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Assessing the energy and environmental performance of vertical hydroponic farming

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In cooperation with Grönska Stadsodling

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Summary

The global population is increasing rapidly, and the amount of people living in urban areas are expected to almost double within 30 years. With a rising population, the demand for food and pressure on arable land is also increasing. Currently, about 26 % of the greenhouse gases emitted from Sweden come from agricultural activities, and with an increasing population, it is essential to aim to reduce the emissions from food supply.

Vertical farming has seen increasing popularity as a way to reduce the need for arable land and grow crops where they are to be consumed. When farming indoors in a closed environment, the plants are protected from the weather, insects and pests. There are no leakages of nutrients in closed systems and the amount of water used is very limited in comparison to conventional farming. However, artificial lighting is needed in order for the crops to grow. Additionally, vertical farming is capital intensive and requires technical knowledge to be able to make use of the new techniques and equipment available.

In this study, the sustainability of the vertical farming system at Grönska Stadsodling, hereafter referred to as Grönska, has been evaluated. Grönska is located in southern Stockholm and produces primarily basil in pots that are sold to retailers around the city using vertical-hydroponic techniques. The energy use and environmental impacts for the production of herbs (basil) were assessed using life cycle assessment (LCA) from a cradle-to-gate perspective. This included the materials (e.g. soil, fertilizers) and energy consumption used for growing basil plants. The use (consumption), waste management and transportation to and from the company were not included in this study.

The results illustrated a large share of energy used for the manufacturing of gardening soil, which also resulted in the second largest environmental impact. The largest source of environmental impacts was the energy consumed for lighting, despite the use of LED lighting. There are possibilities to reduce these impacts by e.g. installing solar panels and optimizing the output of LEDs for the plant production. Furthermore, energy could be saved by changing the growing material, for something with less environmental impacts e.g. coir pith or by recycling the soil used. While extended transportation distances of food is one of the main arguments for urban agriculture, energy consumption and environmental impacts for transportation were found to be a minor part of the energy use and environmental impacts. Finally, the socio-economic implications of urban farming should be taken into account when reviewing sustainability aspects. This study only reviewed energy and environmental impacts, but the socio-economic benefits and resilience for the local community are important to highlight.

Keywords: Vertical farming, vertical agriculture, hydroponic, agriculture, plant factory, urban farming, urban gardening, local food, food security

Sammanfattning

Jordens befolkning ökar stadig, antalet människor som lever i en urban miljö förväntas dubbleras inom 30 års tid. Med en ökande befolkningsmängd ökar efterfrågan på livsmedel och pressen på jordbruksmark. Jordbruket står idag för ca 26 % av de totala utsläppen av växthusgaser i Sverige. Utsläppen från jordbruket måste minska samtidigt som det skall finnas tillfredställande mängd mat till befolkningen.

Vertikal odling är en metod för att odla på en begränsad yta. Plantorna är skyddade från väder och vind, men även insekter och bakterier i viss mån. I de slutna systemen sker inga näringsläckage och mängden vatten som går åt är mycket reducerad i jämförelse med det konventionella jordbruket. Det krävs dock alltid artificiell belysning för att plantorna ska växa. Dessutom är vertikal odling kapitalintensiv och kräver tekniskt kunnande för att kunna utnyttja den nya tekniken och utrustningen.

Produktionen i företaget Grönska, beläget i södra Stockholm, har granskats med hjälp av verktyget livscykelanalys (LCA). Grönska odlar basilika i krukor som säljs till butiker i Stockholmsområdet. Odlingen sker hydroponiskt och med light-emitting diods (LED) belysning. Livscykelanalysen innehåller beräkningar av energi och miljöpåverkan i samband med Grönskas produktion. Inkluderat i studien var de material som används för att ta fram basilikan och energin som gick åt för att driva lokalerna. Studien inkluderade inte användning, avfall samt transporter till och från företaget.

Resultatet visade på en stor energiåtgång tillika miljöpåverkan från framställningen av den plantjord som basilikan sås och växer i. Näst största energimängden gick åt för belysning av odlingen, vilket också hade en stor miljöpåverkan. Energi kan sparas genom att byta växtmedium, alternativt skörda basilikan innan försäljning så att jorden kan återanvändas i produktionen. Förslag på andra växtmedium är t.ex. cocosfiber som räknas som restavfall och har en miljöpåverkan som är nästan 300 gånger mindre per kilo än plantjorden.

Långa transporter av livsmedel är ett att av de återkommande argumenten för urban odling. Flertalet studier har dock visat på att transporterna, från producent, inte har den största miljöpåverkan sett till hela livscykeln av en produkt. Urban odling har många fördelar ur ett socioekonomiskt perspektiv. Städerna förlitar sig idag på de globala systemen med industriella jordbruket och långa produktionskedjor. Att odla lokalt är en möjlighet för samhällen att vara mer självständiga och förberedda för potentiella kriser.

Nyckelord: vertikalodling, urbanodling, lokalodling, jordbruk, säkra mattillgångar, miljöpåverkan

1 Background and description of the project

As the population increases globally, with the number of people living in urban areas expected to double within 30 years, crop production must also increase (Kozai, et al., 2016). It has been estimated that 26 % of the Swedish greenhouse gas (GHG) emissions come from agriculture; similarly accounting for roughly 20 % of European GHG emissions (European Union, 2012). Furthermore, the rising concerns about food security have stimulated research and the development of ways to protect the cultivation of crops (Shimizu, et al., 2011). Vertical farms with advanced technologies are being promoted as an option, as well a compliment, to conventional agricultural systems, e.g. greenhouses.

For sustainable food production in the future, there is an interrelated issue of environment, society and resources to be solved; see e.g. Kozai, et al. (2016). Crop production is facing several obstacles such as a decreasing number of farmers and decreasing area of arable land. The recent pressure on the ecosystem has resulted in a loss of biodiversity and green space (Kozai, et al., 2016). The cultivation is also affected by more and more extreme weather and there are also high levels of environmental pollution, which causes damage to soil. Furthermore, a shortage of resources such as fresh water, fossil fuel and biomass is to be expected in a near future. This will require increased societal inquiries to improve quality of life, food security with access to nutritious and safe food, recreational areas and healthy communities (ibid.). In order to address these concerns, especially in the urban environment, urban land-use must be flexible if it is to meet as many socio-economic and sustainability goals as possible (van Leeuwen, et al., 2010). Planners should be open to taking on creative solutions and designs for land-use where local needs are fulfilled (ibid.)

Thus, food production must be efficient, the products of high quality, and the resources used minimal, in order to improve social welfare (Kozai, et al., 2016). Research on food security in Europe is limited, and the overall view differs (Borch & Kjærnes, 2016). However, the European food system is a part of the global system and dependent on long value chains and links, e.g. production, transport and deliveries (McMichael, 2011; Cordell &White, 2015). If there are disturbances somewhere in the world, such as drought or heavy rains, this could have a large impact on the European food system.

For fresh foods, it is important to produce food as locally as possible and to reduce transportation (Kozai, et al., 2016). Hydroponic and vertical farming systems have increased recently, and have the potential to reduce resource consumption, e.g., energy demand and water consumption (Kozai, et al., 2016). However, these systems will not replace open-field production or the conventional greenhouses but could serve as a much-needed compliment, and it will also allow for innovation in the food sector and a number of new business opportunities (Kozai, et al., 2016). The viability of vertical farming and hydroponic systems have also been improved dramatically with new technologies such as light-emitting diodes (LED), allowing for cultivation in areas where the number of hours with sunlight is limited (Singh, et al., 2015).

1.1 Grönska

The production of leafy greens in vertical hydroponic systems at Grönska has been the basis for this study. Today, Grönska produces around 50 000-60 000 plants per year and plan to expand to 600 000- 700 000 plants annually, in the near future. Today the main crop is basil, but they are experimenting with the production of other herbs and micro-greens to provide their main customer segment within Stockholm with local, fresh greens all year round. In contradiction to similar projects, often in larger scale, the production system is located unoccupied space in existing buildings, e.g., residential buildings. Using this approach, there is no need to build new production plants. Furthermore, by using existing buildings, often with residents above, there is already a beneficial ambient temperature, as well as available utilities, such as electricity and plumbing

1.2 Vertical farming

The traditional methods for cultivating crops, e.g. in outdoor fields and greenhouses, has recently been challenged by a modern innovation, namely vertical farming. Using this approach, the crops are stored in boxes, on stacked shelves, depending on the size of the production and stacked vertically; see Figure 1. This could be done from just a few, two or three shelves, up to the height of a skyscraper (van Leeuwen, et al., 2010).

