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Reviewing the energy and environmental performance of vertical farming systems in urban

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In cooperation with Node Farm

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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 25 % of the greenhouse gases emitted from Sweden come from agricultural activities. Thus with an increasing population, it is essential to aim to reduce the emissions from the 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 Node Farm has been evaluated. Node Farm is located in southern Stockholm in an old refrigerated shipping container, and will start the production of cress during spring 2018. The energy use and environmental impacts for the production of hydroponic herbs (cress) were assessed using life cycle assessment (LCA) from a cradle-to-gate perspective. This included the materials (e.g. hempflux and plastic boxes) used for growing cress and the energy consumed for heating and lighting. The use (consumption), waste management and transports to and from the company were not included in this study.

The results illustrated a large share of energy used for the manufacturing of the plastic box to package the cress. Also the largest source of negative environmental impacts was due to the manufacturing of the plastic box. There are possibilities to reduce the energy consumption and environmental impacts by choosing another material for packaging. 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 in reviews of the sustainability. This study focuses on energy and environmental impacts, but the socio-economic benefits and resilience of 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 Node Farm, beläget i södra Stockholm, har granskats med hjälp av verktyget livscykelanalys (LCA). Node Farm kommer att påbörja sin produktion av krasse under våren 2018. Livscykelanalysen innehöll beräkningar av energiåtgång och miljöpåverkan från produktionen. Inkluderat i studien var de material som används för att odla krassen och den energi som gick åt för lokaldrift. Studien inkluderade inte användning, avfall samt transporter till och från företaget.

Resultatet visade på en stor energiåtgång tillika miljöpåverkan från tillverkningen av den tilltänkta plastlådan, som ska användas vid försäljning. Förslaget med papper istället för plast gav en minskning av både energi och växthusgaser. För en större förbättring bör alternativa förpackningssätt övervägas.

Långa transporter av livsmedel är ett 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, and the number of people living in urban areas could be expected to almost double within 30 years, crop production must also increase (Kozai, et al., 2016). About 26 % of the Swedish greenhouse gas (GHG) emissions come from agriculture; and also accounts 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 ecosystems 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 the 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 insecurity 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 agricultural systems have increased recently, and have the potential to reduce resource consumption, e.g. energy demand and water consumption (Kozai, et al., 2016). The vertical farming systems will not replace open-field production or the conventional greenhouses, but it 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 Node Farm

Node Farm is about to start up their production during spring 2018. It is a small company to start with using one refrigerated container, located in southern Stockholm. The container is no longer working as a refrigerator, but the already established insolation and the possibility to move it, and stack several at height is the reason choosing the container for vertical farming.

The ambition is to increase the production as soon as an optimal production system has been established for the production in the container. The main crop will be cress which will be sown on hemp fibre, i.e., Hempflax. The cress will continue to grow on the Hempflax after packaging and availaility to retail, see Figure 1 which shows an example of cress growing on hemp fibre and how it could be presented to costumers.

Figure 1: Cress growing on hemp fibre. Picture borrowed from (Node Farm, 2017).

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 2 for an example of a typical vertical farm with herbs growing on shelves. 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 2: Vertical farming with boxes of herbs stacked vertical, picture borrowed from (Livyon, 2018)

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 3.

