cultivation cycle?

   Free Text

8. Which months do you harvest?
   - *a. January*
   - *b. February*
   - *c. March*
   - *d. April*
   - *e. May*
   - *f. June*
   - *g. July*
   - *h. August*
   - *i. September*
   - *j. October*
   - *k. November*
   - *l. December*

9. What is the average annual yield of your cultivation (tones per hectare)?
   Number

10. What is the extent of your cultivation area (hectares)?
    Number

11. How many plants/strawberries do you place per hectare (plants/ hectare)?
    Number

12. What type of nursery plants do you use?
    - *a. Frigo Bare roots*
    - *b. Fresh Bare roots*
    - *c. Fresh Tray plants*
    - *d. Frigo Tray plants*
    - *e. Fresh plug plants*

13. If you grow your plants soilless, in what type of substrate do you grow your crops?
    - *a. cococoir/cocopeat*
    - *b. Peatmoss*
    - *c. Other (Biochar)*
    - *d. Rockwool*
    - *e. Combination of cocopeat and peatmoss*

14. What type of material do you use for your growing media
    - *a. Polyethelene Grow Bags*

   b. *Polypropylene pots*
   c. *No application*

15. What is the lifespan of the material used as growing media?
    a. *Single Use*
    b. *Two years*
    c. *Three years*
    d. *Over Three years*

16. How much volume (L) is each growing container (growbag or pot)?

    Free Text

17. What type of cover material do you use?
    a. *Polyethylene*
    b. *Copolymer plastic*
    c. *Polyvinyl plastic*
    d. *Polycarbonate plastic*
    e. *Glass*
    f. *Tempered safety glass*
    g. *Laminated glass*
    h. *Non applicable*

18. If you use polyethylene as a cover material what is its width in mm?
    a. *One-year Polyethylene (up to 120 microns)*
    b. *Two-Years polyethylene (120-140 microns)*
    c. *Three-Years polyethylene (140-180 microns)*
    d. *Perennial years polyethylene (more than 180 microns)*

19. If it’s perennial production system, how often do you renew it?
    a. *Number (Years)*
    b. *Not applicable*

20. Which is the amount of fruit waste produced per cultivation cycle?

    Free Text

21. Do you produce any other type of waste? If yes, please specify the type and the amount of waste produced per cultivation cycle.

    Free Text

22. Which waste management method do you use?
    a. *Landfill*
    b. *Compost*
    c. *Other*

C. SOIL

23. What is the type of soil?

a. *Clay*	*f. Sandy Clay Loam*
b. *Sand*	*g. Sandy Clay*
c. *Loamy sand*	*h. Clay loam*
d. *Sandy loam*	*i. Soil-less*
e. *Loam*	

24. What is the percentage (%) of Organic matter in your soil?
    Free Text

25. Which method of soil disinfection do you use?
    a. *Steam*
    b. *Soil solarization*
    c. *Soil/Substrate disinfection with chemical compounds (metab sodium)*
    d. *Soil/Substrate disinfection with mild environmental friendly compounds (chloride, microorganisms, equisetum arvensis etc)*
    e. *Non applicable*

D. IRRIGATION

26. Which of the following methods of irrigation do you operate?
    a. *Drip irrigation*
    b. *Over head irrigation (micro-sprinklers)*
    c. *Both a and b*

27. If you use irrigation pumps, what is their horsepower (hp or KW)?

Free Text

28. Approximately how much cubic meters (m^3) of water is being consumed in every irrigation of one ha per day?

Free Text

29. How many tonnes of water do you irrigate per cultivation cycle (tonnes per ha)?

Free Text

30. Do you apply any measures to assure water quality?

Free Text

E. ENERGY

31. How many hours does your pump works for the irrigation of 1 ha?

Number

32. How many working hours do you use your tractor per cycle per ha?

Number

33. What is your tractor’s horse power (hp or KW)?

Number

F. FERTILISERS

34. What type of fertilisers do you use?

   a. *Water soluble / crystalline*
   b. *Control release (coated)*
   c. *Slow release*
   d. *Combination of the above*

35. What type of mulching do you apply?
   a. *Plastic*
   b. *Straw*
   c. *Wooden chip*
   d. *Biodegradable plastic*

36. How many tonnes of manure (liquid manure with the irrigation or digested manure as the main fertilization) per hectare per production cycle do you apply?
   Number