Figure 1: Vertical farming at Grönska with boxes of herbs stacked vertically.

Indoor vertical farming is a way of protecting crops from harsh environments with changing weather conditions. Besides the protection from the weather, the isolation keeps insects, weeds and other harmful deterrents to the plants at a distance (Xydis, et al., 2017). In conventional farming, the quality of crops is highly dependent on the weather conditions and rich soils. With indoor farming, the production could take place anywhere, and can take place all year-round as it is not dependent on soil, local climate or the sun (Kozai, et al., 2016). In countries like Sweden, where the growing season is limited, this technique is an option for year-round production of fresh vegetables and herbs.

One of the benefits with vertical farming in urban environments is that the production can take place where the crops are consumed, and there is no need for long transportation. However, vertical farming could not be counted as a part of urban gardening. Urban green areas have many socio-economic benefits for the inhabitants in the city such as recreational, climate regulating, infiltration of rainwater as well as health benefits (van Leeuwen, et al., 2010). Due to the production taking place indoors, vertical farming may not have the same level of socio-economic advantages.

Most arguments against vertical farming arise when it is to replace conventional farming, with staple crops that are efficiently grown outdoors. However, proponents of vertical farming suggest it is not a replacement, but a compliment to food production, with high-value crops grown in facilities using LED lights and green electricity (Kozai, et al., 2016). Vertical farming can only suit a selection of crops, mainly salads and herbs, that will not grow taller than the average height of the shelves, which is around 40 cm (Kozai, et al., 2016). The plants in the vertical farms must also be fast-growing, meaning they will be harvested within roughly one month after planting and require low intensity of light and high density of plants. Furthermore, they must also be valuable plants, fresh and high in nutrition, where more than 85 % of the actual crop can be sold (Kozai, et al., 2016). Good examples of crops, besides salad, that could be cultivated indoors with artificial lighting are fruit-vegetables like tomatoes and peppers, berries and high-end flowers. Crops that are not well suited for this kind of cultivation are staple crops including, e.g. rice, corn and potatoes (Kozai, et al., 2016).

One of the primary disadvantages with vertical farming is the initial costs. Even if the costs could be limited eventually by better design and increasing demand, electricity, labour and material will always be needed (Kozai, et al., 2016). The efficiency of vertical farms have been compared to that of conventional greenhouses and greenhouses have been determined to be more energy efficient as they use direct solar energy for light and heating (Graamans, et al., 2018; Kozai, et al,. 2016). Vertical farms must always use artificial lighting even if there are windows; this is due to the narrow and deep shelves used to increase the yield, given the reduced floor area. Electricity for lighting has been found to be the greatest energy consumer in vertical farms (Kozai, et al., 2016). However, vertical farms use the local resources in terms of water and land area more efficient than conventional greenhouses (Graamans, et al., 2018). These studies have mainly focused on pure energy efficiency and output rather than the value of local produce and the potential of using existing premises. For energy use by vertical farms in comparison to conventional greenhouses see Figure 2.

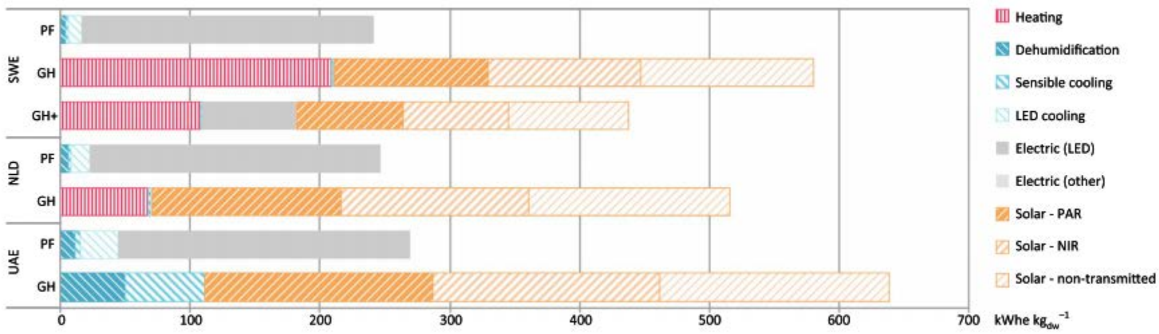

Figure 2: Energy usage for dry matter in lettuce production, using greenhouses versus vertical farms in Abu Dhabi (UAE), the Netherlands (NLD) and Sweden (SWE). Figure taken from (Graamans, et al., 2018).

As Kozai et al. (2016) argue, vertical farming cannot replace the conventional production systems for crops that we have today. Hamm (2015) thereafter states that the production costs, in terms of energy use and GHG emissions, for vertical farming ends up too high when natural sunlight is removed from the equation. Hamm (2015) agrees that further research needs to be focused on finding new sustainable, and resilient food systems mainly in developing countries, but finds it questionable to change something like conventional crop cultivation using sunlight (i.e., a renewable energy source). A vertical farm could improve the production by designing an optimal lighting system, increasing the yield by using multiple shelves, shorten the growth period by monitoring the environment optimally, assure there is no time lost in the production line, increase the density of plants and control waste (Kozai, et al., 2016).

Across the world, vertical farming has seen tremendous growth. As an example, Japan is the leading country when it comes to the development of vertical farming (Kozai, 2013). The number of vertical farms producing mainly lettuce has increased exponentially over the last few years. In 2009, there were 35 vertical farming factories in the country (Kozai, 2013) and in 2017 this number exceeded 150 (Hauashi, 2017). The projects in Japan have sometimes been government funded, but they have also been a connecting point for different industries such as electronics, chemical, transport as well as agriculture and food companies (Hauashi, 2017). No other country has as many vertical farms as Japan; subsequently, the cost of leafy greens has been reduced extensively by mass production (Hauashi, 2017).

1.3 Hydroponics

Hydroponic systems could be described as growing systems where crops are grown in nutrients baths and cultivation often takes place indoors and without any soil (Aldrich & Bartok, 1994). The difference between hydroponic systems and conventional greenhouse cultivation is primarily related to the support system and how water and nutrients are supplied to the plants (Aldrich & Bartok, 1994).

There are different types of hydroponic systems. Two of these types, that have become commercially used are e.g., 1) deep flow technique (DFT) and 2) nutrient film technique (NFT) (E. Son, et al., 2016). With the DFT system, nutrients are supplied automatically to the water whenever the concentration becomes lower than the set value. The plants are suspended above the water tank and the roots are in direct contact with the nutrient solution. The difference between the DFT and the NFT systems, is that in the later, the plants are suspended in a sloping bed so that the water flows slowly through the root system, from a high to low, resulting in a reduced water level (ibid.) A third type of hydroponic system, namely aeroponic systems, has also gained popularity. In the aeroponic systems, the nutrient solution is sprayed directly on the roots of the plants (ibid.)

Some advantages have been reported from greenhouses using hydroponic systems compared to conventional production systems with soil, including a greater density of plants and a decreased area requirement (Aldrich & Bartok, 1994). Furthermore, the yields could in some cases be larger than when plants are grown in soil. When plants are grown in a closed, dense system, evaporation is kept at a minimum thus reducing amount of water used. There are also fewer outbreaks of diseases and insects when no soil is used; see e-g- (Aldrich & Bartok, 1994; E. Son, et al, 2016).

However, despite the many benefits, a number of disadvantages have also been outlined with hydroponic systems. These include the initial costs of installations, with pumps and tanks greater need of technical knowledge and increased energy costs in comparison to conventional cultivation (Aldrich & Bartok, 1994). Depending on the layout of the structure, the average energy consumption for a hydroponic plant has been estimated to be between 14-17 kWh/m² (Xydis, et al., 2017). However, through the use of e.g. LED lighting, there is the possibility to change the settings and develop the products and production methods further. It is possible to change just the lighting and composition of diodes, or the content in the nutrient balance in order to test how the crops react to small changes (Kozai, et al., 2016). For vertical farming to be a sustainable option, it needs further development and would benefit from governmental support with funding to reduce the initial costs (Barbosa, et al., 2015).