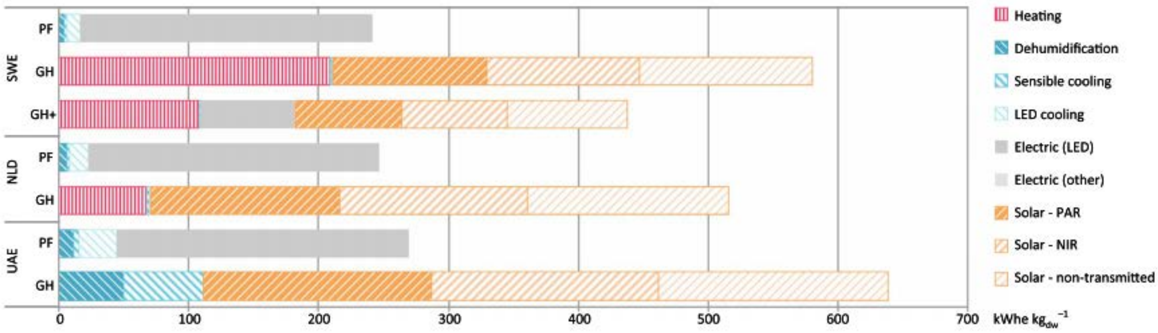

Figure 3: Energy usage for dry matter in lettuce production, using greenhouses versus vertical farms in Abu Dhabi (UAE), the Netherlands (NLD) and Sweden (SWE). Figure taken from (Graamans, et al., 2018).

As Kozai et al. (2016) argue, vertical farming cannot replace the conventional production systems for crops that we have today. Hamm (2015) 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 the amount of 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.) The 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/m^2 (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). Whether 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 LEDs. 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

Traditionally, plants are grown in soil. However, in recent years, several new organic materials have been introduced on the market during the past 50 years 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; coir, pine bark, wood fibre and green compost are commonly used materials. As resources become more and more scarce, renewable options that minimise waste could be considered a great opportunity as well as a challenge (ibid.)

Hydroponic systems are often without any growing media, but the case examined use a growing media on which the finished products were presented. At Node Farm the cress is sown on Hempflux. 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 Node Farm 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 per functional unit at Node Farm and which inputs are the most significant?
- What are the environmental impacts due to the production at Node Farm?
- What improvements could be made for greater energy efficiency and less greenhouse gas emissions during production at Node Farm?
- What are the benefits and drawbacks of 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 Node Farm, 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 from Node Farm.

A limitation in the study is the 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 employed in order to quantify the energy consumption (measured in equivalent MJ energy) and carbon footprint (measured in CO_2-eq) from the production at Node Farm. 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 4. 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 4, 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.

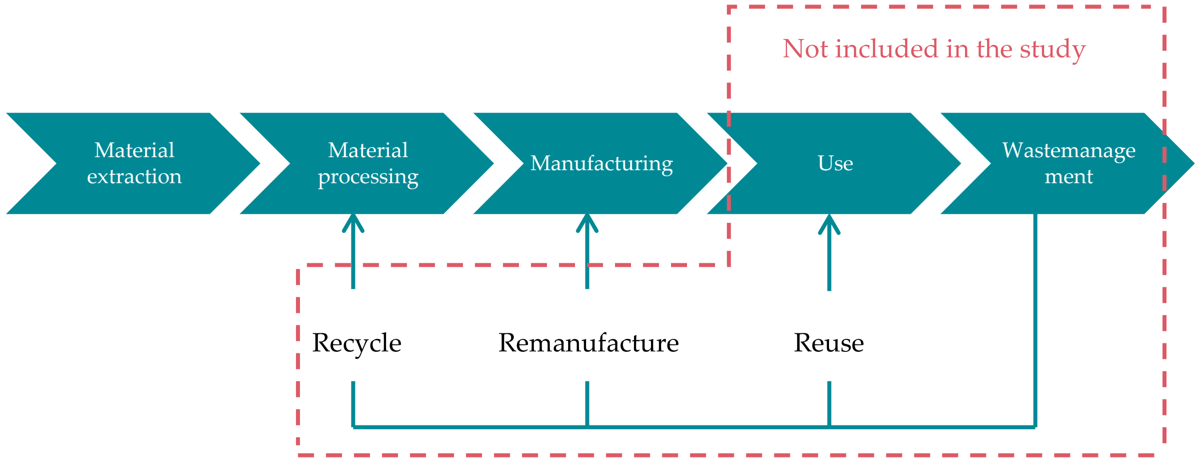

Figure 4: Different phases of an LCA from cradle-to-grave.

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. cress, as it is made available to the retail market.

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).

3.2 The production system

The scope for the production system at Node Farm was determined in collaboration with the company. Details on the production methods used for the assessment of the production of a pot of cress were provided by Node Farm. This included all inputs and outputs used to produce the finished product to the consumer, see Figure 5. To get to this stage, the steps in the cultivation such as the production of the seeds, hemp and packaging materials. At the company; electricity used for lighting, ventilation and heating was included.

