Tomato Production in Portugal and the Netherlands, which is more environmentally sustainable?

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Abstract

Tomato production is an energy-intensive process which, in certain cases, emits significant amounts of CO_2, contributing to the climate crisis. Tomatoes can be produced in various geographical locations, however, for efficient and sustainable growth, specific conditions must be met. In Portugal, tomatoes can be grown readily, with an ideal climate ripe for efficiently growing tomatoes. However, if Portuguese tomatoes are to be consumed in other countries, transportation by truck is necessary, potentially emitting significant amounts of CO_2. An alternative is producing tomatoes locally, for example, in the Netherlands, yet, due to sub-optimal climate conditions, artificial heating and lighting are necessary to reach sufficient tomato yields. This thesis will explore different tomato-growing scenarios to find the most environmentally sustainable option. In order to achieve this, a replication study is performed, replicating different tomato-producing scenarios mentioned in academic articles by calculating CO_2 emissions. This thesis finds that importing tomatoes from Portugal to the Netherlands is more environmentally sustainable than producing tomatoes in the Netherlands, using artificial heat and light.

Introduction

Fresh fruit is essential to human life and health (Kader, 2001). Providing us with the necessary nutrients and vitamins ensures healthy and happy physical and mental well-being (Oguntibeju et al., 2013). When considering fresh fruits, problems may arise concerning sustainable production (Soto-Silva et al., 2016). Sustainability becomes increasingly relevant when also considering the geographical location of the production and transportation of fresh fruit. Sustainability means "meeting the needs of today without compromising the ability of future generations to meet their needs." (Brundtland, 1987). In other words, to ensure that the production of tomatoes today does not harm future generations' abilities to do so. Sustainability has three aspects, financial, social and environmental. The focus of this thesis will be on the environmental aspect of sustainability. Doing so is more manageable from a research perspective, allowing for a more in-depth analysis of the problem and potential solutions. However, it is essential to note that the three dimensions of sustainability (economic, social, and environmental) are interconnected and equally important for achieving sustainable development. This topic is relevant as sustainability is an increasingly essential and active topic. In Dutch supermarkets, consumers can typically choose between locally grown or imported fruits; hence, it is interesting to analyse the differences in the production process of tomatoes in Portugal and the Netherlands and compare which can do so most sustainably.

As researching all or even multiple fruits would be too extensive, this thesis will focus solely on the production and transportation of cherry tomatoes in two countries, Portugal and the Netherlands. These countries have very different climates, allowing for an interesting comparison between the production of cherry tomatoes in each. Tomatoes are consumed by many cultures all around the world. However, the production and transportation of cherry tomatoes require specific conditions and are very interesting to research; hence, cherry tomatoes will be the focus of this thesis (Peet & Welles, 2005).

Climate and Transportation

Portugal has a hot and dry climate, with many days filled with bright long hours of sunshine and approximately 300 days of sunlight with an average yearly amount of around 2500-3200 hours (Mora & Vieira, 2020) (Current Results, 2023). On the other hand, the Netherlands has much milder temperatures and a significantly higher amount of rainfall and clouds, reaching far fewer hours of sunlight in a year, around 1800 hours (Statistica, 2023). This difference can be attributed to the distance of each country to the equator, as the closer to the equator, the warmer the climate and the longer the hours of sun get ("Equator", 2011).

Tomatoes require specific conditions to grow efficiently. The best conditions for tomato plants to flourish include temperatures between 21 °C and 27 °C and plenty of sunlight hours (Peet & Welles, 2005). Therefore, Portugal has the ideal climate, meeting both the temperature and the light conditions for efficient tomato growth. This climate needs to be mimicked if this process is to be done in the Netherlands. In other words, artificial heat and light must be used to ensure sufficient light and heat - using significant amounts of energy and gas, which may be unsustainable.

It is clear that due to the significant differences in the climate in Portugal and the Netherlands, the production process of cherry tomatoes, the efficiency and sustainability of each are very different. Although Portugal requires minimal artificial light and heat to produce cherry tomatoes, they must be transported by truck to other European countries - increasing their carbon footprint. Consequently, production in the Netherlands with no excessive transportation requirements will be compared to production in Portugal with the added transportation element. In this case, the least amount of greenhouse gases produced in the production process will be considered the most sustainable option.

Research Question

The main research question, "Is importing cherry tomatoes from Portugal more environmentally sustainable than growing locally in the Netherlands with the necessary use of heat lamps to mimic the ideal growing conditions?" will be answered throughout this thesis. The relevant measurement will be the CO_2 emissions from the different production processes in the Netherlands and Portugal: using heat lamps compared to transportation from Portugal to the Netherlands without heat lamps.

Furthermore, estimating CO_2 emissions should be in terms of kilograms (kg) of cherry tomatoes. This is because kilograms can provide a more accurate representation of the overall environmental impact of tomato production as it considers the production scale (Vermeulen et al., 2012).

Several other factors can improve environmental sustainability by limiting water usage or chemical pesticides, but the focus will be on CO_2 emissions. This is because researching other environmental impacts is not possible due to time constraints, as well as CO_2 being one of the most dominant causes of climate change. This thesis will attempt to answer the main research question by providing sufficient evidence to back up all claims and to figure out the most sustainable method of producing a kilogram of cherry tomatoes.