1.4 Light

Energy use is an important factor in greenhouse cultivation contributing to 20-30 % of the total production costs (Brumfield, 2007). In regions where the hours of sunlight are not sufficient for optimal plant growth, lighting becomes a necessity (ibid.) Lighting has seen extensive improvements in the past decades. High-pressure sodium (HPS) lamps were introduced between 1983-1995 in Japan, (Kozai, 2013). After that came straight-tube fluorescent lamps as they had improved the Photosynthetically Active Radiation (PAR) output per watt (Kozai, 2013). With the fluorescent light, the vertical farms could densify their production systems and gain a much higher yield. The transition to light-emitting diodes (LED) started in 2005 (Kozai, 2013) and is today the main source of lighting (Kozai, et al., 2016). The LED lamps do not consist of a filament that burns, but are illuminated by movements of electrons in a semiconductor material, often silicon or germanium (Gayral, 2017). The diodes are mainly composed by red, far-red and blue diodes today (Singh, et al., 2015). Weather it would be beneficial to include green lights are to be further explored according to Singh, et al. (2015).

LEDs are low in radiant heat and can therefore be placed near the growing plant. This makes LEDs a more suitable lamp for vertical farms with narrow height shelves (Singh, et al., 2015). LEDs also allow for optimisation of light for greenhouses as it is easily scaled up and down. Electricity costs in a vertical farm could be reduced by using advanced LED systems; the lighting could be further improved by installing reflectors to increase the ratio of the light and improvements of light quality (Kozai, et al., 2016). In a study by Zhang, et al. (2017) a comparison is made regarding 1000-watt HPS lamps vs. 650-W LED and 150-W incandescent lighting systems vs. 18-W LED. In both cases, a clear reduction in energy consumption can be seen in favour of the LED. In the first case the energy consumption is reduced by 40 %, and in the second it is reduced by 86% (Zhang, et al., 2017).

One of the main obstacles in the development of vertical farms is the costs of building a lighting system, and the energy consumption to run it (Shimizu, et al., 2011). According to Kozai, Niu & Takagaki (2016) the lighting of a vertical farm, lit by artificial light, accounts for 70-80 % of the total electricity costs which makes it one of the most important aspects. When the LEDs were introduced on the market, the energy consumption from illumination decreased considerably; nonetheless, it has still been found to be the main use of energy.

1.5 Growing media

Hydroponic systems grow plants, often without any growing media. However, the case study reviewed in this report, i.e. at Grönska, use gardening soil filled pots suspended in a nutrient solution. However, in recent years, several new organic materials have been introduced on the market as environmental aspects have been added to the previous drivers, i.e. productivity and efficiency, when choosing growing media (Barrett, et al., 2016). To replace peat, materials such as, coir, pine bark, wood fibre and green compost are commonly used. As resources become more and more scarce, renewable options that minimise waste could be considered a great opportunity as well as a challenge (ibid.).

According to Quantis (2012) different mixes of growing media have varying environmental implications, i.e. influencing different environmental impact indicators. In a study for the European Peat and Growing Media Association (EPAGMA) four indicators were investigated, i.e. climate change, resource use, ecosystem quality and human health. The different material investigated were bark, coir pith, green compost, mineral wool, black and white peat, perlite, rice hull and wood fibres. It was found that a mix of 50 % peat, 30 % bark and 20 % wood fibres had the lowest impact on the given indicators. However, in general, it was difficult to detect one growing media with the least or most impact across all the indicators (ibid.)

2 Aim

The overall aim of this study is to examine the inputs and outputs for the Swedish company Grönska in order to develop more sustainable production system. This is done by reviewing the energy consumption and environmental impacts of the current production system in order to provide insights for greater efficiency and less environmental impacts.

- How much energy is consumed for a functional unit at Grönska and which inputs are the most significant?
- What are the environmental impacts due to the production at Grönska?
- What improvements could be done for greater energy efficiency and less greenhouse gas emissions during production at Grönska?
- What are the benefits and drawbacks with vertical farming in urban areas in comparison to conventional production of similar crops?

Furthermore, the study provides a review of the value of locally produced food and usage of existing facilities instead of building new factories for production.

2.1 System boundaries

This study was limited to review the farming of microgreens done at the company Grönska, in terms of energy consumption and environmental impacts. The total energy consumption and processes contributing to this were included in the study, i.e. the material flows and electricity for local operation. To put the results in a context, conventional farming operations and other vertical farms were examined in literature. The result is based on data collected at Grönska.

A limitation in the study is availability of accurate data for specific materials and operations in the dataset used. Materials with similar properties or a composition of materials have been estimated.

3 Methodology

3.1 Life Cycle Assessment

Life cycle assessment (LCA) is an internationally recognized method for structured and comprehensive assessment of the use of resources and the subsequent emissions associated with a product or service (JRC, 2010). In this study, LCA was conducted in order to quantify the energy consumption (measured in equivalent MJ energy) and carbon footprint (measured in CO_2-eq) from the production at Grönska. LCI data was obtained from (Ecoinvent, 2016). The LCA was conducted from a "cradle-to-gate" perspective, where extractions of resources for the major steps of the production were included. These included the operational services in the production, packaging and distribution of the final product; see Figure 3. The resource use after delivery to retail, impacts from consumption such as cooking and waste management were not included in this study. Possibilities for recycling, remanufacturing and reuse are also excluded, as the main product is not well suited for these options being a fresh herb for consumption; again see Figure 3 for a review of the system boundaries. There could be possibilities for reuse or recycling of the material around the plants such as the pots, but this was not investigated in this study.

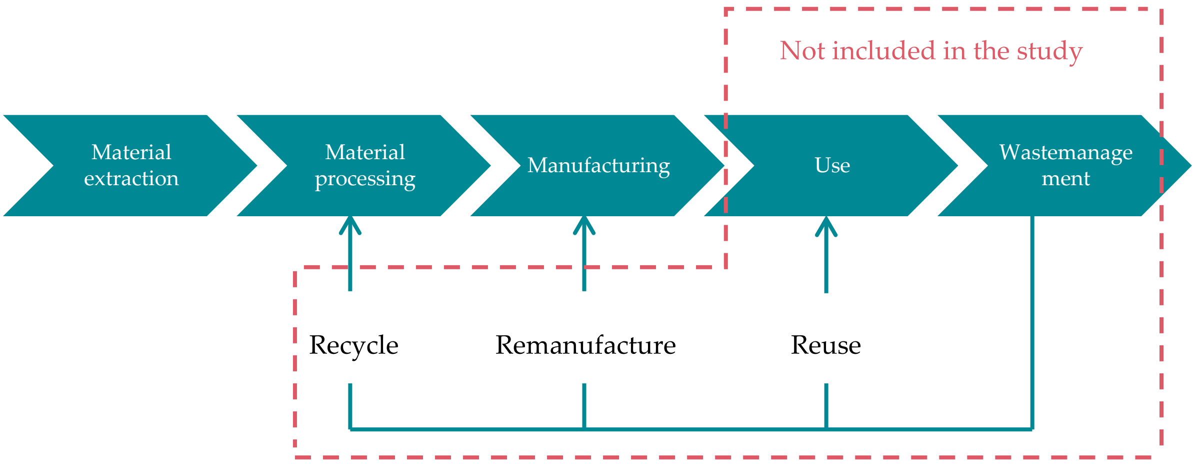

Figure 3: Different phases of an LCA from cradle-to-grave.

To be able to make a meaningful comparison to other similar products, the functional unit is an important element (JRC, 2010). The functional unit for the study was one finished pot with herbs i.e. basil, as it is made available to customers in a shop.

To be able to analyse the efficiency of vertical farming, compared to other conventional farming techniques, sensitivity to the choices of functional unit was introduced; where kg dry matter per m^2

was also reviewed. This is the unit often used by farmers to compare the efficiency in different cultivation techniques, with densification of crops and different species.

The assessments were limited to carbon footprints and energy assessments of the production system. For the carbon footprinting, using the LCI datasets for different inputs, the GHG emissions were calculated based on the LCIA method CML baseline 2014. The energy assessments were based again on LCI datasets provided in Ecoinvent (2016). However, in order to review the energy consumption per unit of the different inputs, the ReCiPe method was used. This includes all energy consumption for the material and energy inputs. In subsequent sections the energy consumption is discussed as direct (i.e. from production of the plants) and overall energy consumption (which includes all energy inputs for products and processes used to produce the plants). ReCiPe is an LCIA method that combine mid- and endpoint life cycle impacts, i.e. the parameters going into the system, the midpoint indicators and what endpoint indicators they result in (Hischier & Weideman, 2010).