The finished products consist of a block of Hempflux, being the growing medium, cress and a hard plastic wrapping. The production takes place in old refrigerated containers located in central Stockholm. During production, watering is done manually and for heating and lighting electricity is used at the location.

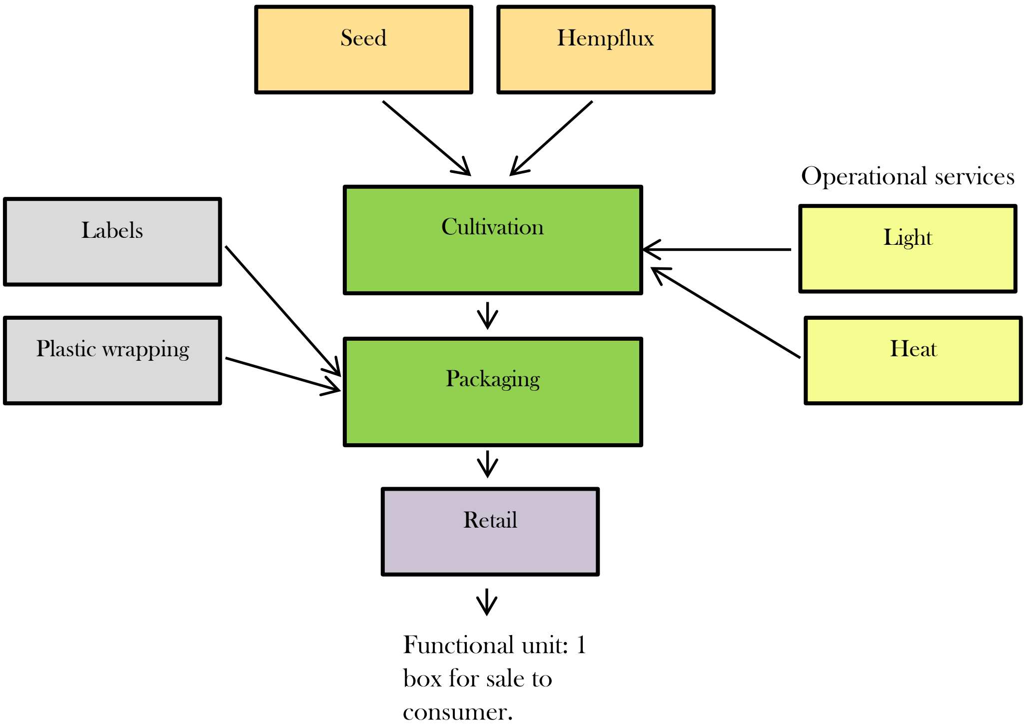

Figure 5: shows the scope for the production system at Node Farm

Node Farm aims to harvest every 10 days. With the weight of one plant being around 20g ,the yearly harvest is estimated to be 2 793 kg; with the total number of plants amounting to 139 650 pieces.

3.2.1 Direct energy

In the shipping container, electricity is used for heating and lighting. No ventilation is installed and watering is done by hand. The heat required is supplied by a cab heater and is estimated to be in use 6 hours per day, only during the wintertime. For lighting, 36 fluorescent are on 14 hours each day. The calculation of energy consumption was accomplished by multiplying the number of diodes with their effect (W) and the amount of hours they are in use annually. For calculations of CO_2-eq the Nordic mix for electricity was used.

3.2.2 Material inputs

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

The wrapping of the finished product will be a see-through plastic container. The height is assumed to be 3.5 cm, the width 6 cm and the length 10 cm. The plastic container is assumed to be made out of polyethylene terephthalate (PET) and have similar values for energy and CO_2-eq/kg as a plastic bottle. The total area was calculated and data for the plastic was collected in Ecoinvent (2016).