This thesis will include a replication study of previously published research comparing tomato production and sustainability in different geographical regions. Therefore, the methodology will include a justification for replicating this study and a section on how the original study conducted research and reached conclusions. The literature review section will extensively analyse various academic sources on tomato production, transportation, and sustainability. The results section will calculate CO_2 emissions for different tomato-producing scenarios, which will be mentioned in the methodology. The discussion will explain how the results relate to this thesis's research question and objectives and include limitations to the CO_2 calculations and areas for future research.

Literature Review:

Agriculture is a crucial industry that provides food and drives economic growth in many countries (Praveen & Sharma, 2019). However, it heavily relies on weather and climate conditions, making it vulnerable to the negative impacts of climate change, which can have broad sustainability-related consequences (Fleming & Vanclay, 2010). The agricultural sector is already under significant pressure to adopt more sustainable practices, particularly in reducing carbon dioxide emissions, primarily due to the agricultural industry's negative environmental impact (Fleming & Vanclay, 2010). In the face of climate change, the physical changes in landscapes and weather patterns, as well as shifts in governmental regulations and market demands, will profoundly affect agriculture (Praveen & Sharma, 2019). To ensure that future generations have access to sustainable food sources, it is imperative to reassess current farming methods and understand how they may be impacted by climate change (Praveen & Sharma, 2019). Therefore, this section will evaluate various academic literature articles on tomato production to determine the most sustainable approach. By doing so, it will be possible to understand better the potential effects of climate change on different farming practices and identify the best practices for ensuring the sustainable provision of food.

Tomatoes require relatively high amounts of light and high temperatures for efficient growth and good fruit production; this is not to say that without these conditions, tomatoes will not grow, but it is generally assumed that meeting these conditions will result in more efficient growth and thus, more fruit (Kinet & Peet, 1997). Different processes, as well as different conditions, impact the yields of tomatoes significantly. The first interesting comparison is the difference between field-grown and greenhouse-grown tomatoes. Producing tomatoes in a greenhouse is often perceived as a very artificial process characterised by the poor nutritional quality of the tomatoes and intense usage of chemical fertilisers (Muñoz et al., 2007). Furthermore, large areas covered in greenhouses generally also result in significant visual impacts, disturbing the view.

In contrast, open-field cultivation is typically seen as an 'eco-friendly' production with a much smaller visual impact (Muñoz et al., 2007). However, despite perceptions, significant differences exist in each process's operation, efficiency and productivity. High-tech greenhouse tomato production has been proposed as the path to sustainable fruit production and intensification (Maureira et al., 2022). One of the main benefits of high-tech greenhouses is total control over the indoor climate. They enable optimal temperature-controlled environments with many benefits, such as increased productivity and the ability to extend the duration of the growing season (Maureira et al., 2022). Greenhouse production may yield more kg of tomato with less on-site water and land inputs over open-field agriculture (Maureira et al., 2022).

Some farmers experience difficulty improving productivity as they need help implementing available technologies (Violet et al., 2022). This is also because less land is available for agriculture, and there is a higher degree of soil and land degradation. Furthermore, uncontrolled high pest and disease infestation levels also result in significant losses. Farmers have therefore been compelled to rely on pesticides to increase production and meet product demands (Violet et al., 2022). Hence, comparing field-grown and greenhouse-grown tomatoes is important to understand which process is less likely to be harmed by pests and disease. To combat some of the issues experienced by traditional field-grown or greenhouse tomato production, some modern greenhouses have started producing using hydroponics.

Hydroponics is a type of crop cultivation that occurs without soil and instead uses nutrient solutions (Khan, 2018). Hydroponics have numerous advantages, can significantly increase crop year-round productivity and quality, as well as having less environmental pollution. In addition, crops can be grown in towers, eliminating the need for large amounts of land, soil and soil-borne pests and disease (Khan, 2018); thereafter, decreasing the need to use large amounts of pesticides. This, in turn, reduces soil erosion and air and water pollution (Nguyen et al., 2016). Hydroponically producing tomatoes is limited to greenhouses; therefore, if the goal is to reduce pesticides and create a potentially healthier fruit, doing so in a greenhouse may be the more efficient process (Maureira et al., 2022).

One significant aspect to consider in greenhouse tomato production is carbon dioxide emissions. Greenhouses provide a controlled environment for efficient tomato cultivation and extended growing seasons. However, the energy-intensive nature of maintaining optimal conditions in greenhouses, such as temperature and lighting, can contribute significantly to greenhouse gas emissions (Theurl et al., 2014). In the case of conventional greenhouses, which utilise soil-based cultivation methods, energy consumption for climate control and lighting systems can result in notable CO_2 emissions. On the other hand, greenhouses employing hydroponics offer the advantage of increased water and nutrient efficiency (Theurl et al., 2014). These hydroponic systems typically require less energy for irrigation and nutrient delivery, thus reducing overall CO_2 emissions compared to traditional greenhouse methods (Maureira et al., 2022). Therefore, while both greenhouses contribute to CO_2 emissions, hydroponic systems tend to have a relatively lower carbon footprint, making them a potentially more sustainable approach for tomato production.