3.2 The production system

Details on the production methods used for the assessment were provided by Grönska. This included all inputs and outputs used to produce a finished product to the consumer[1]. All upstream processes in the cultivation, such as production of the two kinds of pots, seeds, soil and fertilisers were included in the calculations. Energy use at Grönska, e.g., electricity used for lighting, ventilation and heating was included. The finished product is presented in a pot with soil, wrapping paper and a label, so the production of the label and wrapping paper was also added to the study. Figure 4, shows the flowchart of the material and energy inputs used for the calculations of energy and environmental impact for the production at Grönska. See subsequent text for more details.

[1] Due to proprietary reasons, the actual figure for inputs and energy consumption are not provided in the text, nor in the Appendix.

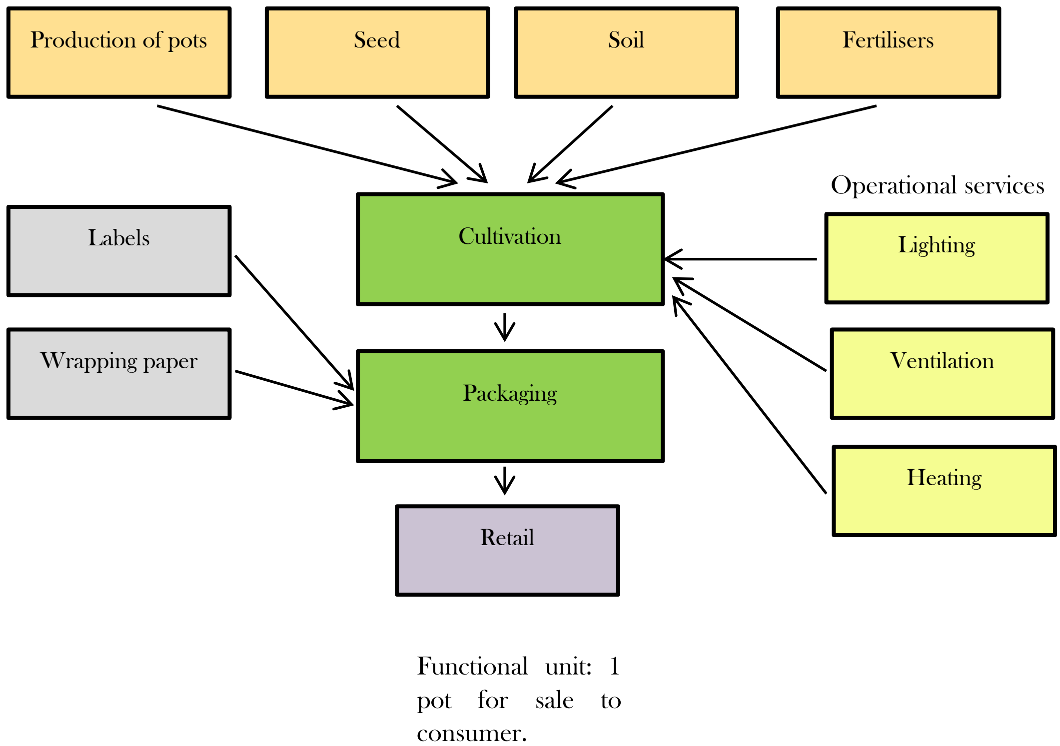

Figure 4: Flowchart of the production system at Grönska.

The annual flows of energy and materials were outlined for a production capacity of 5 000 plants monthly and amounting to 60 000 plants yearly.

3.2.1 Direct energy

The energy consumption for production at Grönska was calculated for heating, ventilation and light. A number of electric radiators are installed for heating and were estimated to be in use 12 hours per day. The ventilation was assumed to be in operation 24 hours per day.

For lighting, LEDs in red and blue are in use 12 hours per day, and all year around. The calculation of energy was done by multiplying the number of diodes with their effect (W) and the amount of hours they are in use annually.

Details on the energy consumption, e.g., total number of units and effect figures were also provided by Grönska. When calculating the GHG emissions for these components, LCI data for the Nordic electricity mix was chosen, instead of the Swedish electricity mix, to give a more general result. The Nordic mix is estimated to be 100g CO_2-eq/kWh which could be compared to the Swedish of 48,85g CO_2-eq /kWh (IVL, 2017).

3.2.2 Material inputs

The total amount of seeds (weight) used in the production were provided in kilograms. There were no seeds in the database (Ecoinvent, 2016) that exactly corresponded to the ones used. Comparable LCI data for grass seeds were used to correspond to the herb seeds used.

For the packaging material used for the finished product, i.e. wrapping paper and labels; data was collected from (Ecoinvent, 2016). The wrapping paper, modeled as "wood containing paper, lightweight coated." The lightweight coated option was chosen due to the actual paper being coated in wax to sustain humidity and the processes to make this were assumed to be similar. The size of the labels were measured and scaled up to the annual amount used. Here a product was chosen which had similar properties to a label such as being a thin sheet of paper with acrylic binder on one side.

The pots currently used for the final product are made out of polystyrene mixed with carbon black Strömberg (2017). For the energy consumption the process for making polystyrene was used. In order to model the –moulding of the plastic, we assumed the moulding was similar to that of making a PET bottle.

Data for fertilizer consumption in the hydroponic system, measured in annual kg of mineral fertilizers was provided by Grönska. These fertilizers consist of nutrients and fillers, where the major or primary nutrients are Nitrogen (N), Phosphorus (P) and Potassium (K), and the fillers are secondary or micronutrients such as sulphur (S), calcium (Ca) and zinc (Zn) (Yara, 2015). The mutual breakdown of the major nutrients would commonly be 15 (N) +17 (P) +20 (K) which is used in the calculations for this study. A highly concentrated fertilizer could contain up to 52 % of major nutrients (Yara, 2015), but for the calculations made the concentration of major nutrients has been estimated to 20 %.

The amount of soil was calculated from the inner volume of the pots used and scaled up by the number of plants produced. It was assumed that each pot had 0.000343 m^3 (343 cm^3) of soil. Emissions for the production of gardening soil were obtained from (Martin, 2018). LCI data for all processes were taken from (Ecoinvent, 2016). See Table 1, in Appendix 1, for a listing of LCI data sources used in this assessment.

3.2.3 Excluded

The transportation of the final product from Grönska will mainly be done by cargo bike. A few deliveries by car could occur due to bad weather but they are excluded in this study. To water, harvest and package the plants currently there is a large share of human labour required, which is also excluded in the study. Finally, the energy usage and environmental impacts from the construction of the production site, i.e., the infrastructure used to produce the plants, was not included in the study.

3.3 Scenarios Reviewed

3.3.1 Current Production System

Grönska is currently producing 5 000 plants per month, 60 000 per year. The baseline for the study has been the current production using gardening soil and a plastic pot for the finished product; see description of the current production system above.

3.3.2 Current, Paper Pot

Grönska would like to switch from the current black plastic pot to another material, a pot made out of peat and wood pulp; referred hereafter as the paper pot. A comparison was conducted to show the potential for improvements with this new pot. Data for a mix of peat and wood pulp were used to model the material inputs for the cup. The assessment was conducted assuming that the process was similar to the production of a paper mug; with data collected from (Institute for Lifecycle Energy Analysis, 1994).

The paper cup has the benefits of being lighter and compostable. As it is degradable, the herbs or salads could be replanted directly in the paper pot in a new pot with soil. Drawbacks with the paper pot could be that it absorbs water, adding weight to the functional unit which has an impact e.g. the transport of goods. The paper pot also becomes more fragile due to absorption of water, and could easily break during transportation.

3.3.3 Current, Growing Medium

Furthermore, according to discussions with Grönska, it is envisioned that new growing mediums will be used. This can include a number of different options such as more organic certified gardening soil, soil containing less peat or completely new growing media such as wood pulp or coir pith/coconut husk. For this study, the current system, which uses primarily peat, is substituted for soils produced from more by-products, and thereafter even new types of growing mediums. This includes, a review of the use of coir (produced from coconut shells). Data for coconut husk (coir pith or coconut fibre) was collected from (Ecoinvent, 2016) and examined in terms of environmental impact. A subsection is dedicated to reviewing the implications of growing medium changes.

3.3.4 Baseline: Comparisons to Greenhouse and Open Field Cultivation for Area Output

Comparisons were done with conventional production systems for herbs and leafy greens. Information on other systems was compiled from available research, on vertical farming system and conventional farming of similar crops, both in greenhouses and open fields. The primary sources for the comparison were scientific articles. A full list of data sources could be found in Table 2, see Appendix 1.