The cress in sown in Hempflax, a growing medium consisting of untreated hemp fibers (HempFlax, 2017). The hemp comes in pieces with the thickness of 1 cm, width 6 cm and length 10 cm. The plants are packed in the plastic box with the Hempflux. Hemp is an alternative to non-renewable resources and is mainly grown in central Asia (Haufe & Carus, 2011). The energy demand for producing hemp fibers is 5 GJ/t and the emissions of CO_2-eq vary depending on the product (Haufe & Carus, 2011). Interesting alternatives to hemp could be coconut fibers or peat.

3.2.3 Excluded

Labels are only used when the product is sold in supermarkets; the overall aim of Node Farm is to deliver to restaurants. Therefore, the impacts from labels were excluded in this study. Deliveries are also primarily conducted by bike, and thus no impacts are included. Human labour and the construction of the production site were also excluded in this study.

3.3 Scenarios Reviewed

3.3.1 Current Production System

Node Farm will produce approximately 2 800 kg of cress annually. The growing cycles are estimated to 10 days; i.e. harvest could be done every 10 days. The total amount of plants would be roughly 140 000, with an average weight of 20g each.

3.3.2 Baseline: Comparisons to Greenhouse and Open Field Cultivation

Comparisons were done with conventional production systems for herbs and leafy greens. Information on other systems was compiled from available research of vertical farming systems 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 1, see Appendix 1.

The background is compiled of data found in literature. Arbitrary productions of crops with similar character to those in the case study have been reviewed. As the functional unit is one pot of cress, similar crops were assumed to be salads of varying kinds and other 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, but mainly 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 larger in the United States, 0.3 kg dry matter per m^2 (Turini, et al., 2011; Iowa State University, 2017), in comparison to Sweden 0.1 kg dry matter per m^2 (Ögren, et al., 1992).

For year round production of basil, in greenhouses, the fresh herbs in pots could be harvested every 6 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 Result

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 6. At Node Farm, the yield was estimated to be roughly 11 kg per square meter of floor area. For further

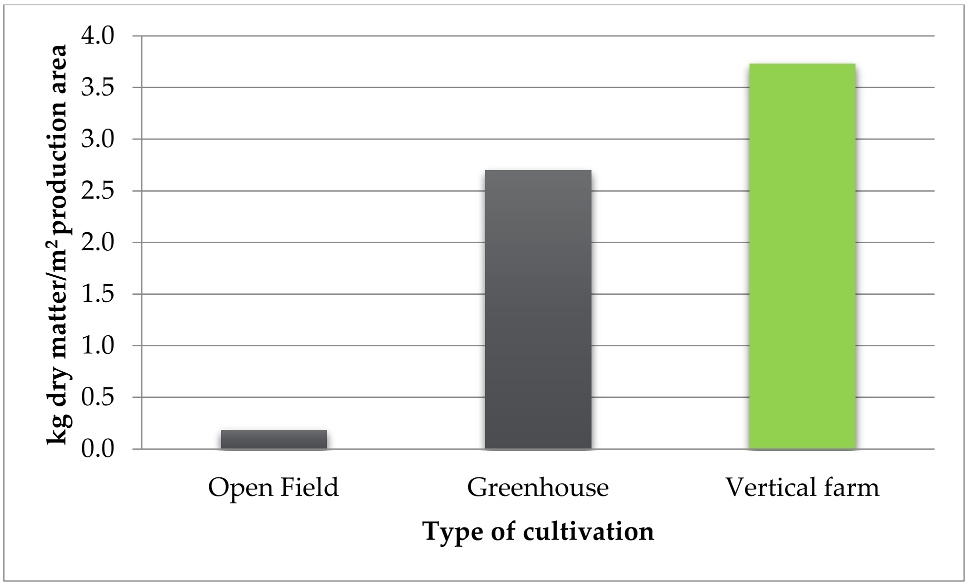

Figure 6: Kilograms dry matter of lettuce produced per square meter at an open field, in a greenhouse and a vertical farm, see Table 2 in Appendix 2.

4.2 Energy usage

The energy use for Node Farms operations was calculated for the entire production at the company Node Farm and for the production of all inputs. The calculations were made for one product without varieties. The energy consumption was estimated to amount to 0.37 MJ per functional unit or 3.4 GJ per square meter of area used.