Production must be increased accordingly to meet the increasing demand for fresh fruit and vegetables worldwide. However, scaling up food production to meet increased demands will strain the world's water supplies, which are already in danger of depleting due to climate change (O'Connor & Mehta, 2016). When comparing open-field farming to greenhouse farming of tomatoes, greenhouses offer much greater opportunities over traditional open-air farming of tomatoes. The protective covering on a greenhouse prevents moisture from escaping and diffusing solar radiation, blocking hard winds and maintaining a controlled environment. Greenhouses, therefore, offer an excellent alternative to open-field farming when the goal is to use less water in production (O'Connor & Mehta, 2016). General open-field tomato production in no specific country is estimated to use approximately 100-300 litres of water per kilogram of tomatoes produced. When producing a kilogram of tomatoes in an open field using a drip irrigation system, this is reduced to around 60 litres per kilogram. In an advanced and controller greenhouse, the amount of water is reduced to approximately 22 litres of water per kilogram of tomatoes produced, and this is reduced again to around 15 litres of water per kilogram of tomatoes when also making use of hydroponic systems (Nederhoff & Stanghellini, 2010) (van Kooten et al., 2006). Finally, greenhouses have another added advantage over open fields in terms of water preservation, namely that all rainfall on the rooves of greenhouses can be caught, stored and reused. In the case of an open field, this water is typically wasted on the ground (van Kooten et al., 2006).

As a final part of the comparison between greenhouse and open-field cultivation of tomatoes, it is good to summarise and determine which of the two methods has the most negligible negative impact on climate change. Firstly, regardless of whether a tomato is produced in a greenhouse or an open-field environment, the number of pesticides and fertilisers used directly affects the surrounding environment, causing soil erosion and water contamination, among others (Zhang et al., 2021). Hence, it depends on the number of pesticides and fertilisers each farmer uses, as different amounts will result in different levels of greenhouse gas emissions. Therefore, if no pesticides or fertilisers are used, this will already result in a much more sustainable practice (Zhang et al., 2021). The same applies to product waste, energy used and type of energy used; they can contribute significantly to the negative carbon footprint of farming, yet it will be different in every situation, region and specific tomato species (Davis, 2011). Finally, an essential factor, which will be extensively discussed in the next section of this literature review, is the environmental cost of transporting tomatoes and the impacts this has on the overall sustainability of producing tomatoes.

Transportation of fresh crops

Transportation is a critical element of the production process of any perishable product. Without adequate transportation systems, there is no way of getting tomatoes from the farms on which they are produced to supermarkets for consumers to purchase (Inkinen & Hämäläinen, 2020). Light trucks (small trucks, 1-1.5 tons) are the standard transport from the farmhouse, retail shops, or wholesale markets. On the other hand, heavy trucks (10 tons) are used for long-distance transportation - from country to country (Roy et al., 2006). Most transportation of perishable goods like tomatoes from one country to another is done by heavy-duty trucks (HDTs). These

HDTs are mainly refrigerated trucks, which ensure the preservation of tomatoes while on the road. Such systems, however, consume a considerable amount of energy, contributing to total greenhouse gas emissions (Roy et al., 2006). HDTs may also lead to the deterioration of urban air quality due to their significant contribution to the total volume of traffic emissions. As expected, the greater the distance between the packing house to the consumption area, the greater the emissions increase significantly (Roy et al., 2006). Despite the vast amounts of pollution created by HDT refrigerated trucks, they play a crucial role and, in most cases, are the only viable solution to connect hinterland farms to where the fruit is demanded. Hence, they cannot be substituted easily by alternative methods of bringing tomatoes to consumers (Inkinen & Hämäläinen, 2020). On average, diesel trucks consume around 35 litres of diesel to transport fresh products over a distance of 100km (Wang & Rakha, 2017), (Direct, B 2019).

As was previously mentioned, there are alternatives to importing significant amounts of food and contributing significantly to pollution in this process. One of the alternatives is to produce locally in the seasons where this is possible. The consumption of local and in-season products has become a helpful principle that can be used to simplify the choices regarding fresh fruits and vegetables in affluent regions and reduce the carbon footprint of food in certain seasons (López et al., 2022). This, however, greatly depends on the distance that tomatoes need to travel to reach the end consumer, as short-distance transportation may be a more practical option over producing locally inefficiently (Schönhart et al., 2009). Efficiency will always be lower locally, as farming is limited to a few months a year. In contrast, farms specialising in year-round production are likely to produce much more efficiently, resulting in less water consumption and a potentially lower carbon footprint despite utilising transportation trucks (Schönhart et al., 2009).

So far, in this literature review, it has been established that several different methods of producing tomatoes exist indoors in greenhouses and outdoors in open fields. Not only is there a difference between outdoor and indoor growing, but within greenhouses, there are also several methods, such as hydroponics or in-ground growth. These different methods have been mentioned as sustainable food is becoming increasingly popular and necessary (O'Connor & Mehta, 2016). Finally, transportation has also been mentioned, as this is a critical element in the production of tomatoes. In the following and final section of this literature review, the consumer and consumer preferences surrounding tomatoes and production processes will be the main focus, as consumers are the people who purchase and drive success for any product.

Traditionally, price, convenience, taste, and health are the primary determinants of consumer food choices. Sustainability concerns such as land use, water and energy consumption, pollution, carbon emissions, biodiversity loss, and deforestation are also recognised (van Bussel et al., 2022). Despite this recognition, consumers may still need to grasp food production's impact on the environment entirely. This highlights the importance of educating consumers about sustainable food practices and promoting sustainable food production. Ultimately, consumers may need to gain knowledge or interest in sustainable food, but it is crucial to make them aware of the impact of their choices on the environment.

Furthermore, it is interesting that consumers also typically perceive locally-produced foods as more sustainable (van Bussel et al., 2022). However, as this literature review has tried to explain, this is only sometimes true. It is, therefore, important to make consumers aware of the consequences of consuming certain foods and that local production may or may not always be the healthiest and most sustainable option. Only then is it possible to achieve the most sustainable method of food production and ensure a healthy and sustainable future (Isenhour, 2011). This thesis aims to calculate the most environmentally sustainable tomato-producing method and location. This will be done by building on and combining existing research to ensure more sustainable food consumption patterns.

The next section of this thesis will be the methodology, showing how results will be achieved by summarising and explaining the important points of two previously selected and relevant academic research papers. Before explaining the methods of this thesis, however, the final section of this literature review will summarise the findings of one of the research papers by Urbano et al. (2022), as this research paper assesses different tomato production scenarios in different regions. This research paper will also be used as the basis for replicating the results, this will be explained further in the methods section.

Literature on results by Urbano et al. (2022)

Urbano et al. (2022) conducted a study comparing the environmental performance of different agricultural scenarios. They found that open-field production near the customer was more environmentally beneficial than greenhouse production, regardless of the distance from the customer. Local open-field scenarios performed better than long-distance ones with unheated greenhouses. However, the difference in environmental burdens between the best zero-mile scenario and the best long-distance scenario was smaller than expected, attributed to lower yields and less efficient resource use in open-field horticulture. Urban agriculture (UA) was found to have the potential to reduce environmental impact, but the optimal scenario varied depending on the impact category. It was noted that open-field production remains more efficient and yields higher quantities of higher-quality tomatoes. The type of fertilisers used and their impact on agricultural and horticultural assessments were also highlighted. Organic systems exhibited better environmental performance in greenhouse scenarios compared to conventional systems. The authors suggest that optimising agricultural models and practices minimises environmental impacts and addresses issues like rural depopulation and land availability. In summary, open-field production near the customer is the most environmentally sustainable option, while using artificial heat and light in greenhouses is the least sustainable (Urbano et al., 2022).

Methodology

This thesis project was produced without primary data; in other words, it comprises literature and academic writings. Instead of gathering data, however, a replication study of two scholarly articles is done. Replication studies have proven to be valuable in combining and adding to existing literature. Performing such a replication study can be a useful way of contributing to the field of research, especially when the topic at hand is such a literature and fact-intensive one. Another reason for performing a replication study is that this thesis will be able to validate or invalidate previous research findings and compare the previously done research to different geographical locations. (Doran et al., 2022). Overall, there are several reasons why a replication study is a valuable contribution to the field of research. By providing additional evidence supporting previous findings, addressing generalizability, evaluating and comparing methodologies, and demonstrating reproducibility, replication studies can help build a stronger foundation for future research in the field hence why this is the chosen approach in this particular thesis project. This methodology will include a review of the methodologies in both academic papers; at the end of this methodology, one of the two will be chosen based on several factors, and the results of this research will be presented and compared to the literature review of this thesis.

This replication study will use a combination of two articles. The first article that will be extensively used is very similar to the topic of this thesis, analysing and comparing the sustainability of tomato production in regions in Morocco and comparing this to production in parts of France. This scenario can readily be compared to the topic of this thesis, with the difference in geographical locations but with similar goals of finding the more environmentally sustainable option. Furthermore, this paper focuses more on water and energy consumption in tomato production (Payen et al., 2015). In contrast, this thesis gives greater weight to each production process's environmental sustainability - CO_2 emissions. The second research that will be used in the replication study is a much broader topic, namely, assessing eight different production methods of tomato and analysing how transportation affects the environmental sustainability of these different processes (Urbano et al., 2022). This section will also explain the data sources used in this research and describe what changes or modifications were made to the data. Finally, it is also essential to analyse the data analysis techniques used, explain how the data was organised and determine if there are any potential sources of error or bias in the methodologies.

Firstly, the methodology and data-collecting techniques in the article by Payen et al. (2015) will be summarised. This article collected the data in both primary and secondary methods. Primary data was gathered through in-depth field surveys in the Souss-Massa region of Morocco for three annual crop cycles from 2009-2011. The surveys were conducted in one seedling nursery, three farms, and one packaging station. The collected data included information on agricultural inputs, like fertilisers, pesticides, water, electricity and fuels, the number of materials used in greenhouse components, packaging components, agricultural machinery, and final products for the nursery, tomato cultivation, and packaging stages. The secondary data, such as input transportation and manufacturing, fuel consumption for truck refrigeration, and freight ship container, were obtained from the literature and the Ecoinvent 2.2 database, which is a database that supports various types of sustainability assessments.

According to the article, the collected primary data was high quality, and the secondary datasets were of essential quality when self-evaluated. The Life Cycle Assessment (LCA) modelling was performed using Simapro 7.3.2 software, which gives users the insights to drive sustainable change. An economical allocation was used at the nursery as there was sufficient seedling price data. The packaging station's energy (fuel and electricity) and water consumption were allocated to tomatoes using a physical approach. The study used primary and secondary data to model the LCA with Simapro 7.3.2 software. The collected data were sufficiently high quality to proceed with the research and produce relatively accurate results.

The academic article by Urbano et al. (2022) evaluated the environmental impact of fresh tomato consumption in a medium-sized European city using the four-step LCA approach. These steps define the goal and scope, life cycle inventory (LCI), life cycle impact assessment (LCIA), and life cycle interpretation. The study analyses the production and transportation of fresh tomatoes in terms of Global Warming Potential (GWP), Cumulative Energy Demand (CED), and other environmental impact categories. The model city for the study was León (Spain), and the functional unit used was 1 kg of tomato put on the consumer's table. In the study, eight scenarios were considered and grouped into three categories. Scenario 1 involved conventional tomato production in unheated greenhouses in Almería, Spain, almost 900 km from León. Scenario 2 involved organic tomato production in the same setting as scenario 1. Scenario 3 involved tomato production in a heated, artificially illuminated greenhouse in León, less than 100 km from the city, with two options regarding the heating system. Scenario 4 involved tomato production in an unheated greenhouse without artificial illumination. Scenario 5 involved open-field tomato production in a conventional system and scenario 6 involved the same in an organic system.

Scenario 7 involved open-field production in urban lots managed and funded by the city council for occupational therapy and entertainment, exclusively organic. Finally, scenario 8 involved micro-agriculture in raised beds with artificial substrates located on private balconies for leisure, with two irrigation options. Data for the LCI was collected from commercial farms for most scenarios, except for scenario 8, which was obtained via a research experiment managed by the authors of this research paper. A private institution provided data for scenarios 1 and 2, while data for scenarios 3, 4, and 5 were collected from greenhouses belonging to private companies and farmers. Data for scenario 6 was obtained from the field-record book of an organic farmer, and data for scenario 7 was provided by the person in charge of urban allotments belonging to a city council. The inventory data for the LCA were taken from the Ecoinvent database v. 3.6 using the system model Allocation at the Point of Substitution (APOS).

Both methodologies share similarities and differences in their data collection and analysis approaches. Both studies relied on primary and secondary data sources and utilised external programs like Ecoinvent to model and analyse their life cycle assessment data. However, Payen et al. (2015) focused on agricultural inputs and materials used in tomato cultivation in a specific geographic region, while Urbano et al. (2022) evaluated the environmental impact of tomato production and transportation in different locations and scenarios for consumption. Despite these differences, both methodologies have potential limitations, such as missing or incomplete data, inaccurate self-evaluations of data quality, or potential biases. Nonetheless, the significant amount of information from several different locations and processes in these articles makes it interesting to compare their results in the next section to determine the most environmentally sustainable tomato production process and region.

Although Payen et al. (2015) have a similar research topic of comparing two countries with slightly different production processes, this thesis will focus on the results by Urbano et al. (2022), assessing different scenarios in different geographical locations and production processes. This is because it will give a broader spectrum of results and be more readily applicable to this thesis. As summarising and comparing both sets of results to the collected literature would be too extensive for this thesis, one of the two research articles must be chosen to ensure sufficient focus on the results. The focus will be on four of the different scenarios discussed by Urbano et al., namely: scenario one (greenhouse production 900km away from the customer without the use of artificial light and heat), scenario three (greenhouse production near the customer with the use of artificial heat and light), scenario four (greenhouse production near the customer without artificial heat and light) and scenario five (open-field production near the customer). These four scenarios best match the topic of this thesis. They encompass the relevant production processes and variables, such as distance from customers and the use of artificial heat and light.

To estimate CO_2 emissions for tomato production processes in Portugal and the Netherlands, emission factors for truck transportation (if applicable) and energy use for heat lamps and light are multiplied by activity data (distance, weight, fuel efficiency, power consumption, and duration). For the first production process (production in Portugal with transport to the Netherlands), emission factors for truck transportation are used. For the second production process (production in the Netherlands), emission factors for energy use in the greenhouse are used. The resulting CO_2 emissions are compared, and the primary sources of emissions are identified.

Ethical considerations

As a final part of this methodology, it is important to consider the ethical implications. This thesis did not include any interviews or use sensitive or personal information and data. All information has been used safely by referencing all academic papers and authors when applicable.