Because the functional unit is one pot of basil, similar crops were assumed to be salads of varying kinds and herbs. In the reviewed studies, data for yield was provided in fresh weight. In order to allow for comparison, the dry matter content was assumed to be 6 %, an average value for different kinds of salads (van Holsteijn, 1980).The conventional open field farms were mainly based on conventional practices, i.e., non-organic. The focus was limited to crops with similar qualities, e.g. leafy greens, i.e. lettuce heads. Several studies were reviewed and the cultivation took place in different countries such as Spain, Greece, the United States, Nigeria and Sweden. The yield for salad was found to be slightly higher in the United States, i.e. 0.3 kg dry matter per m^2 (Turini, et al., 2011; Iowa State University, 2017), in comparison to Sweden, where an average dry matter content of 0.1 kg dry matter per m^2 was reported (Ögren, et al., 1992).

For year-round production of basil, in greenhouses, the fresh herbs in pots could be harvested every six weeks during summer and every 8 weeks during winter (Fraser & P. M. Whish, 1997). This amounts to an average harvest every 7 weeks. In a study by Saha, et al. (2016) the yield from producing basil in greenhouses with hydroponic systems was 9 600 kg dry matter per hectare and 0.96 kg/m^2. The total harvest per year would then be $0.96 * 7 = 6.72$ kg/m^2 year.

4 Results

4.1 Production per area

In this study, open field cultivation and conventional greenhouses were used for comparison to the data collected at the vertical farms with hydroponic systems and LED lighting. In the comparison of yield per land area using the data collected, the results from the literature shows a much larger harvest in vertical farms compared both to greenhouses and open field cultivation, see Figure 5. At Grönska, the yield was estimated to roughly 0.6 kg per square meter.

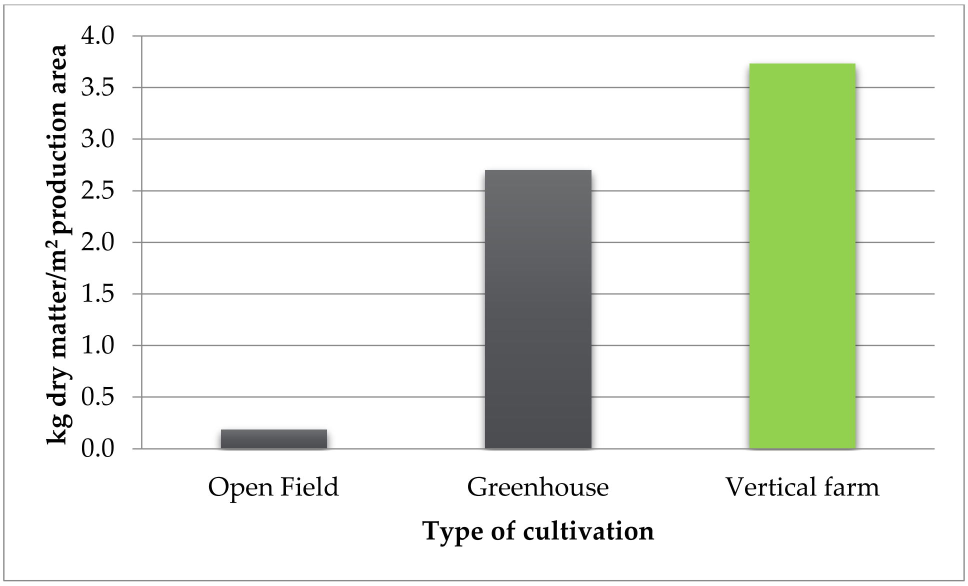

Figure 5: Kilograms dry matter of lettuce produced per square meter at an open field, in a greenhouse and a vertical farm, see Appendix 2.

4.2 Energy use

From the review of the energy consumption, the results suggest that the annual energy use with the plastic pot was higher (296 000 MJ) than with the paper pot (286 000 MJ), see Figure 6. The energy use for the functional unit (i.e. per basil plant) amounted to roughly 4.9 MJ with the plastic pot and 4.81 MJ per basil plant with the paper pot. When comparing growing area, the energy used per square meter was 17.1 GJ for the plastic pot and 16.7 GJ for the paper pot.

As illustrated in Figure 6, the largest share of energy during the production, can be attributed to the gardening soil. For the scenario with the plastic pot the gardening soil accounted for 47 % of the total energy consumption, and in the paper pot scenario it is increased slightly to around 48 %. Thereafter, the second largest energy consuming process was for the lighting systems. In this study, the lighting system amounted to roughly 32 % of the total energy consumption when using the plastic pot, and roughly 33 % when using the paper pot. The wrapping paper used for presentation of the product at the supermarkets accounted for about 8 % of the total amount of energy consumed.

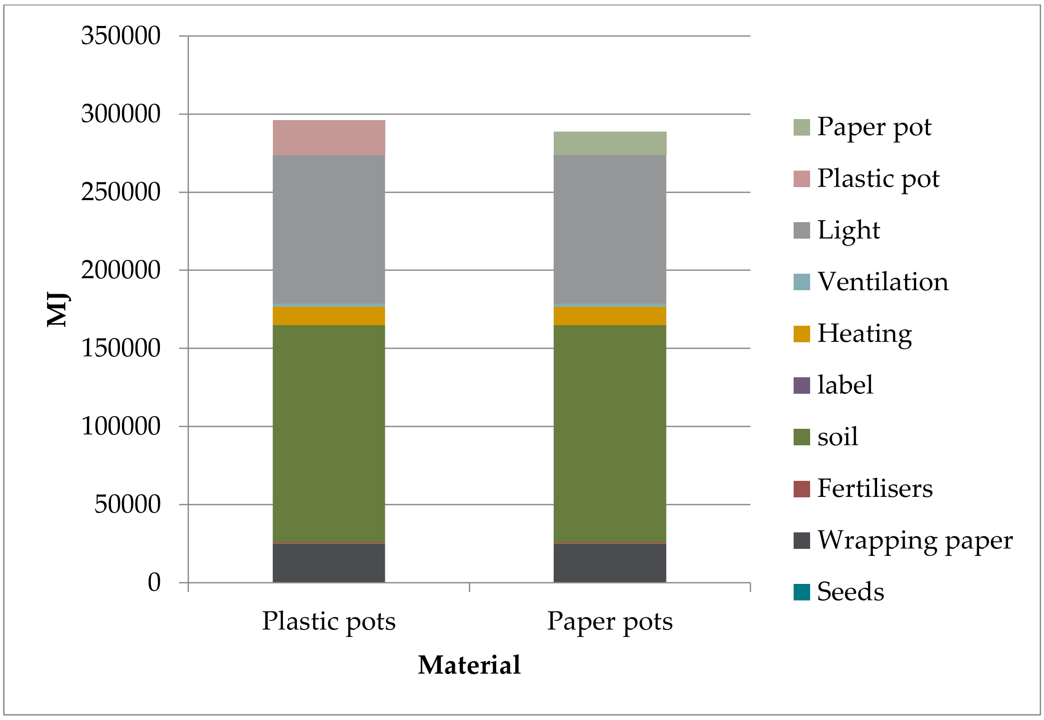

Figure 6: Annual energy use at Grönska.

4.3 Carbon footprint

The total GHG emissions (measured in CO_2-eq) for the annual production of basil plants were estimated to be roughly 6 550 kg CO_2-eq with the plastic pot and 5 740 kg CO_2-eq with the paper pot, see Figure 7. It gives a result of 0.11 CO_2-eq for the functional unit using the plastic pot and 0.10 CO_2-eq using the paper pot.

The largest GHG emissions can be attributed to the energy used for lighting the growing area. Roughly 40 % of the total GHG emissions were due to lighting in the case with the plastic pot, and 46 % due to lighting for the paper pot. The process with the next largest GHG emissions was the manufacturing of gardening soil, accounting for roughly 40 % of the total GHG emissions in the case with the plastic pot and 46 % in the case with the paper pot. Other categories did not contribute significantly to the total GHG emissions. Ventilation, heating and fertilisers all account for only 1-5 % of the total amount of GHG emissions.