Out of the different materials used for producing the cress at Node Farm the plastic container was the one with the highest energy consumption, see Figure 7. After that came the seeds standing for 10 % of the energy consumption. The growing material, Hempflax, heating and light were all below 5 % of the energy consumption.

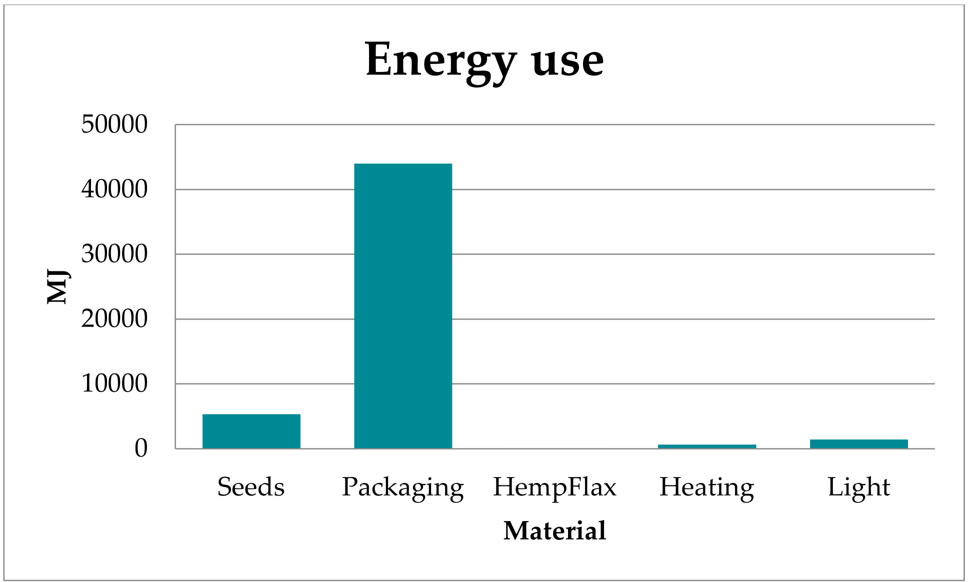

Figure 7: Annual energy use at Node Farm.

4.3 Carbon footprint

The carbon footprint was found to be 0.017 kg CO_2-eq per functional unit or 99 kg CO_2-eq per square meter. Also here the plastic container to pack the cress in had the greatest environmental impact amongst the material and services used. Lighting the production site had the second largest environmental impact, accounting for 22 % of the total amount of CO_2-eq emitted. Heating amounted to roughly 9 % of the total amount of CO_2-eq emissions.

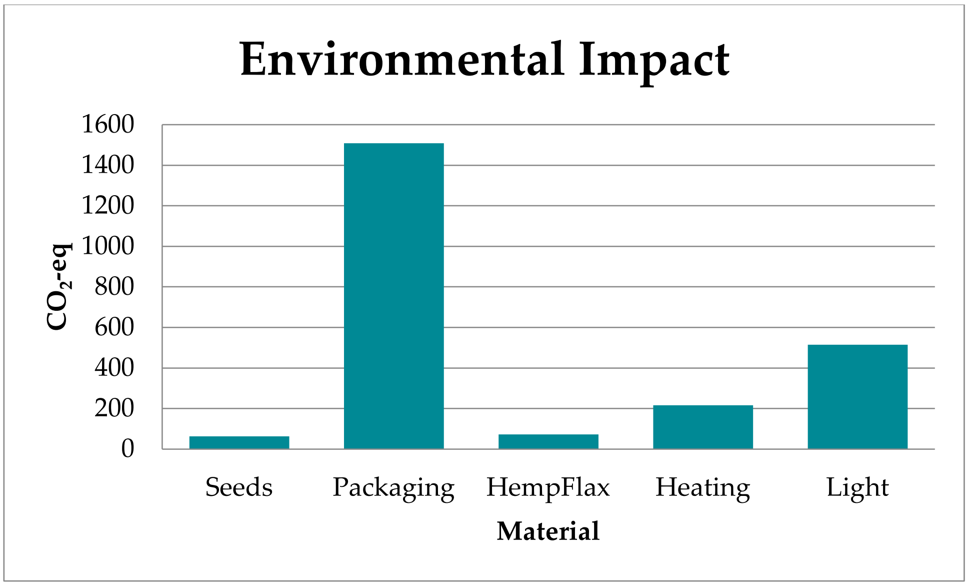

Figure 8: Annual GHG emissions at Node Farm (shown in kg CO2-eq)