Results

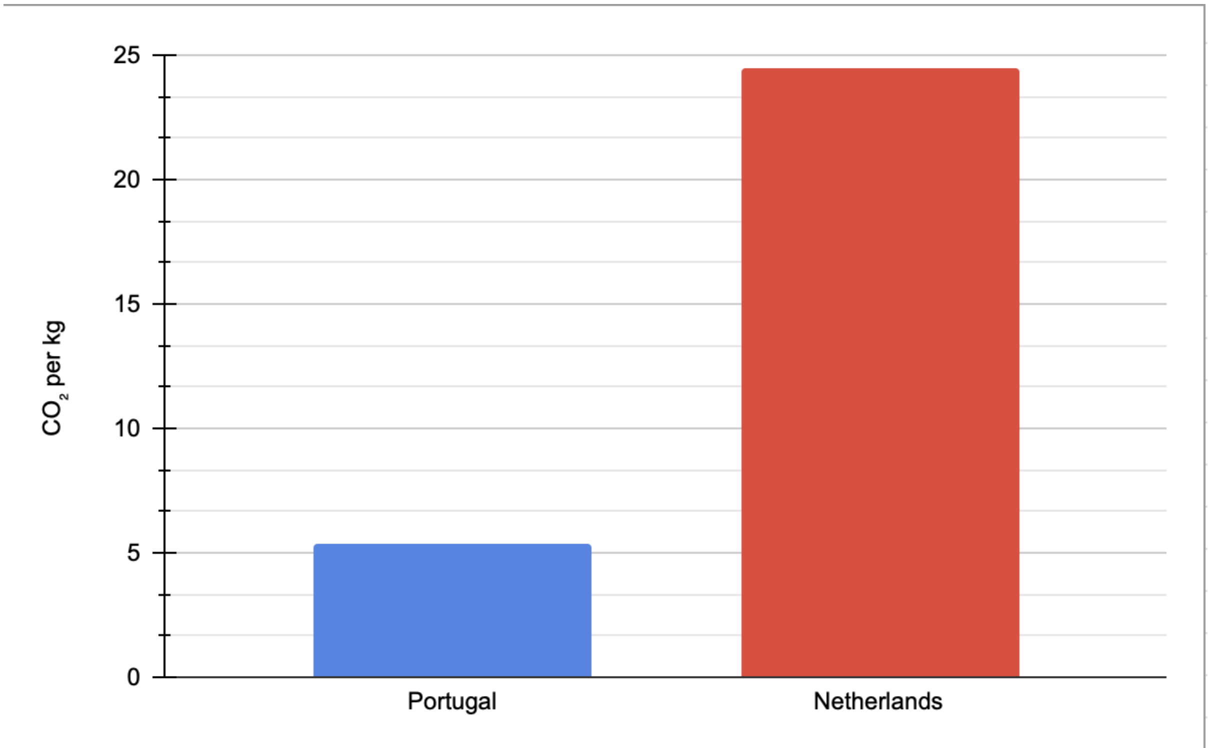
The first scenario for which a CO_2 calculation is made in Urbano et al. (2022) is greenhouse production 900km away from the customer without artificial light and heat. In this scenario, production is done in a greenhouse instead of an open field, and no artificial heat or light is used. This scenario is most similar to production in Portugal, with no need for artificial lighting or heat due to the right climate conditions in Portugal. According to Google Maps, the distance from Odemira (where production is done), Portugal, to Den Haag, the Netherlands (where Portuguese tomatoes are transported to), is 2335km. Knowing the distance and the total kg of tomatoes that heavy-duty trucks haul (15,600kg) (Roy et al., 2006), it is possible to calculate the amount of CO_2 emitted for this journey. Assuming that an average truck consumes 35L of diesel per 100km travelled, it is possible to calculate the total amount of litres of fuel consumed ((2335 / 100) * 35 litres), resulting in a total fuel consumption of 816.25 litres per journey to the Netherlands from Portugal (Wang & Rakha, 2017). Furthermore, assuming the average emission factor for diesel fuel is 2.68 kg CO_2 per litre, it is possible to calculate the total amount of CO_2 emissions (CO_2 emissions from trucks in the EU: An analysis of the heavy-duty CO_2 standards baseline data - International Council on Clean Transportation, 2022). This is the total fuel consumed multiplied by the emission factor, which leads to 2186.85 kg CO_2 for the journey. Despite Portugal having a ripe climate for the production of tomatoes, a minimal amount of heating is necessary to maintain optimal growing conditions. Therefore, in addition to the CO_2 emitted by transportation, 12m3 of gas per m^2 of a 6.1-hectare greenhouse results in an additional 1,302,960kg of CO_2 per year per greenhouse, as 1m3 of gas emits approximately 1.78kg of CO_2 (Lansink & Bezlepkin, 2003).

The second scenario for which a total CO_2 amount will be calculated is greenhouse production near the customer using artificial heat and light. In this scenario, production is done in the Netherlands, so there is no need to transport tomatoes over a distance of 2335km. However, as the weather conditions in the Netherlands are not optimal for growing tomatoes efficiently, artificial heat and light are necessary to produce tomatoes year-round. According to Statistica 2022, the average size of a greenhouse in the Netherlands is 6.1 hectares (61000 m2). Therefore, it is necessary to estimate the total amount of energy used for heating and lighting a greenhouse of that size, followed by calculating the total amount of CO_2 that this process emits. A typical 6.1-hectare greenhouse will require approximately 150 kWh of light per m^2 per year and 25m3 of gas per m^2 per year to heat the greenhouse; furthermore, 1m3 of gas emits approximately 1.78kg of CO_2, resulting in 2,714,500kg CO_2 for the whole greenhouse (Lansink & Bezlepkin, 2003). A 6.1-hectare greenhouse will require a total of 9,150,000kWh for the artificial lamps. 1kWh of energy results in an average of 0.371kg of CO_2 emitted or 3,394,650kg CO_2(CarbonFund, 2022) (Carbon Intensity of Electricity, 2022). Combining these calculations results in 6,109,150kg of CO_2 emitted in a year of greenhouse operations with artificial heat and light.

So far, the total amount of CO_2 emissions has been calculated, both for production in Portugal with the added factor of transportation as well as production in the Netherlands, with no transportation yet the need for artificial light and heat to ensure successful tomato growth. It is impossible to compare the CO_2 emissions from a single journey to the Netherlands to the CO_2 emissions of a whole greenhouse using artificial light and heat. Therefore, it is crucial also to calculate the amount of CO_2 emitted for each process in terms of kg of tomatoes. For the first scenario, a truck hauling 15600kg of tomatoes emits approximately 2186.85 kg CO_2 for the journey. It is, therefore, relatively easy to calculate the amount of CO_2 emitted per kg of tomatoes. The result is 0.14 kg CO_2 per kg of tomatoes, meaning, for every kg of tomatoes produced and transported to the Netherlands, 0.14kg of CO_2 is emitted. However, this does not yet include the CO_2 emitted for the heating in Portugal. In Portugal, the yields are the same as in the Netherlands for a similar-sized greenhouse. For a high-tech greenhouse, like many in the Netherlands and Portugal, an average yearly yield of cherry tomatoes for a 6.1-hectare greenhouse is approximately 250,000kg; therefore, production in Portugal with minimal heating and transportation produces approximately 5.35kg of CO_2 per kg of cherry tomatoes. The scenario of production in the Netherlands with the necessary use of artificial heat and light results in 24.44 kg CO_2 per kg of tomatoes.

The third scenario is conventional production in a greenhouse near the customer without artificial heat and light. In the case of this thesis, this means producing tomatoes in the Netherlands, in a greenhouse, with no use of artificial heat and light. The fourth scenario is very similar: local production, in an open field, without artificial heat lamps or lights. These methods are the most environmentally sustainable, requiring neither long-distance transportation nor artificial heat and light to grow tomatoes. These methods will, therefore, also result in the lowest amount of CO_2 emitted per kg of tomatoes produced. However, growing in a greenhouse or an open field in the Netherlands without artificially mimicking the ideal growing conditions will lead to inefficient and poor tomato quality production. On the one hand, therefore, local production, especially if done in an open field, is the most environmentally sustainable in terms of least CO_2 emissions; however, these scenarios are only possible if the climate allows for outside growth of tomatoes or greenhouse growth of tomatoes without artificial heat and light, which the Netherlands, as discussed in the literature review, does not have. Therefore, these scenarios should be excluded from the calculation section, as they would score perfectly regarding CO_2 emissions relating to transportation, artificial heat, and light. In that case, other factors such as water consumption and pesticide use must also be considered, and this thesis, however, focuses only on the CO_2 emissions from transport and energy usage.

Figure 1



The figure above shows the results for scenarios 1 and 2. The blue column shows the amount of CO_2 emitted per kg of cherry tomatoes produced with minimal artificial heat and the transportation by truck to the Netherlands. The red column shows the amount of CO_2 emitted per kg of cherry tomatoes produced locally in the Netherlands, using artificial light and heat. These results are the same as are mentioned in the text above. However, the added visual component quickly displays the considerable difference between importing cherry tomatoes from Portugal and producing them locally in the Netherlands.

Discussion

Tomato production involves various processes contributing to CO_2 emissions, including transportation, greenhouse operations with artificial light and heat, and energy sources. This discussion will assess some limitations and sources for inaccuracy. Recommendations for future research and technological advancements will be mentioned.

Transportation accounts for a relatively small portion of CO_2 emissions in the first scenario, where tomatoes are grown in Portugal and shipped to the Netherlands. According to the calculations, 0.14 kg of CO_2 is emitted for every kilogram of tomatoes produced and delivered. However, it is essential to highlight that this estimate still needs to account for the CO_2 emissions created by heating in Portugal. Given the low heating requirements, the total CO_2 emissions per kilogram of tomatoes produced in Portugal and transported to the Netherlands are around 5.35 kg. However, artificial heat and light are required in the Netherlands' second scenario of tomato production, and CO_2 emissions are substantially higher. According to the calculations, the total emissions per kilogram of tomatoes produced in the Dutch greenhouse with artificial heat and light amount to about 24.44 kg of CO_2. This significant difference in emissions between the two scenarios can be traced mainly to the substantial energy usage of artificial heat and light required in the Netherlands to maintain optimal growing conditions.

The results demonstrate the production's environmental advantage in Portugal, where the favourable climate conditions significantly negate the need for artificial heat and light. Although transportation contributes to the CO_2 emissions in this scenario, it is outweighed by the significant energy savings achieved by avoiding artificial heating and lighting systems. This finding highlights the importance of considering the holistic environmental impact of different stages in the production and supply chain. Moreover, the results underscore the significance of local climate suitability in determining the sustainability of tomato production. Portugal's ripe climate for tomato cultivation eliminates the need for energy-intensive practices, resulting in lower CO_2 emissions per kilogram of tomatoes compared to the Netherlands, where artificial systems are required to compensate for less favourable weather conditions. This finding aligns with sustainable agriculture principles, which emphasise leveraging natural resources and local environmental conditions to minimise the ecological footprint of food production.

Limitations

In the first scenario, CO_2 emissions are primarily driven by transportation. Calculations consider factors such as the distance between the production site and the destination, truck fuel consumption, and average emission factors. However, these calculations rely on average values and may not account for individual truck efficiency or variations in emission factors. In reality, transportation is done in many different types of trucks that likely have different fuel consumption patterns and routes. The second scenario focuses on greenhouse production, where CO_2 emissions result from energy consumption for artificial lighting and heating. Estimations are made based on the energy requirements of a greenhouse of a specific size. However, the energy source used in greenhouse operations can vary, ranging from renewable to non-renewable sources. This discrepancy highlights the importance of considering the energy mix when assessing the environmental impact.

Even though the CO_2 emissions have been made on estimates, there are still very likely multiple sources of error and limitations to these calculations. It appears that scenario 1, production in Portugal without the need for excessive artificial heat and light, has the lowest CO_2 emissions from producing 1kg of cherry tomatoes; however, this may not be the case if all factors are considered. Calculations for both scenarios, such as the size of the greenhouse of energy consumption, were based on averages in Portugal and the Netherlands; however, it is impossible to account for whether or not this energy is sourced from renewables. Furthermore, greenhouses frequently employ creative energy and heat creation methods, resulting in very different CO_2 emission results. The calculations made do not take into account any energy or heat generation methods that specific greenhouses employ, nor do the calculations take into account the specific type of lamp that is used (if lamps are used to generate light), as different types of lamps will have different kWh values and cause different results. To achieve better quality results, further research and precise measurements are necessary to improve the reliability of CO_2 emission calculations and gain a comprehensive understanding of tomato production's environmental impact.

Future research and implications

Regardless of the potential inaccuracies from the calculated results, all tomato farmers need to focus on making their respective processes as sustainable as possible. To mitigate the CO_2 emissions from greenhouse production using artificial heat and light, sustainable energy solutions such as solar, wind, or geothermal power can be employed. Additionally, implementing energy-efficient technologies and practices, such as improved insulation and optimised lighting setups, can reduce energy consumption and emissions. In this way, tomato farmers can provide a healthy and popular fruit without the severe consequences of excess CO_2 production resulting in climate change.

To mitigate the environmental impact, future strategies should focus on optimising transportation routes, improving truck efficiency, and exploring alternative energy sources for greenhouse operations. Renewable energy sources can significantly reduce CO_2 emissions associated with artificial light and heat. Investing in energy-efficient technologies within greenhouses will also contribute to lowering carbon footprints. Additionally, it is essential to consider other sustainability factors, such as water consumption and pesticide use, in a comprehensive analysis. This study's implications extend beyond tomato production as a basis for assessing other greenhouse crops' environmental sustainability and supply chains. Continued research and innovation in sustainable agricultural practices are essential to minimise the carbon footprint of food production and ensure a more sustainable future for the agricultural industry.

Consumers need to be made aware of what type of tomato in the supermarket is most environmentally sustainable, as only then can they decide on which type of tomato to purchase. Only with complete information and transparency can consumers decide whether or not they prefer to buy locally-produced tomatoes with higher CO_2 emissions or whether they prefer tomatoes that have been imported but perform better in terms of environmental sustainability. One possible way to do this is to make changes to the packaging (for example, by adding a green ‘most sustainable’ sticker) of each respective tomato in order to ensure the accurate and complete information transfer to the customer in the hope that consumers choose the more environmentally sustainable option.

Finally, the calculations of CO_2 emissions discussed and presented in the results section are estimates. It is possible to reach higher accuracy in these results if an LCA is performed, as mentioned in Urbano et al. (2022), with specialised software. Emissions factors used for the CO_2 calculations are based on average values and may, therefore, not accurately reflect the specific conditions of each scenario. The results still provide valuable insights into the environmental impact of each scenario and give a good general idea of how each scenario scores in terms of environmental sustainability.

Conclusion

This thesis has attempted to answer the research question: Is importing cherry tomatoes from Portugal more environmentally sustainable than growing locally in the Netherlands with the necessary use of heat lamps to mimic the ideal growing conditions? An extensive literature review was conducted to have multiple perspectives and sources to find an adequate answer to this research question. The literature review included different types of tomato production and strategies and reasons for tomato production. Unlike traditional research papers, this thesis included a replication study rather than primary research. This replication study discussed two academic articles on tomato production in different regions. One of these academic papers was then selected, some scenarios relating to the thesis topic were chosen, and calculations were made to find the least environmentally harmful production method.

Tomatoes can be produced in many countries using many processes and methods. In Portugal, the climate is perfect for the efficient production and exporting of tomatoes, with only very little gas needed to heat the greenhouse when necessary; however, the downside is that a significant amount of CO_2 is emitted when transporting products across countries by trucks. Local production in the Netherlands may seem more environmentally friendly, as less CO_2 is emitted. This is the case when the production of tomatoes is done in an open-field environment or a greenhouse with no artificial heat or light; however, due to the climate in the Netherlands (milder temperatures and less light), artificial heat and light are required to match the efficiency of an identical greenhouse in Portugal. However, energy and gas to light and heat the greenhouse significantly impact the environment regarding CO_2 emissions. Therefore, this thesis calculated some of the possible scenarios and options for producing tomatoes, which resulted in the outcome that producing in Portugal and exporting to the Netherlands is much more environmentally sustainable when only the CO_2 emissions are considered.

The discussion part of this thesis has already discussed some of the limitations of this research. However, they will be briefly explained again in the following sentences: It is firstly important to note that CO_2 is one of the many factors contributing to climate change, and even though it is one of the most relevant factors, several other factors could contribute to a worsening of the environment. Therefore, in future studies, other factors such as water usage and efficiency in different systems and pesticide use should be considered to provide more accurate results. Another limitation of this study is that estimations about truck efficiency, energy efficiency, gas efficiency, and sources are made. The calculated results are rough estimates of the possible amounts of CO_2 emissions, and real values may differ. Different tomato-producing companies use different types of trucks with different fuel consumption patterns. Furthermore, different greenhouses in the Netherlands source energy and gas from different origins, and some greenhouses may even produce energy and heat themselves.

The idea that local production and consumption can address various global problems is commonly suggested. In the context of the Netherlands, local tomato production could contribute to solving climate change without the excessive use of artificial heat and light. If all countries consider their neighbouring countries when determining consumption and production patterns, it is possible to make progress in tackling the climate crisis. However, there are situations where other countries are significantly more efficient in production, rendering local production impractical. In cases like the example of this thesis, where Portugal demonstrates much higher efficiency and emits far less CO_2, countries must collaborate and specialise in different tasks. Global challenges like climate change can be addressed or resolved only through extensive cooperation.

Finally, this thesis is meant to build on existing literature and information about producing tomatoes. Ideally, these results are replicated by individuals with more time and data to lead to better results and, thus, a better understanding of how not only tomato production affects the environment, but how all agriculture affects the environment. Changes in the production and consumption patterns of agricultural produce must ensure healthy and happy living for the current and future generations. Consumers must be aware of how the choices they make in the supermarkets affect the environment. With this thesis, it is the hope that consumers can make better choices in the supermarket in the future to ensure sustainable living on earth.

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