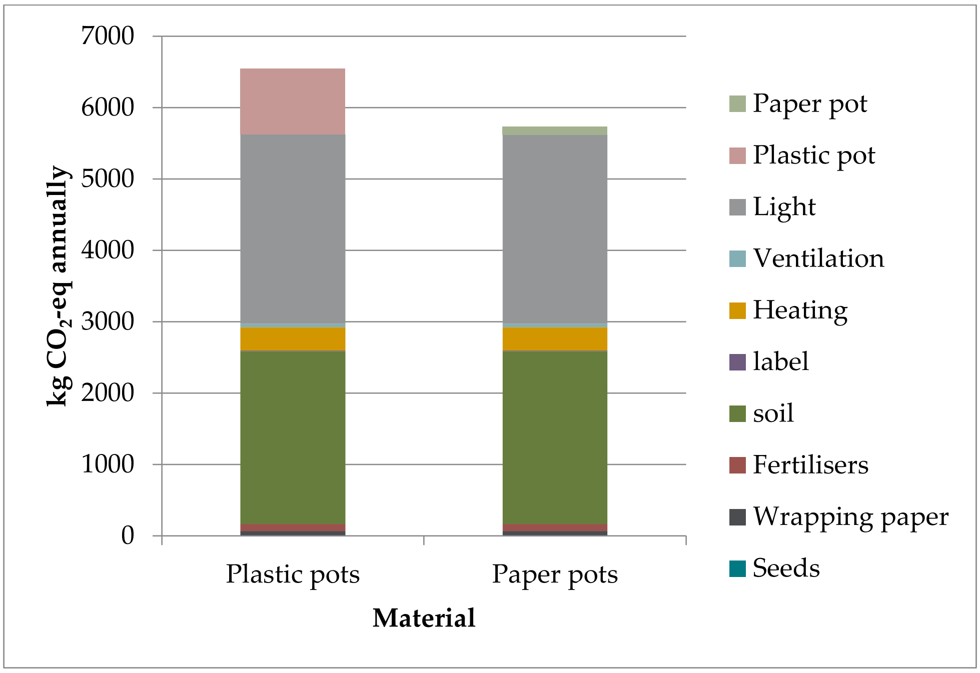

Figure 7: Annual GHG emissions at Grönska (shown in kg CO2-eq)

The carbon footprint for one plant is 0.11 kg CO_2-eq, if one plant has the average weight of 28 g. Accordingly, the impact per kg of plant produced is 3.9 CO_2-eq/kg basil using a plastic pot, or 379 CO_2-eq/m^2. For the paper pot, the corresponding values are 0.10 CO_2-eq for one paper pot, 3.41 CO_2-eq/kg fresh basil and 332 CO_2-eq/m^2.

4.3.1 Choice of Medium

When comparing the environmental impacts of the gardening soil currently used to that of coir pith, for the two scenarios, the GHG emission can be significantly reduced; see Figure 8. The scenario with the highest impacts, i.e. using a plastic pot and gardening soil, accounts for almost the double amount of GHG emissions in comparison to the lowest, i.e. using paper pot and coir pith offering insights into future selection for growing.

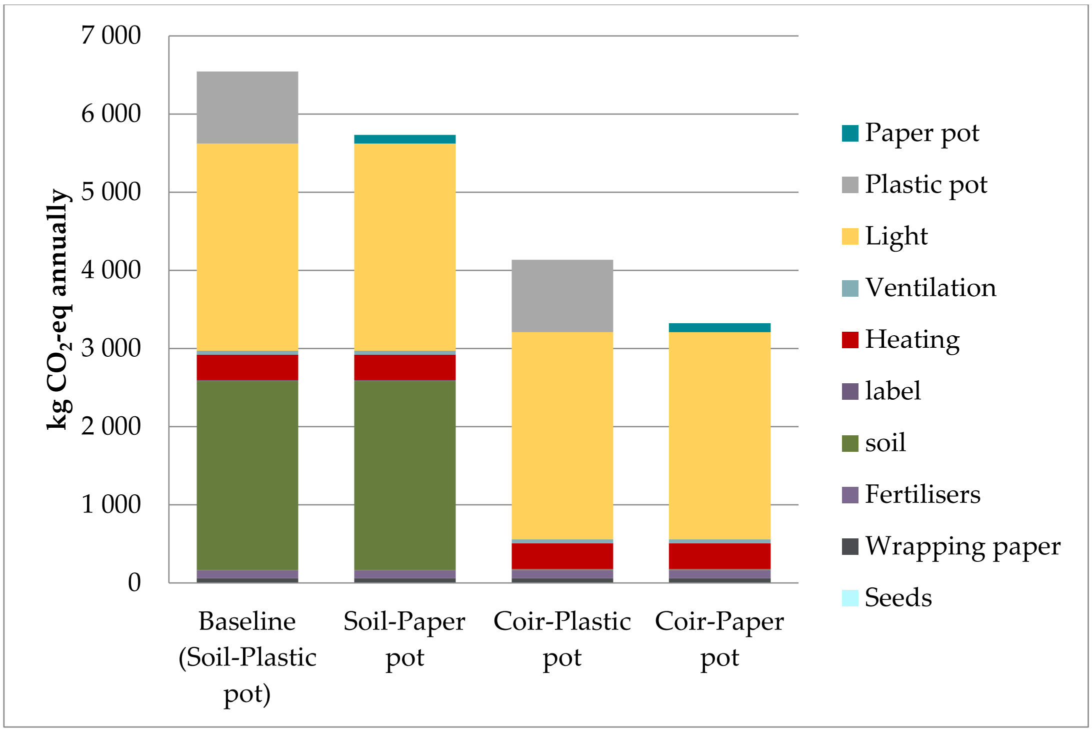

Figure 8: Comparison of the different growing media in both plastic and paper pots

4.3.2 Sensitivity to Data Choices

Electricity

In the assessment, the electricity LCI dataset chosen was the Nordic electricity mix (IVL, 2017). Thus, the data could be sensitive to the choice, if e.g., Swedish electricity mix was chosen in its stead. Figure 9 below reviews the sensitivity. As shown, there could be a reduction of GHG emissions of nearly 40% if the Swedish electricity mix was chosen.

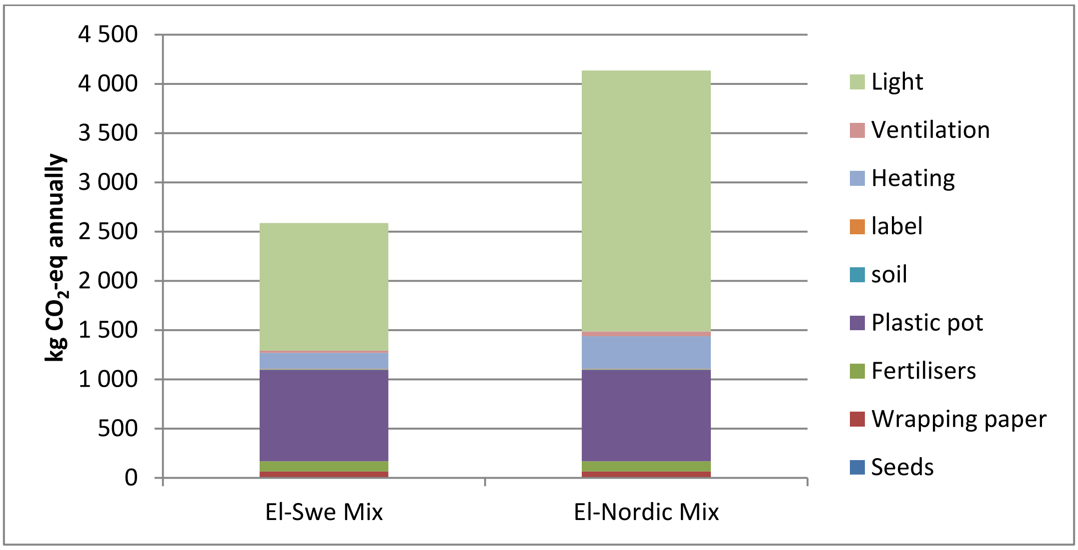

Figure 9: Sensitivity to Electricity Choice for the overall emissions (in this case Plastic Pots with soil)

Transportation

A further examination of the possible contribution to GHG emissions due to transportation was made for the materials used at Grönska. The average distances of travel were set to 100 km and the emissions were calculated by the weight of each material that was transported, see Table 3 in Appendix 3. The result showed an average contribution of 3.5 % to the total amount of GHG emissions annually at the Grönska. Furthermore, 80 % of the GHG emissions from transports where that of delivering soil.

5 Discussion

5.1 Benefits and Drawbacks for Vertical Farming

The results of this study have shown many benefits as well as drawbacks for vertical-hydroponic farming. A drawback could be that the initial costs for starting a vertical farm, with hydroponic water systems and artificial lighting, are higher than that for conventional farms. The costs could be reduced with governmental support such as subsidies or funding. Furthermore, development of the techniques could make them more efficient and also reduce both the capital and the operational costs.