4.3.1 Sensitivity to Data Choices

Packaging material

When comparing the environmental impacts of the plastic box that is ought to be used to that of cardboard, the GHG emissions was slightly increased, see

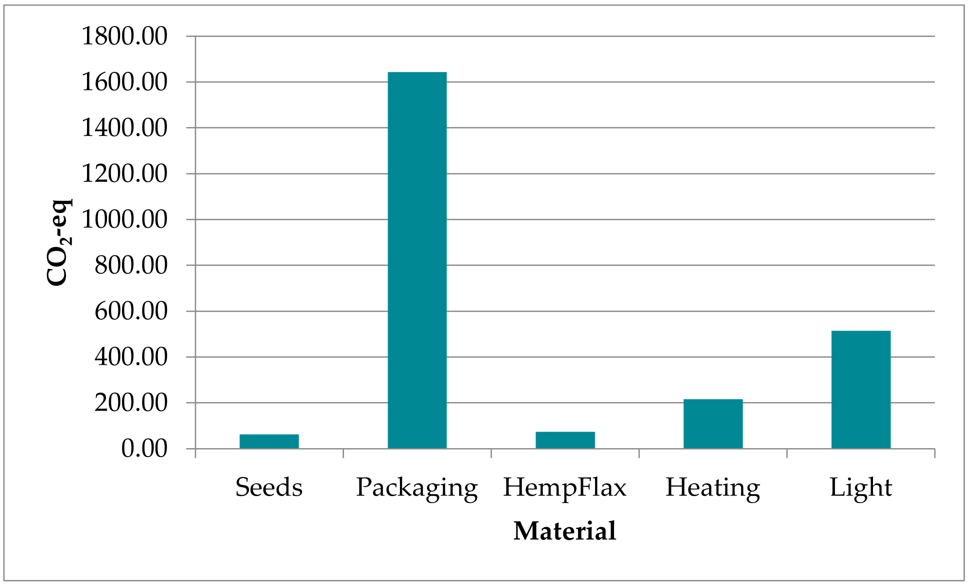

Figure 9: Annual GHG emissions at Node Farm (shown in kg CO2-eq) using a cardboard box for packaging.

The total GHG emissions from the plastic box would be roughly 1 510 kg CO_2-eq, and with the cardboard box, the same amount of packaging, would account for 1 640 kg CO_2-eq.

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 6 below reviews the sensitivity in overall emissions using the Swedish electricity mix versus the Nordic mix, in the two scenarios i.e. using a plastic box or a cardboard box.