37. How many liters or kilos of biostimulants do you use per hectare per cycle?
   Number

38. How many kg of nitrogen (N) do you apply per hectare per cycle?
   Number

39. How many kg of phosphorus (P) do you apply per hectare per cycle?
   Number

40. How many kg of potassium (K) do you apply per hectare per cycle?
   Number

G. PESTICIDES

41. How much chemical/ conventional insecticides (kg or Liters) do you apply per hectare per cycle?
   Number

42. How much chemical/ conventional fungicides (kg or Liters) do you apply per hectare per cycle?
    Number

43. How much chemical/ conventional acaricides (kg or Liters) do you apply per hectare per cycle?
    Number

44. How much chemical/ conventional weedicides (kg or Liters) do you apply per hectare per cycle?
    Number

45. How much organic/ non residual pesticides (kg or Liters) do you apply per hectare per cycle?
    Number

H. TRANSPORTATION

46. Your strawberries are distributed
    a. *In Local market*
    b. *Exports*

47. Provide the percentage of the strawberries distributed in local market.

    Free Text

48. Provide the percentage of the strawberries exported.

    Free Text

APPENDIX II

Questionnaire (Greek Version)

A. ΓΕΝΙΚΕΣ ΕΡΩΤΗΣΕΙΣ

1. Ποια είναι η τοποθεσία στην οποία καλλιεργείτε τις φράουλες; Χώρα/Περιοχή (π.χ Βερόνα, Ιταλία):

   Ελεύθερο κείμενο:

2. Τι κλίμα της περιοχής σας χαρακτηρίζετε εώς:
   - a. *Ορεινό*
   - b. *Εύκρατο*
   - c. *Μεσογειακό*

3. Ποιος είναι ο κυρίαρχος τύπος φράουλας που καλλιεργείτε;
   - a. *Day Neutral (π.χ Albion)*
   - b. *Short day (π.χ Fortuna)*
   - c. *Long day (π.χ Elsanta)*

4. Ποιες ποικιλίες φράουλα καλλιεργείτε; (Αναφέρετε ποσοστό, π.χ Victory (80%), Fortuna (20%)
   7

   Ελεύθερο κείμενο:

B. ΠΛΗΡΟΦΟΡΙΕΣ ΚΑΛΛΙΕΡΓΕΙΑΣ

5. Ποια μέθοδο καλλιέργειας χρησιμοποιείτε;
   - a. *Υπαίθρια*
   - b. *Υπαίθρια με χαμηλά τούνελ*
   - c. *Μη θερμαινόμενο θερμοκήπιο ή τούνελ*
   - d. *Θερμαινόμενο θερμοκήπιο ή γυάλινο θερμοκήπιο (glasshouse)*
   - e. *Διχτυοκήπιο (Net protection)*

6. Ποια τεχνική καλλιέργειας χρησιμοποιείτε;

a. *Ολοκληρωμένη Διαχείριση-ΧΩΡΙΣ ΠΙΣΤΟΠΟΙΗΣΗ*
b. *Βιολογικά Πιστοποιημένη*
c. *IPM πιστοποιημένη (GLOBAL GAP)*
d. *Μειωμένα υπολείμματα- Πιστοποιημένη για Ευρωπαϊκά σουπερμάρκετ (IFS, BRC)*

7. Ποια είναι η διάρκεια του καλλιεργητικού κύκλου ;

Ελεύθερο κείμενο

8. Ποιους μήνες πραγματοποιείτε η συγκομιδή; (Περισσότερες από μια απάντηση)

a. *Ιανουάριο*
b. *Φεβρουάριο*
c. *Μάρτιο*
d. *Απρίλιο*
e. *Μάιο*
f. *Ιούνιο*
g. *Ιούλιο*
h. *Αύγουστο*
i. *Σεπτέμβρη*
j. *Οκτώβρη*
k. *Νοέμβρη*
l. *Δεκέμβρη*

9. Ποια είναι η μέση ετήσια απόδοση της καλλιέργειας σας ; (τόνοι ανά εκτάριο)

Αριθμός:

10. Πόση είναι η έκταση της καλλιέργεια σας; (εκτάρια)

Αριθμός:

11. Πόσα φυτά/φράουλες τοποθετείτε ανά εκτάριο (Φυτά/εκτάριο);

Ελεύθερο κείμενο:

12. Τι είδους φυτά χρησιμοποιείτε?

a. *Φρέσκα φυτά δίσκου με αναπτυγμένη ρίζα(Fresh tray plants)*
b. *Φυτά δίσκου του ψυγείου με ανεπτυγμένη ρίζα (Frigo Tray plants)*
c. *Φρέσκες γυμνές ρίζες (Fresh Bare roots)*
d. *Γυμνές ρίζες του ψυγείου (Frigo Bare roots)*
e. *Φρέσκα φυτά σε δισκία (Fresh plug plants)*