In a comparative study of greenhouses versus vertical farms, in Abu Dhabi, Amsterdam and Kiruna, by Graamans, et al. (2018), the efficiency of production and energy consumption was reviewed. Even if the consistency in the production from vertical farms was stable and gave good results, the efficiency is still dependent on the resources needed (Graamans, et al., 2018). It was found that vertical farms require more energy than greenhouses mainly due to lighting (ibid.). Vertical farms generate an opportunity to grow crops in locations and altitudes that are not optimal for the plants to begin with. As they are not dependent on the outdoor environment and can produce constantly independent of sunlight or rain it is the only option to conventional greenhouses and small-scale urban gardening in the urban areas. Part from being independent from weather conditions and using a small land area, vertical farms also consume other resources sparingly. For example the amount of fresh water used for hydroponic farming is much less in comparison to conventional greenhouses or open fields. There is no runoff and because the system is closed there is almost no evaporation. If fresh water becomes a more scarce resource it will result in a greater interest for closed systems and hydroponic farming in order to reduce the need of water in agriculture.

When comparing vertical farms to conventional farming, at greenhouses and open fields, the result showed a larger yield per square meter from vertical farms. Vertical farms efficient use of land area could thereby be determined and this contributes to releasing pressure on arable land. However, comparisons of energy use and environmental impacts are more difficult. This is mainly because entire lifecycle perspectives rarely are used to determine energy consumption in conventional farming. The presented result is often from a production stage solely including operational service. In the review at Grönska, material flows for the entire production were examined and contributed to the overall results.

Today, labeling of products has a limited use among consumers according to a study conducted by G. Grunert, et al. (2014). The level of concern for sustainability does not necessarily correspond with the use of indicators showing environmental impacts (G. Grunert, et al., 2014). However, it is possible that the environmental impact of a certain product will become increasingly communicated to consumers in the future; providing further justification for the functional unit used for comparison in this study. A multi-criteria method of environmental performance of service and goods is the product environmental footprint (PEF) (European Comission , 2010). PEF models the environmental inputs and flows of material and energy, GHG emissions and waste, associated with the production. The aim is to reduce the environmental impacts throughout a product, or service, life cycle (ibid.).

5.2 Transportation

One of the greatest arguments for urban farming is the reduced need for transportation. With the cultivation taking place in close connection to the consumption, the distance for transportation is greatly reduced. Lettuce, herbs and micro-greens with higher water content are fragile foods, they need to be stored and packed carefully during transport. Otherwise, the risk is high for large amounts of waste (Kozai, et al., 2016). In order to provide these products to people in urban areas there is a need for a resource efficient system with high-quality output that could be located on small areas in the urban environment (Kozai, 2013).

In many food systems, and when reviewing food consumption in general, transportation of the food to consumers is not the main source of environmental impact; see e.g. Martin and Brandao (2017) and Martin et al. (2016). Despite claims that local foods, or foods with low "miles" may have less impacts, it has been shown that the products being eaten are of more concern than the distance travelled, and further complicated by the type of transportation method used; see e.g. Coley et al (2009); Edwards-Jones et al. (2008); Edwards-Jones (2010). It has even been found in some studies that impacts from transportation can increase with deficient logistics (PWC, 2009).

The transport is just a share of the total impacts from a product or service, and it could be more energy efficient to transport large volumes at the same time rather than small amounts around a city (Naturskyddsföreningen, 2016). In a comparison of lettuce grown in greenhouses and sold in the UK, to lettuce grown in polytunnels or open fields in Spain, and later shipped to be sold at the market in UK (Edwards-Jones, 2010). It was found that the GHG emissions generated by the British production in greenhouses during winter were greater than that of the lettuce sent to the UK by truck (ibid.). It could be assumed that this period, where transport stands for less GHG emissions than the production, is longer in a country with a colder climate.

The total emissions from domestic transports were, 2016, 16 855 ton CO_2-eq out of that road traffic accounted for 15 771 ton CO_2-eq (Naturvårdsverket, 2017). When looking in to the different kinds of vehicles used on roads, roughly 30 % of the GHG emissions originate from freight transports in light and heavy trailers. Cars account for 65 % of the total emissions from road traffic (ibid.). The transport home from the grocery store is one of the largest shares of GHG emissions from a product in a lifecycle perspective (Naturskyddsföreningen, 2016). According to Coley, et al. (2009)

a round trip of 7.4 km to the grocery store, to buy organic vegetables, is likely to cause more GHG emissions than that of conventional products being delivered to residential homes.

By an investigation of the largest supermarkets in Sweden, it was found that almost all herbs from competitors sold in pots were produced in Sweden. Therefore, comparisons of the impacts from logistics for the supply of the products may provide advantages for Grönska. However, as no information on the logistics from competitors could be found, it will be important to review further the impact these have for comparison; and due to the fact that these competitors also use conventional greenhouse methods, adding further to the comparison.

New opportunities for reducing the transports from retail to the consumer's home have arisen with increasing e-commerce (Winslott Hiselius, et al., 2015). E-commerce and different delivering service allow efficiency in transports. Part from reduced traveling, vehicles with less environmental impacts can be chosen for these transports. Even if e-commerce alone can't be the solution for reduced travels, it can be a supportive option for more sustainable transports, and it eases up for a car-free lifestyle (ibid.). Larger operational systems delivering food to the households will reduce the need for car transports and emissions of carbon (Coley, et al., 2009). However, carbon is not the only important impact and there are other factors to be considered such as biodiversity, landscape, fair trade and local employment and the benefits of vertical farming could be found within these categories (ibid.).

5.3 Improving the Energy Efficiency

The results suggest that the overall energy consumption was dominated by production of gardening soil and lighting. Similarly, in the literature, crops grown indoors with artificial lighting have been found to be more energy consuming than conventionally grown crops of similar character (Graamans, et al., 2018).

In a study by Djevic &Dimitrijevic (2009), four different kinds of greenhouse structures were evaluated. The results showed an energy use ranging between 8-14 MJ/m^2 for each harvest, with an average of 11.8 MJ/m^2 (ibid.). At every square meter 20 salad heads were planted resulting in energy consumption of 0.59 MJ/per plant. At Grönska the annual energy consumption is 3 285 MJ/m^2 for heating, ventilation and lighting. Split on the 60 000 plants, that are produced annually, the energy use equates to roughly 1.8 MJ/per plant. Thus, energy consumption, once again in vertical farming systems, as illustrated in this study are higher compared to traditional greenhouses. When reviewing the energy consumption for heating in particular, the current system may have lower emissions than conventional greenhouses. Nilsson & Nimmermark (2013) evaluated the energy use for heating a 2000 m^2 greenhouse using different kinds of insulation, e.g. single vs. double-layered plastic and glass, up to the temperatures 16, 18 or 20 ^{o}C. For a year-round production at 20 ^{o}C, using residual heat, the energy needed per square meter varies between 120 and 388 kWh/m^2 with an average of 250 kWh/m^2 (Nilsson & Nimmermark, 2013). In comparison, the energy consumed for heating at Grönska is roughly 190 kWh/m^2 annually. Thus, vertical farming was shown, in this case to have less heat demand.

The Swedish greenhouse market has reduced their energy consumption from 371 kWh to 215 kWh per square meter according to a report by Jordbruksverket (2013). In comparison, at Grönska, the local operations add up to roughly 1 750 kWh where 87 % is that of lighting. To compare the energy consumption and greenhouse gas emissions per product is not in favour of vertical farms as their greatest competitiveness lies in the density in the production and the yield per square meter of land.

At Grönska a large number of diodes are used for lighting, and even if the power consumption is low, the total need for electricity results in a large environmental impact. To reduce this, new compositions of diodes and changing the output could be an option. Another option could be to use a renewable energy source, e.g. solar panels on the roof instead of relying on electricity from the grid. This could provide, while potentially costly, an option to reduce the impacts from energy use. However, the environmental impacts from solar panels from their use, manufacturing, maintenance and waste management may need to be reviewed (Kalogirou, 2004). With a large energy demand, land displacement for the solar panels could be an issue to reckon with; although it could be avoided by locating the solar panel on a rooftop.