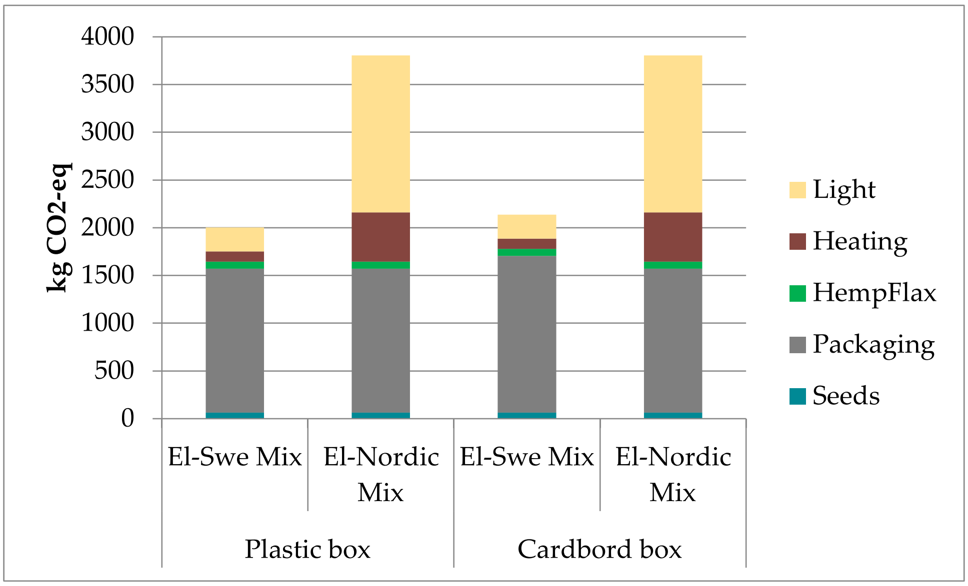

Figure 10: Sensitivity to Electricity Choice for overall GHG emissions

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 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 initial 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. Apart 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 in closed systems and hydroponic farming in order to reduce the need for 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 of Node Farm, material flows for the entire production were examined and contributed to the overall results.

Today, labelling 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 Improving the Energy Efficiency

Röös and Karlsson (2013) found reductions in many impact categories possible from Swedish foods, primarily due to the large share of renewable energy in greenhouses in Sweden. As Röös and Karlsson (2013) illustrate, Swedish consumers generally consume more greenhouse based vegetables annually than those produced from conventional farming practices. As shown in the origin of the different food products, many of these come from greenhouses abroad, thus putting a limit on the potential for eating seasonal and regional foods.

5.2.1 Packaging materials

Packaging of food enables the food to travel safely and still be wholesome at the time of consumption (Marsh & Bugusu, 2007). It protects the food from chemical, biological and physical influences. The choice of material must be balanced between food protection and i.e. energy use, environmental impacts and material costs. Food packaging is a large share of the municipal solid waste (ibid.).

When using plastic, polyethylene, for wrapping of the finished product this material accounts for 86 % of the total energy use at Node Farm. Other materials should be evaluated for reduction of the energy consumption. For instance, paper boxes or cardboard could reduce the energy use from roughly 4400 MJ annually, to 3400 MJ, but will still account for the larger share of energy use at the company. The paper box also accounted for a larger environmental impact and the plastic box.

According to Marsh & Bugusu (2007) the packaging material must be chosen and designed for each product so that it is suitable for the characteristics of the product. Common materials for food packaging are glass, aluminium, tinplate and different kinds of plastic, e.g. polyolefins, polyesters and polyvinylchloride. Plastics are often the used because they are mouldable, strong, and high in clarity and maintain the products quality. Meanwhilst, glass is brittle and heavy, and aluminium is relatively expensive and is limited to shape. However, there are several priorities to balance when choosing materials for a product and the primary purpose must be that of maintaining safety and the quality of the food (ibid). Environmental impacts could be decreased by ensuring closed material flows; i.e., preferably by reusing of material and making it easy for the consumers to sort the waste that is generated.

5.2.2 Reuse of shipping container

Reuse of shipping containers is one of the latest architectural trends (Aktan, 2017). They are fast to put in place and easy to move again. Shipping containers have the environmental advantages of preventing further use of construction materials. According to Aktan (2017) the reuse of one shipping container could save about 3 500 kg of steel. They are designed for rough weathers and are very durable, but they are not corrosion or rust-proof (ibid.).

5.3 Socio-Economic Aspects of Urban Vertical Farming and Food Security

There have been an increasing number of small-scale vertical farms, producing vegetables in urban areas due to the rising demand of 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 make vertical farming an attractive option.

Trade holds a great role in providing food security (Jambor & Babu, 2016). Those in favour of trade argue that the open markets make production move to locations where it is the most efficient. Furthermore, arguments in favour of trade are that incomes benefit from export, that the surplus reaches deficit areas and that liberalization of trade stimulates economic growth (ibid.). Many can benefit from the locally produced microgreens. The collaboration with retailers is already given, but also restaurants that could influence the production directly and get what they desire are a valuable collaboration both ways. They, as reliable costumers, and the supplier making specific products that might not be found on the market.