13. Εάν δεν χρησιμοποιείτε χώμα στη καλλιέργεια σας, τι τύπο υποστρώματος χρησιμοποιείτε;

a. Κοκοφοίνικας-Cococoir/cocopeat
b. Τύρφη-Peatmoss
c. Άλλο (Biochar)
d. Πετροβάμβακας-Rockwool
e. Συνδυασμό κοκοφοίνικα & τύρφης

14. Τι είδους υλικό χρησιμοποιείται για τη τοποθέτηση του υποστρώματος;
    a. *Πλαστικά σακιά πολυαιθυλενίου (Polyethylene Grow Bags)*
    b. *Γλάστρες πολυπροπυλενίου (Polypropylane pots)*
    c. *Δεν εφαρμόζετε*

15. Ποια είναι η διάρκεια ζωής του υλικού τοποθέτησης του υποστρώματος;
    a. *1 έτους*
    b. *2 χρόνια*
    c. *3 χρόνια*
    d. *Πάνω από 3 χρόνια*

16. Πόσος όγκος (σε λίτρα) είναι το κάθε δοχείο φυτού (σακί ή γλάστρα);

    Ελεύθερο κείμενο:

17. Τι είδος είναι το υλικό κάλυψης που χρησιμοποιείτε;
    a. *Πολυαιθυλένιο*
    b. *Πλαστικό συμπολυμερούς*
    c. *Πλαστικό πολυβινυλίου*
    d. *Πλαστικό πολυανθρακικού*
    e. *Γυαλί*
    f. *Γυαλί ασφαλείας σκλήρυνσης (Tempered safety glass)*
    g. *Πολυστρωματικό γυαλί (Laminated glass)*
    h. *Δεν εφαρμόζεται*

18. Εάν χρησιμοποιείτε πολυαιθυλένιο ως υλικό κάλυψης, ποιο είναι το πάχος του σε (mm);
    a. *Μονοετές πολυαιθυλένιο (μέχρι 120 microns)*
    b. *Διετές πολυαιθυλένιο (120 – 140 microns)*
    c. *Τριετές πολυαιθυλένιο (140-180 microns)*
    d. *Πολυετές πολυαιθυλένιο (περισσότερο από 180 microns)*

19. Εάν είναι πολυετής, πόσο συχνά το ανανεώνεται;
    a. *Αριθμό (χρόνια):*

    b. *Δεν εφαρμόζεται*

20. Πόση ποσότητα απορριμμάτων φρούτων παράγονται ανά καλλιεργητικό κύκλο?

    Ελεύθερο κείμενο:

21. Παράγονται άλλου είδους απορρίμματα; Εάν ναι, παρακαλώ διευκρινίστε το είδος και την ποσότητα των απορριμμάτων που παράγονται ανά καλλιεργητικό κύκλο.

    Ελεύθερο κείμενο:

22. Ποια μέθοδο διαχείρισης αποβλήτων χρησιμοποιείται;
    a. Ταφή απορριμμάτων (landfill)
    b. Κομπόστ
    c. Άλλο

C. ΧΩΜΑ

23. Τι είδους χώμα χρησιμοποιείτε;
    a. *Πηλώδες (Clay)*
    b. *Αμμώδες (Sand)*
    c. *Αργιλώδης άμμος (Loamy sand)*
    d. *Άμμο- Πηλώδες (Sandy loam)*
    e. *Αργιλώδες χώμα (Loam)*
    f. *Sandy Clay Loam*
    g. *Αμμώδης πηλός (Sandy Clay)*
    h. *Αργιλώδης πηλός (Clay loam)*
    i. *Εκτός χώματος (Soil-less)*

24. Ποιο είναι το ποσοστό (%) την οργανικής ύλης στο χώμα σας;
    Ελεύθερο κείμενο:

25. Ποια μέθοδο απολύμανσης χώματος χρησιμοποιείτε;
    a. *Ατμού*

  b. *Ηλιακή απολύμανση (soil solarisation)*
  c. *Απολύμανση με χημικές ενώσεις (π.χ metab sodium)*
  d. *Απολύμανση με ήπιες ουσίες φιλικές προς το περιβάλλον (π.χ χλωριούχες ενώσεις, μικροοργανισμοί, equisetum arvensis κ.ο.κ)*
  e. *Δεν εφαρμόζεται*

D. ΑΡΔΕΥΣΗ

26. Τι είδος άρδευσης εφαρμόζεται;
  a. *Στάγδην (Drip irrigation)*
  b. *Over hear irrigation (micro-sprinklers)*
  c. *Όλα τα πιο πάνω*