5.3.1 The Use of Growing Media

The results of this study suggest that there is a significant environmental impact from manufacturing of gardening soil used in the production of leafy greens (i.e. basil) at Grönska. Grönska sells a product consisting of a living plant, not harvested, in a pot. If the aim is for the basil to continue to flourish also after being sent to retail, then there is a need for soil. The functional unit, being one pot of basil, contains roughly 28 g of basil and about 200 g of soil, making soil the heaviest component of the functional unit. To reduce the impacts, an alternative could be to harvest the basil before sending it to retail. This way the soil could be reused within the company. Further studies with different compositions of soil could also be of interesting as well as other mediums for the plants to grow in.

Dry matter content of lettuce is dependent on the growing medium, according to a study, based on production on Malta, and can vary between 6-14 % of the fresh weight (Agius, 2015). However, in this study the dry matter was set to the lower value and calculated the same for all producers. Comparing lettuce production with that of basil could be a misguiding as the dry matter content differs significantly. Depending on the species of basil, the dry matter content can vary between 26 % and 32 % according to a study made by Dzida (2010).

Results suggest that with the regular garden soil and the plastic pot, the soil account for 44 % of the total emissions, roughly 5 500 kg CO_2-eq annually, during the production at Grönska. If the growing media was changed to coconut husk, the total emissions would be reduced to roughly 3 100 kg CO_2-eq annually, and represent less than 1 % of the total emissions from the company. When reviewing more in detail, it was found that coconut husk has a global warming potential of 0.00066 kg CO_2-eq per kg material which could be compared to that of gardening soil being 0.196 kg CO_2-eq per kg material (Martin, 2018).

Also when comparing energy consumption for gardening soil and coir pith, the amount of energy used was lower choosing coir pith. Gardening soil accounted for 47 %, (139 GJ), of the total amount of energy used annually at Grönska. With coir pith, the energy consumption would be roughly 125 MJ for the growing media annually and account for less than 1 % of the energy use (Ecoinvent, 2016). The results illustrated that media blends containing large shares of peat had higher impacts on resources and climate change (Quantis, 2012). This is mainly because of land use change during peat harvesting. If the media contain large share of compost, the impact on human health will be greater than other mixes. Here transportation and the processing of emissions contribute to the health impacts. Coir pith, the outer layer of the coconut shell consisting of mainly fibres

(Horticultural Coir Ltd, 2007), was the constituent that contributed the largest impact on Ecosystem services (Quantis, 2012).

Vertical farms, which are located in existing buildings, may relieve pressure on arable land by not requiring large grounds for their operations (Sanyé-Mengual, 2015). A good opportunity for urban farming is the possibility to more closed flows, taking advantage of the metabolic flows in the building where they are located (Sanyé-Mengual, 2015). Rainwater could be harvested from the building and used for watering of the plants. Furthermore, the organic waste from households in a residential building is a good example of exchange of resources at the spot (ibid.). The organic waste could be composted and used as a component in the growth medium. This could be a good way of reducing the energy use in the production at Grönska. Further research will also be needed to understand the nutrient requirements for efficient production at Grönska using the different growing media.

5.4 Socio-Economic Aspects of Urban Vertical Farming

There have been an increasing number of small-scale vertical farms, producing vegetables in urban areas due to the rising demand for local foods but also the increasing need for food in general. As new technologies, such as LEDs, have made it possible for even small-scale investments in this farming technique, more and more entrepreneurs are entering the area. The rising concerns for food security and need for independence from the global system makes vertical farming an attractive option.

There are many who can benefit from the locally produced microgreens. The collaboration with retailers is already given, but also restaurants that could influence the production directly and facilitate valuable collaboration. They, as reliable costumers, and the supplier making specific products that might not be found on the market.

Today urban centres are greatly reliant on industrial agriculture to feed the population. The risk of not getting a sufficient supply of fresh food is a threat to the well-being of the society (Chavis, 2015). The reliability to harvest at certain times could be valuable if unpredictable harm such as extreme weather or crisis affecting the transportation chain, would damage the conventional harvest and its delivery. Urban agriculture is an opportunity for communities to be more self-sufficient and less dependent on the global supply chains. By growing food locally there are new job opportunities, the possibility to sell the produce, and create other products from the crops grown (Chavis, 2015).

Furthermore, as Röös and Karlsson (2013) illustrate, Swedish consumers generally consume more greenhouse based vegetables annually than those produced from conventional farming practices. Several studies have also found that consumers prefer locally labelled foods, outlining customer beliefs that regionally produced foods have the potential to reduce environmental impacts and strengthen local economies, and are even of higher quality and taste compared to imported varieties (Edwards-Jones et al., 2008; Hempel and Hamm, 2016; Joosse and Hracs, 2015; Toler et al., 2009).

6 Conclusion

Vertical farming has the benefits of being independent from weather conditions, such as the cold in the Scandinavian countries. The energy use is higher for vertical farms than conventionally grown vegetables and herbs, but other resources i.e water, nutrients, arable land and pesticide are used more scarce. Vertical farming is an opportunity to grow crops in urban environments and thereby support the local community with jobs and strengthen food supply.

The environmental impacts may not be in favor for vertical farming when comparing to results found in literature for conventional farming. Since there were no assessment done, in a similar way, with the entire lifecycle perspective on herbs sold in pots it is hard to say that conventional farming would be better. Furthermore, there are several other impact categories that could be examined and found valuable, e.g. which exemplify the implications of the limited use of pesticides and fertilizers. Also, vertical farming could hold an important role in social well-being and strengthen self-sufficiency, by diminishing risks connected to the reliance on the global food production system, and long delivery chains; thus creating of more resilient communities.

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Appendix 1

Table 1: LCI data

Flow		Name	Reference
Seeds		market for grass seed, organic, for sowing	(Ecoinvent, 2016)
Wrapping paper		market for paper, wood containing, lightweight coated	(Ecoinvent, 2016)
Fertilisers	Nitrogen (N)	market for nitrogen fertiliser, as N	(Ecoinvent, 2016)
	Phosphate (P)	market for phosphate fertiliser, as P2O5	(Ecoinvent, 2016)
	Potassium (K)	market for potassium fertiliser, as K2O	(Ecoinvent, 2016)
Pots	Plastic	market for polyethylene terephthalate, granulate, bottle grade	(Ecoinvent, 2016)
	Paper	Material specific energy MJ/kg paper cup, market for carton board box production, with offset printing	(Institute for Lifecycle Energy Analysis, 1994), (Ecoinvent, 2016)
Soil			Martin (2018)
Label		market for laminating service, foil, with acrylic binder	(Ecoinvent, 2016)
Heating		Electricity, Nordic mix	IVL (2017)
Ventilation		Electricity, Nordic mix	IVL (2017)
Light		Electricity, Nordic mix	IVL (2017)
Coir pith		market for coconut husk	(Ecoinvent, 2016)

Appendix 2

Table 2: Comparison of yield in open fields, greenhouses and vertical farms.

Open Field			
	Fresh weight	Dry matter	Source
	2.7	0.2	(Moccia, et al., 2006)
	1.7	0.1	(Ogbodo, et al., 2010)
	2.0	0.1	(Harvest to Table, 2017)
	1.5	0.1	(Ögren, et al., 1992)
	2.0	0.1	(Ögren, et al., 1992)
	0.5	0.0	(Kerns, et al., 2001)
	4.9	0.3	(Turini, et al., 2011)
	5.4	0.3	(Agricultural Marketing Resource Center, 2017)
	3.9	0.2	(Lages Barbosa, et al., 2015)
	3.0	0.2	(Fiteinis & Chatzisymeon, 2016)
average:	2.8	0.2	
Greenhouse			
		2.0	(Graamans, et al., 2018)
		2.1	(Graamans, et al., 2018)
		4.0	(Graamans, et al., 2018)
average		2.7	
Vertical Farm			
		5.0	(Graamans, et al., 2018)
	41	2.5	(Graamans, et al., 2018)
	3.8	0.2	(Touliatos, et al., 2016)
	5.5	0.3	(Touliatos, et al., 2016)
average		3.7	

Appendix 3

Table 3. Estimation of tonne-km for the materials at Grönska

Transportation			Tonne-km
Pea seeds	100	km	12.00
Grass seeds	100	km	0.60
Wrapping paper	100	km	44.95
Nitrogen (N)	100	km	0.78
Phosphete (P)	100	km	0.88
Potasium (K)	100	km	1.04
Plastic	100	km	24.10
Peat/wood	100	km	22.34
Soil	50	km	617.40
Label	40		19.20
tot			***743***

The environmental impact was calculated from the total amount of tonne-km required times the carbon dioxides emitted per tonne-km. Data for environmental impacts were collected in (Ecoinvent, 2016).

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