The Food and Agriculture Organization (FAO) was founded by the United Nations (UN) after the Second World War, with the goal to fight hunger globally (Farsund, et al., 2015). Food security was introduced as a term in 1974 with the focus on availability and price stability. FAO has since 1999 regularly reported on the state of food security globally (FAO, 2003). Food security should “ensure that all people at all times have both physical and economic access to the basic food that they need”. Food availability is the range of quality food at sufficient amount. There should be a satisfying amount of energy in the food supplied. The accessibility aims at the demand side having the resources required to purchase healthy nutritious food. Access is measured in economic and physical aspects, e.g. price and infrastructure. Utilization of food is divided into nutrition and that of quality, and hygiene. Nutritious well-being requires adequate diets, clean water, sanitation and healthcare. Finally, these terms, for supply and demand, should be valid at all times (ibid.). Today, urban centres are greatly reliant on industrial agriculture to feed the population. It is a vulnerability to rely solely on others, and governance could enhance the well-being of the society through reduction of risks (Adger, 2006). Agriculture in urban, or peri-urban areas, is a multifunctional phenomenon by providing a large variety of activities around environmental, social and economic agriculture (Zasada, 2011). To some extent, resilience lies in diversity, and resilient food supply is to come from a diversity of suppliers. 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). Urban farming projects can facilitate entrepreneurship in many ways i.e. skills/workforce training for agriculture services, business management and administration, produce to restaurants or other retailers, and education. It could also stimulate social non-profit entrepreneurship addressing the risks with food security or food deserts, being when an area in the developed countries doesn’t have access to healthy and safe food (ibid.).

Social farming originates from rural self-help networks but does today stand for activities that use agriculture to promote social services, e.g. rehabilitation, therapy, sheltered work or education (Di lacovo & O'Connor, 2009). It has the benefits of empowerment in terms of life quality, employment and social inclusion. Node Farm has the visions of working with education and integration and their operation would thereby be run as a social farm producing herbs in the urban area. Social farming with an educational direction are often divided into; education of primary school children, with the aim to expose them to farming, or towards offering children who are socially excluded a way back into the community (Di lacovo & O'Connor, 2009). The exclusion could be of different reasons, e.g. family issues, jurisdictional problems or learning difficulties. If the direction is more towards employment focus if often on people or groups that are marginalised on the labour market. Reviewing social farming projects around Europe financing is partly done by public bodies, e.g. from founded projects, subsidised contacts or tax reliefs, but sales of agricultural products and marketing is still needed (ibid.). Node Farm intends to run their operations with a profit. However, if they intend to enlarge their social work for the community, the operation might be able to grow using partly public means. In a study made in Berlin, the stakeholders interviewed agreed that urban agriculture should focus on the efficient use of local resources and energy, consider educational factors (Specht, et al., 2015). Furthermore, new market structures should be created to avoid drawbacks and profit from the full potential (ibid.).

6 Conclusion

Vertical farming has the benefits of being independent of 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 use are reduced. 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 of vertical farming when comparing to results found in the literature for conventional farming. Since there was 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, e.g., exemplifying the impacts associated with the limited use of pesticides and fertilizers. Vertical farming could also have an important role in social well-being and strengthen self-sufficiency, thus diminishing risks connected to a high reliance on the global food production system, and long delivery chains, and additionally create more resilient communities.

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Appendix 1

Table 1. Material flows at Node farm

Flow		Name	Refernce
Seeds		market for grass seed, organic, for sowing	(Ecoinvent, 2016)
Packaging	Plastic box	market for polyethylene terephthalate, granulate, bottle grade	(Ecoinvent, 2016)
	Cardboard box	market for carton board box production, with offset printing	(Ecoinvent, 2016)
HempFlax		Hemp fibres, Hemp and flax textile yarn	(EIHA, 2011), (van der Werf & Turunen, 2007)
Heating		Electricity, Nordic mix	(IVL, 2017)
Light		Electricity, Nordic mix	(IVL, 2017)

Appendix 2

Table 2. Comparison of yield, vertical farming versus conventional farming.

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	
Plant Factory			
		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	

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