27. Εάν και εφόσον έχετε αντλίες για άρδευση, ποια είναι η συνολική ιπποδύναμή τους (hp ή KW);
Ελεύθερο κείμενο :

28. Πόσα κυβικά νερού (m3) καταναλώνεται ,κατά προσέγγιση, σε κάθε πότισμα ενός εκταρίου την ημέρα;
Ελεύθερο κείμενο:

29. Πόσους τόνους νερό καταναλώνετε για το πότισμα ανά καλλιεργητικό κύκλο (τόνοι/εκτάριο);
Ελεύθερο κείμενο:

30. Εφαρμόζεται μέτρα για τη διασφάλιση της ποιότητας του νερού;
Ελεύθερο κείμενο:

E. ΕΝΕΡΓΕΙΑ

31. Πόσες ώρες δουλεύει η αντλία για την άρδευση ενός εκταρίου γης;
Νούμερο:

32. Πόσες εργατοώρες χρησιμοποιείτε το τρακτέρ σας ανά καλλιεργητικό κύκλο ανά εκτάριο;
Νούμερο:

33. Ποια είναι η ιπποδύναμη του τρακτέρ που χρησιμοποιείτε (hp ή KW);
Νούμερο:

F. ΛΙΠΑΣΜΑΤΑ

34. Τι είδους λιπάσματα χρησιμοποιείτε;
    a. *Υδατοδιαλυτά/Κρυσταλλικά*
    b. *Με ελεγχόμενη απελευθέρωση (Επικαλυμμένα λιπάσματα)*
    c. *Βραδείας απελευθέρωσης*
    d. *Συνδυασμό των πιο πάνω*

35. Από τι υλικό είναι η εδαφοκάλυψη που χρησιμοποιείτε?
    a. *Πλαστικό*
    b. *Άχυρο (Straw)*
    c. *Ξυλοτσίπς (Wooden chip)*
    d. *Βιοδιασπώμενο πλαστικό*

36. Πόσα κιλά κοπριάς (υγρή κοπριά με την άρδευση ή χωνεμένη ως βασική λίπανση) χρησιμοποιείται ανά εκτάριο ανά καλλιεργητικό κύκλο;
Νούμερο :

37. Πόσα λίτρα ή κιλά βιοδιεγερτών χρησιμοποιείτε ανά εκτάριο ανά καλλιεργητικό κύκλο;
Νούμερο:

38. Πόσα κιλά άζωτο (N) εφαρμόζετε ανά εκτάριο ανά καλλιεργητικό κύκλο;

Νούμερο :

39. Πόσα κιλά φώσφορο (P) εφαρμόζετε ανά εκτάριο ανά καλλιεργητικό κύκλο;
Νούμερο:

40. Πόσα κιλά κάλιο (K) εφαρμόζετε ανά εκτάριο ανά καλλιεργητικό κύκλο;
Νούμερο:

G. ΦΥΤΟΦΑΡΜΑΚΑ

41. Πόσα κιλά ή λίτρα χημικών/συμβατικών εντομοκτόνων εφαρμόζεται ανά εκτάριο ανά καλλιεργητικό κύκλο?
Νούμερο:

42. Πόσα κιλά ή λίτρα χημικών/συμβατικών μυκητοκτόνων εφαρμόζεται ανά εκτάριο ανά καλλιεργητικό κύκλο;
Νούμερο:

43. Πόσα κιλά ή λίτρα χημικών/συμβατικών ακαρεοκτόνων εφαρμόζεται ανά εκτάριο ανά καλλιεργητικό κύκλο;
Νούμερο:

44. Πόσα κιλά ή λίτρα χημικών/συμβατικών ζιζανιοκτόνων εφαρμόζεται ανά εκτάριο ανά καλλιεργητικό κύκλο;
Νούμερο:

45. Πόσα κιλά ή λίτρα οργανικών/χωρίς υπολείμματα φυτοφαρμάκων εφαρμόζεται ανά εκτάριο ανά καλλιεργητικό κύκλο;
Νούμερο:

H. Μεταφορές

46. Οι φράουλες σας διανέμονται σε:

    a. *Τοπική αγορά*
    b. *Εξαγωγές*

47. Αναφέρεται το ποσοστών των φραουλών που διανέμονται στη τοπική αγορά.
    Ελεύθερο κείμενο:

48. Αναφέρεται το ποσοστών των φραουλών που εξάγονται.
    Ελεύθερο κείμενο: