GREEN-HOUSE-ING
A RESEARCH PAPER ABOUT THE INTEGRATION OF URBAN FARMING IN A CO-HOUSING COMPLEX

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ABSTRACT

Transportation of food, meat consumption, land use for agriculture, and food waste significantly impact our environment and climate change. This paper proposes a co-housing community that produces its own food on-site in Amsterdam. A plant-based diet is taken as the basis for crop selection. Different urban farming methods are described, and the most efficient ones are chosen for growing crops in the proposed building. The impact of this is analysed in terms of land use, CO_2 emissions, Water use, Energy demand and Architectural, Social and Educational impact. The proposal positively affects all of the mentioned subjects except for energy use. The use of energy is increased by 7%. That can be compensated by sustainably harvesting energy. The proposed community can have a positive environmental effect and could become a new main housing typology.

Keywords: *Self-sustaining community, ecological footprint, urban farming, vertical farming, Water-energy-food nexus*

1. INTRODUCTION

1.1. Glossary

The World Wildlife Foundation defines the 'ecological footprint' mentioned in this research plan as "the impact of human activities measured in the area of biologically productive land and water required to produce the goods consumed and assimilate the wastes generated. More simply, it is the amount of the environment necessary to produce the goods and services necessary to support a particular lifestyle" (*Ecological Footprint*, n.d.).

Our 'foodprint' is a term coined by the similarly named organisation used in the same way as 'ecological footprint', but not on our complete lifestyle and consumer behaviour. It is specifically about "the result of everything it takes to get your food from the farm to your plate. Many of those processes are invisible to consumers" (*What Is a FoodPrint?*, n.d.). This paper will make a comparison between farm to plate and Plant Factory on-site to plate.

Traditional agriculture in this paper is based on the Merriam-Webster definition of the word 'agriculture', which states: "the science, art, or practice of cultivating the soil, producing crops, and raising livestock and in varying degrees the preparation and marketing of the resulting products" (*Definition of Agriculture*, n.d.).

According to the Encyclopaedia Britannica, the term 'Horticulture' is mainly used for the intensive commercial production of fruits, vegetables, and ornamental plants(*Horticulture | Definition, Types, Techniques, & Uses | Britannica*, n.d.). The Merriam Webster Dictionary states that Horticulture is "the science and art of growing fruits, vegetables, flowers, or ornamental plants" (*Definition of Horticulture*, n.d.).

In short, the difference between traditional agriculture and horticulture is that agriculture focusses on everything edible, for both humans and livestock, and Horticulture focuses on plant-based products. This means there is some overlap in both definitions. The overlap: plant-based edible crops will be focussed on in this paper.

1.2. Problem Statement

Globally, we are heading towards a food crisis. According to a study done in 2013, global yields are not increasing at a fast enough rate to feed the projected world population of 2050 (Ray et al., 2013; Tauger, 2010). "Farms managed about 45% of the total land area of the EU-27 in 2016" (Cook, n.d.). In the Netherlands, the percentage of Agricultural land is even 54%(CBS, 2020) Increasing the arable farmland in the EU would cause significant biodiversity and species loss.(Jeanneret et al., 2021) Besides this, on average, Dutch people in 2017 used five times the ecological capacity their country holds. This means we are four 'the Netherlands' short (*Footprint Calculator - Measure Your Impact - Global Footprint Network*, n.d.). Food production and consumption make up 26% of global greenhouse gas emissions. Thirty-one percent of these food-related emissions are from livestock and fisheries. That even excludes the emissions from crops for animal feed and land use for cattle, which make up another 22%. Transportation and the supply chain are also significant problems within the food industry and make up 18% of agricultural greenhouse gas emissions. Lastly, there is the problem of emissions caused by food waste. They make up 6% of global greenhouse gas emissions. Over half of the food waste happens during transport.(Ritchie & Roser, 2020; US EPA, 2016)

For all of these reasons, it is essential to reconsider our food consumption, production, and transportation practices (Barbier et al., 2019). To reduce the footprint of our food, we need to shorten or eliminate the supply chain, rethink our omnivorous diet, use arable land in a much more efficient way to lower biodiversity loss, and become more conscious about the value of food.

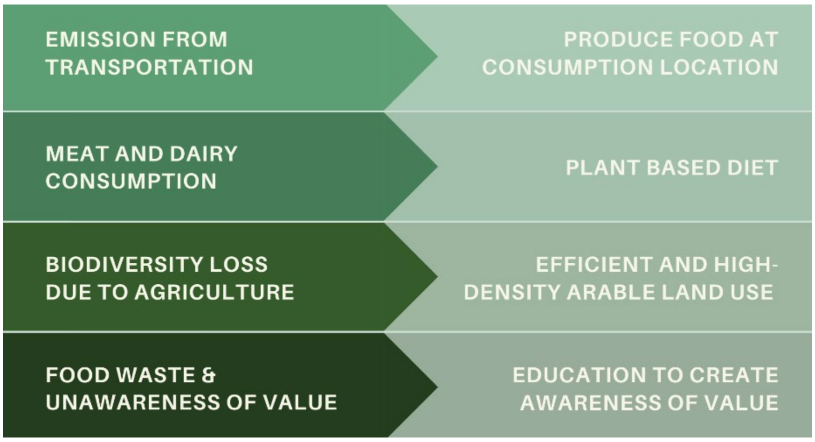

Figure 1: Problem statement and suggested solutions, Own image

1.3. Objective

This thematic research paper aims to find how a community can lower their collective ecological footprint. The proposal is to integrate agriculture into the urban environment. This will eliminate the need for transportation or import of food, and it will reduce the land used for agriculture, which can be returned to nature. The availability of fresh Plant-based food could also promote a (partial) plant-based diet. Bringing people closer to the food production and the growth process may also raise more awareness about food value. In order to figure out how this can be done, this paper will focus on the following main thematic research question: What types of urban farming techniques can provide a community of 200 people with enough plant-based food to be self-sustainable? In order to answer this question, a couple of sub-questions need to be answered:

- What diet and how much food does a community of 200 people need to sustain themselves?
- What types of urban farming techniques can be used, and how do these technologies work?
- Which urban farming techniques best suit the selected crops.
- What are the architectural implications of these crops produced with their selected urban farming technique?
- What is the water use and the water use reduction of growing the crops on-site?
- What is the reduction of space use and land use of growing crops on-site?
- What are the CO_2 emission reductions expected by growing the crops on-site?

The conclusion of this paper will provide an overview of crops that can be grown on-site in a co-housing community in Amsterdam, and it will reflect on the environmental and architectural impact of growing the crops on-site.

1.4. Method

As conceptualising a community that can sustain themselves in food is quite an extensive topic, certain limitations need to be set. The first sub-question is about the chosen diet and preliminary crop selection. This chapter will frame and limit this research to plant-based urban agriculture. In the second chapter, current and upcoming urban farming techniques are described, and pro/con lists provide an overview of yield efficiency, water use and electricity demand. Also, an overview of the architectural implications of the urban farming techniques is provided. Next, the preliminary selection of crops will be linked to the most suitable urban farming technique. When this is done, comparisons between traditional farming methods and the selected urban farming technique will be made. This is done by comparing water use, yield efficiency and energy use for conventional farming and the chosen urban farming technique. Data for this comparison will be retrieved from literary sources and empirical research. The methodology is also explained in Figure 2.

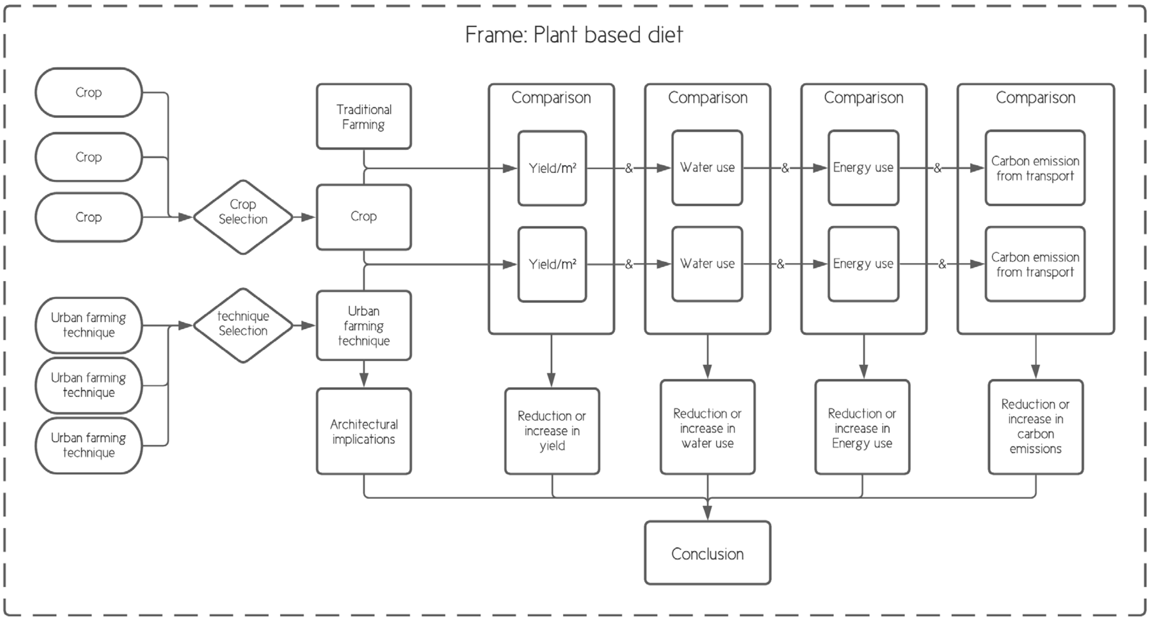

Figure 2: Thematic research method diagram. Own image

All of the data will be compared and calculated using a method developed during the research. This calculator also functions as a tool for future designers to calculate the food, water, energy, and space requirements. The sheet could be adjusted to the needs and wishes of the designer and client, and thus, a new design proposal can be made.

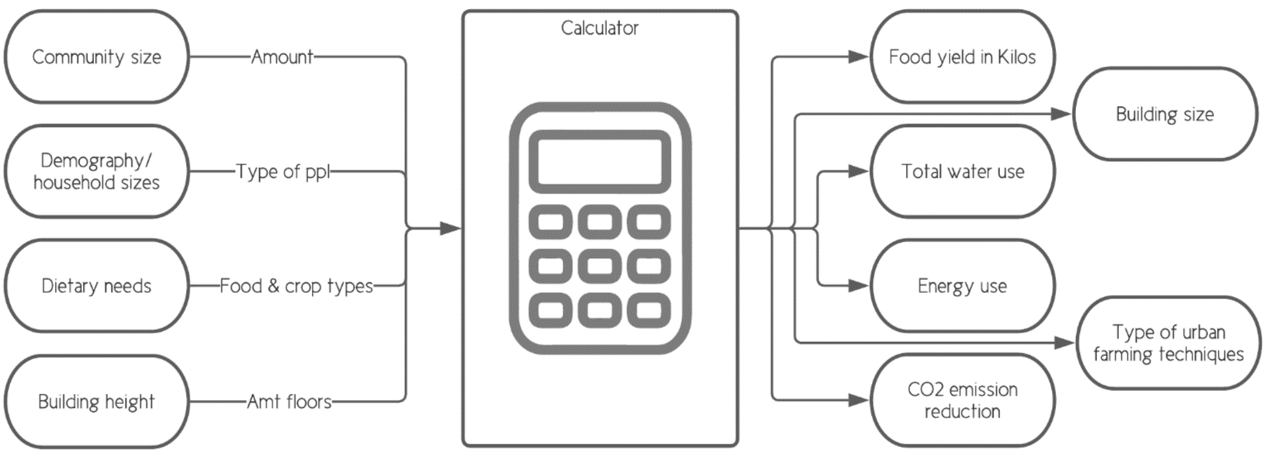

Figure 3: Community Resource Use Calculator (own image)

2. DIETARY FRAMEWORK AND CROP CHOICE

The ‘Schijf for life’ by Lobke Faasen argues that a plant-based diet can be a healthy alternative to an omnivorous diet. It provides enough nutrients, and it will also protect against illnesses. It lowers the risk of heart and artery illnesses and Diabetes type 2.(Faasen et al., 2021)

Besides the fact that this diet is beneficial for one's health, it also has a lower ecological impact. The water footprint of meat consumption, for example, is considerably higher (Ercin et al., 2012; Fabrique [merken, n.d.; Gerbens-Leenes et al., 2013; *The Water Footprint of Food*, n.d.; Vanham, Hoekstra, et al., 2013; Vanham, Mekonnen, et al., 2013) According to Greenpeace, "If everyone ate plant-based, we would need 75% less farmland than we use today. That is an area equivalent to the US, China, Europe and Australia combined" (*7 Reasons Why Meat Is Bad for the Environment*, 2020) Using less farmland is beneficial for biodiversity (Jeanneret et al., 2021). We could start giving land back to forests and other natural habitats.

For each food group, The ‘Schijf for life’ recommends a certain amount to be consumed per day to maintain a healthy diet(Faasen et al., 2021). In Figure 3, the community size is set at 200 people. The recommendation of the Schijf for Life is also multiplied by a margin factor that accounts for food loss or overconsumption. This table is the starting point of the toolkit from which data about cultivation surface, water need and energy demand will flow.

The selected food types make up a sufficient diet but do not contain any extras, sweets or indulgencies. An average person consumes products like sugar, alcohol, coffee and herbs. These can bring flavour and variety to a persons' life.

As becomes visible from Table 1, the food demand in kilos for a community of 200 in a whole year is quite significant. A hundred tonnes of food are needed. When these crops are produced using traditional farming methods, a lot of water and land is required, and the CO_2 emissions from transportation are very high. Most of the food needed are fruits, vegetables, legumes and root vegetables. As these four types of food make up the highest demand, they could bring about the most considerable reduction in CO_2 emissions, land use, and water demand.

Food type:	One Person Per day	Community per Year
	In Kilos	In Kilos
Fruits	0,30	24.090,00
Leafy greens	0,15	12.045,00
Other vegetables	0,15	12.045,00
seaweed	0,00	200,75
whole grain products	0,09	7.227,00
root vegetables	0,10	8.030,00
legumes	0,16	12.848,00
nuts	0,025	2.007,50
flax/chia seeds	0,01	803,00
Total	0,99	79.296,25

Table 1: Food demand based on Schijf for Life

3. FARMING TECHNIQUES AND BUILT FORMS

In order to make a well-argued selection of the methods to use for the different crops, these methods need to be analysed. The technique will be elaborated on, and results will be compared. The urban farming methods described in this chapter are all believed to be more efficient, more technical, or they are based on the principle of giving back to nature

3.1. Agricultural Spatial typologies and built forms

A couple of different typologies can be identified in terms of spatial configuration in new agricultural techniques. In Figure 3, the different spatial layouts can be seen. The typologies are Traditional open-field farming, Glasshouse farming and Plant Factory.

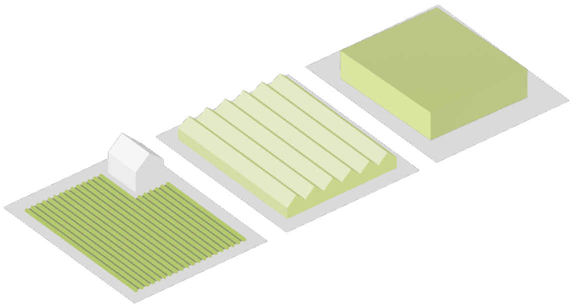

Figure 4: Spatial Typologies of agriculture. Open field, Glasshouse, Plant Factory. (Own image)

3.1.1. Open field agriculture:

Traditionally, crops have almost always been grown and produced in full soil. Since the transition from hunter-gatherers to farmers, soil quality has been most influential. However, the very first farmers made use of only natural resources. They mainly relied on rainwater, had low-tech ploughing, sowing and tilling devices, and for gaining more efficiency, they used animals to perform the heavy operations. In traditional open-field agriculture, we use enormous machines for irrigation, ploughing, tilling, sowing, harvesting and spraying. All of this costs much energy, and most of all, many greenhouse gasses are emitted. Besides this, soil depletion by monocropping and intensive agriculture reduces biodiversity and future crops' quality. New, or in fact, old techniques such as permaculture and pixel cropping provide some relief for the quality of the soil and offer more space for biodiversity. Permaculture is a term coined by Bill Mollison, who described it as follows: "The conscious design and maintenance of agriculturally productive systems which have the diversity, stability, and resilience of natural ecosystems. It is the harmonious integration of the landscape with people providing their food, energy, shelter and other material and non-material needs in a sustainable way." ('Permaculture', 2016) Permaculture is an older technique that has been reinvented or rediscovered as of late by 'sustainable' farmers (*What Is Permaculture ?*, n.d.). The Big Food Redesign is a project that promotes the practices described by Permaculture(*The Big Food Redesign Report | Shared by Food*, n.d.). "Pixel cropping - is a cropping system design and management method that mobilises high-resolution diversity in arable fields." (*Pixel Cropping*, 2020). Similarly, pixel cropping is also a technique in which a symbiosis of different crops is used to increase yield and resource-use efficiency and reduce pests and the use of pest- and herbicides. This, too, is an upcoming farming technique. Both techniques are varieties of the open field spatial typology.

3.1.2. Glasshouse farming

Glasshouse farming is a technique that has been implemented widely in the Netherlands and other countries. By semi-controlling the environment on certain aspects, the yield can be increased (Romero-Gámez et al., 2009), and an almost year-round harvest can be expected (Vijverberg et al., n.d.). Because the Glasshouse separates the Plant growing environment from external factors like heavy weather, pests, drought and diseases, a much more consistent and qualitative harvest is produced. Glasshouses use natural daylight a lot, and sometimes extra (growing) lights are added. Even though advanced food production technologies positively impact the environment, their built forms might still have a negative footprint. Glasshouse structures are often made of steel and glass, and even concrete is used for the foundation. See Figure 4(TheCivilEngineer.org, n.d.). Building a glasshouse can be justified if the structure, for example, is made of re-used elements ánd the yield should at least be 15% higher (Bartzas et al., 2015).

Figure 6: Glasshouse in the Netherlands

3.1.3. Plant factories

Unlike glasshouses, plant factories are completely climate-controlled buildings with little to no connection with the outside world. The plant factory has all the same benefits as the Glasshouse and more (Kacira & Zhang, 2020; *Plant Factories versus Greenhouses_ Comparison of Resource Use Efficiency | Elsevier Enhanced Reader*, n.d.). Where the Glasshouse sometimes loses heat, water and light through the glass or open windows, the plant factory loses nothing or an insignificant amount (Kozai & Niu, 2016). Plant factories make very efficient use of space by implementing vertical farming. See Figure 5 ('Plant factories in Japan zijn aan sterke opmars bezig', 2018). Most plant factories use cutting edge technologies and do lots of research to ensure continual crop quality improvement (*Science + Technology*, n.d.). Some good examples of Plant factories include Sananbio, IFarm, Iron Ox, IGS (Intelligent Growth Solutions), EIT Food, Urban Crop Solutions and CubicFarms.

Figure 5: Plant factory in Japan

3.1.4. Vertical farming

According to the University of Wageningen, Vertical farming can be a solution for empty real estate and unsustainable food production. Vertical farming is described as stacking (usually hydroponic) trays on a single floor(*Vertical Farms Vs Greenhouses – The First Consideration*, n.d.). By producing food in empty buildings in the city centre, we can provide city residents with healthy local food. In the University of Wageningen definition, vertical farms make no use of pesticides, there are no nutrient emissions, and the water use per kilo of vegetables can be dramatically reduced. Land use for one crop can be reduced 10-20 times. Energy consumption is higher than in glasshouses, but the University of Wageningen believes that researchers can develop systems where energy consumption will be reduced over time(*Vertical Farming*, 2017). Leo Marcelis, A professor of Horticulture and Vertical Farming, says: in a high-rise building - on a surface area about the size of a soccer field - you can grow enough vegetables for 100.000 people who each eat 250 grams of vegetables a day." (Marcelis, 2020)

3.2. Growing medium

3.2.1. In Soil

All of the above mentioned spatial typologies and built forms can use the in-soil growth of crops. However, soil often drains resources. It retains a lot of the water while the crop cannot access it all. Similarly, it sucks up the nutrients that are then not used optimally. Growing in soil requires much space as the roots of a plant need space to take in enough water and nutrients.

3.2.2. Hydroponics

The Merriam-Webster dictionary defines Hydroponics as: "The growing of plants in nutrient solutions with or without an inert medium (such as soil) to provide mechanical support." (*Definition of Hydroponics*, n.d.) See an example of a standard hydroponics system in Figure 6(*Hydroponic: Various Hydroponics Systems*, n.d.).

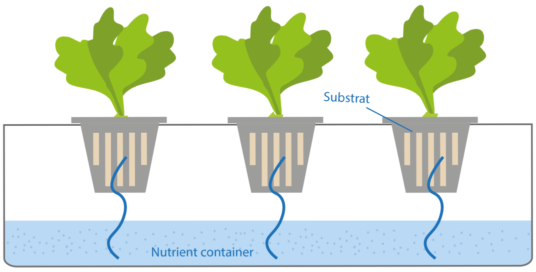

Figure 8: Wick-watering Hydroponics system.

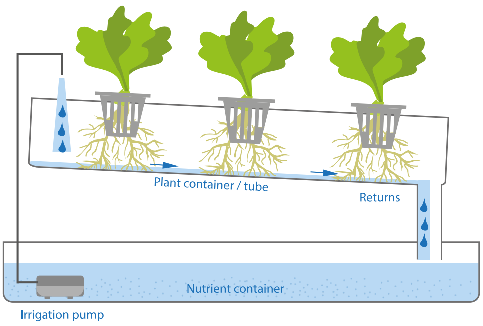

Figure 7: Variation on Hydroponics: NFT: Nutrient Film Technique.

There are various hydroponics systems that all work slightly different. The first example is the most basic one. Here one can see plants dangling above a nutrient solution. The roots will grow towards the solution and absorb the nutrients. A more efficient variation is the Nutrient Film Technique. The solution is constantly pumped around for better aeration (Son et al., 2016). It also prevents nutrients from accumulating, suffocating the roots. See Figure 7(*Hydroponic: Various Hydroponics Systems*, n.d.).

Other hydroponic systems are, for example, Aeroponics and Aquaponics. Respectively, these work with a misting system and a water tank with fish to provide nutrients for the plants. See Figure 8 and Figure 9(*Hydroponic: Various Hydroponics Systems*, n.d.). According to Edengreen, a vertical farming technologies producer, Hydroponics offer 240 times higher yield than traditional farming. They also state that water use is reduced by 98% (*Hydroponics vs. Traditional Farming*, n.d.). According to Seedle Farms, a producer of hydroponically grown vegetables, water use is only reduced by 85%. Seedle Farms note that hydroponically grown vegetables grow twice as fast as when vegetables are grown in soil. Hydroponics also eliminate the need for herbicides, pesticides and insecticides(*Why*

Hydroponics – Seedle Farms, n.d.). A study from 2015 shows that lettuce grown in a hydroponic system on average has a yield that is 11 times higher than conventional farming(Lages Barbosa et al., 2015). According to Pure Greens, a Container farms producer, Basil plants can be placed 5,6 times closer together in their hydroponic farms(*Vertical Farm Yields Stack Up to the Competition*, n.d.). This is mainly because the root systems do not need to spread out as far in the water as they do in soil. Many sources describe yield and energy use increase and water use reduction(*How Hydroponics Works*, 2008). These factors are put together in a scheme, and the average outcome of these sources is used to calculate water use for the selected crops in those respective systems.

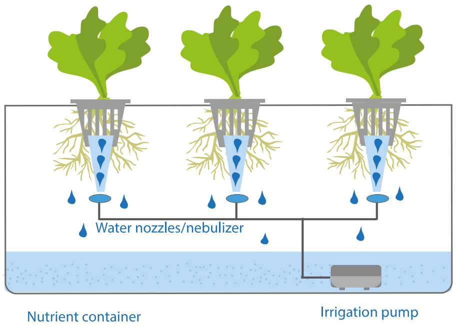

Figure 9: Variation on Hydroponics: Aeroponics.

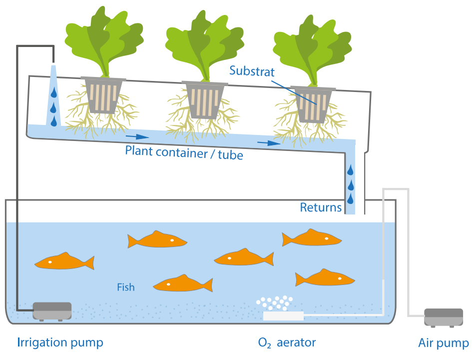

Figure 10: Variation on Hydroponics: Aquaponics.

3.3. Techniques in an oversight

Often, sources mention the use of Hydroponics in a vertically stacked plant factory or a combination of two of these three. However, an attempt is made at separating calculation factors that show how efficient these techniques work compared to traditional, open-field agriculture. The averages shown in Table 1 reflect how the outcomes of all the crops were calculated. Overall, the more 'high-tech' the growing method becomes, the higher the yield and electricity use. The electricity use for a plant factory is not at all that much higher than that for traditional agriculture. This might seem strange but the energy use described here is per kilo produced food. The Plant Factory uses a lot of energy per square meter but because it is very space use efficient, the energy use per kilo food is relatively low. Land (or space) use decreased, as did water use. Fertilizer and pesticide use are also described to be lower in more high-tech methods but these were not taken into the calculations.

Not vertically stacked

	Full Soil			Hydroponics	
	Traditional	Glasshouse	Plant Factory	Glasshouse	Plant Factory
Yield	1	2,00	3,00	11,20	16,80
Land use	1	0,50	0,33	0,09	0,06
Water Use	1	0,36	0,03	0,04	0,00
Electricity use	1	1,30	1,06	Does not apply	Does not apply

Table 2: Calculation factors based on multiple sources (own calculations)

4. Impact of Growing Food on Site

In order to calculate the impact of growing food on-site, a selection of the growing methods per crop has to be made. After extensive research, three choices for each crop were made based on findings in academic articles and websites on farming, urban farming or the specific techniques:

- Glasshouse or Plant factory
- In soil or Hydroponics
- Vertically stacked trays or not

For example, It was pretty clear that all leafy greens and most other vegetables are suitable for vertical stacking and Hydroponics. That was not clear for apples. As they grow on trees, it would be less efficient to stack them or even keep them in a closed environment such as a plant factory. For references on how the choices were made, look at the appendixes on pages 30-34. From all the data gathered on food yields, land use, water use, energy use and CO_2 emissions, together with the selected growing methods, it is calculated how efficient the growing system is for the selected crops in their respective growing practice.

4.1. Housing resource use

In order to provide a detailed image of the water, energy and space needs of the proposed community, the demography has also been defined. The different household sizes are based on the Dutch averages seen in Table 17 (*Bevolking | Cijfers & Context | Huishoudens | Volksgezondheidenzorg.Info*, n.d.; *StatLine - Prognose bevolking; kerncijfers, 2021-2070*, n.d.). For simplicity, it is assumed that in the proposed community, each person gets a 'module' of 25 square meters. That means, in this case, the whole community is about 5.000m2 for residences. That is Net floor surface, so it can be expected that the gross floor surface is about 7.500m2. On average, a one-person household uses 52m3 of water per year. On average, per added person to the household, 47m3 water is added. In total, the proposed community, therefore, uses almost 10.000m3 of water for personal use(*Waternet - Gemiddeld waterverbruik*, n.d.). The estimated energy use is set at 5700kWh for 1-person households, 10500kWh for three-person families, and 13000kWh for five-person families. The increase in energy use is not linear ('Gemiddeld stroomverbruik gasloze woning', 2020). The total energy use of the proposed community is about 810.000kWh per year. See all of these numbers in the Appendix Housing on page 29.

4.2. Land use and yield

More efficient methods like Hydroponics, vertical farming and Plant factories have an enormous potential for saving land. That, in turn, can give back precious land to nature. Looking at land use of single methods, all crops grown in glasshouses would require less than 40% of the space open field farming(see appendixes on page 20). A hydroponic Plant Factory would require less than 5% of the land needed for open-field agriculture. This number is even lower when the hydroponic trays are stacked. These land-use reductions are visualised in Figure 10. The land use of conventionally grown food for a community of 200 people (that already eat Plant-based) is almost 13 hectares, which is about 20 soccer fields. Using the selected growing methods, this number is reduced to a mere 2,4 hectares. This number is still relatively high. Most of the land is used by crops that are simply not suitable for vertical farming or plant factories. The apples, mandarins and pistachio trees would still have to be grown in open field agriculture and therefore have the most considerable impact on land use with 1,97 hectares (82%). The Plant factory and Glasshouse respectively take up 0,24 (10%) and 0,18(8%) hectares of land for 200 people. Perhaps for future

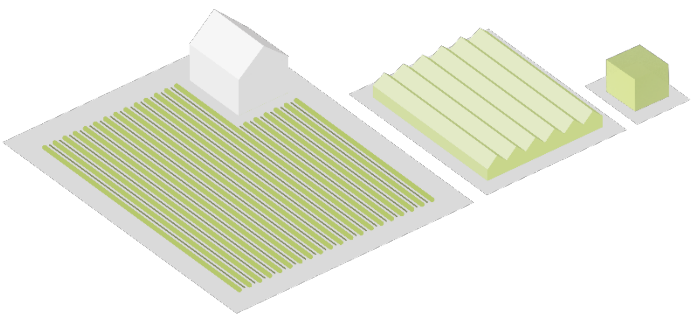

Figure 11: Spatial Typologies and size ratios of agriculture. Open field (100%), Glasshouse (39%), Plant Factory (4,7%). (Own image)

research, picking crops (fruits and nuts) that are more suitable for growing vertically, hydroponically or in a plant factory would seriously reduce the land-use further. For more details on land use and yield results, see the appendix on pages 20-23.

4.3. Water use

Similarly to land use, water use can be drastically reduced by growing crops in more efficient methods. As the world is also heading toward a global water crisis, it is essential to design the future of agriculture so that we reduce stress on freshwater. The water use is reduced by 64% (from 83.300m^3 to 29.200m^3) compared to traditionally farmed crops using selected techniques to grow certain crops. 74% of this water use is still for open-field agriculture, for which only apples, mandarins and pistachios were selected. Therefore, these three crops could be replaced for crops that can be grown hydroponically. That would significantly reduce the total water need of the community. Adding the water needed for housing to the complete water need results in a demand of about 39.100m^3. 56% of the required water can be harvested using the roof and water surface to harvest rainwater. Within current regulations in the Netherlands, purified rainwater from a greywater system cannot yet be used as drinking water, but it can be used to flush the toilet and irrigate crops.

4.4. Energy demand

The different techniques used to grow crops in the proposed community demand more energy than traditional agriculture. For the proposed crops grown on a conventional farm, about 100.000 kWh is needed to provide food for 200 people for a year. In the proposed community using the different techniques, about 104.000 kWh is required. That is a bit of an increase: about 7% more. However, if the energy needed for growing the food on-site can be sustainably sourced or generated, this can be justified. Using solar panels with an energy production capacity of 250kWh per year(*Zonnepanelen Amsterdam*, n.d.), the community would need 3.600 solar panels or 6.000m^2. Solar panels might not be the best solution, however. They take up a lot of roof space that can be used for glasshouses, and the waste of old and out-of-use solar panels is thrown in the shredder and used for concrete filling (*80 miljoen zonnepanelen in 2024 zijn een' tikkende milieutijdbom'*, n.d.). Using re-used solar panels could be a sustainable and circular alternative as it gives the panel a new life. However, they have a lower capacity for generating energy and require more maintenance. Windmills can also be an alternative. They would need to be placed high up and would need to be large enough to deliver this much power (*Hoeveel energie levert een windmolen op?*, n.d.).

4.5. CO_2 emissions

For this section, the calculations were only for CO_2 emissions from food transport. Currently, we import much food out of season. It was determined what percentage of the consumed crops on average was imported(van der Knijff et al., 2011). Besides this, for each crop, a central origin point was chosen for the imported good(Zeven & Wet, 1982) and Dutch grown part(*Akkerbouwgewassen; productie naar regio*, n.d.). The travel distance was determined(*Amsterdam - Shanghai Distance Is 10585 NM - SeaRoutes*, n.d.), and for the imported goods, this was multiplied by the CO_2 emissions per kilometre and kilogram of food. Transportation means from far away are primarily by boat. When the origin point of the imported good was somewhere east of Europe, emissions for a train were used. The goods that came from the Netherlands itself were transported by truck. Almost 16.000.000 kilos of CO_2 emissions from transports are saved by producing food for 200 people on site. The crops that had the highest impact on lowering the community's carbon footprint were mandarins, wheat, and malt. That is very plausible because of how high the demand for these foods is. When the crops' emissions are viewed per kilo of that crop, Mandarins, wheat and coffee beans came out the highest in that order. That means it would be essential to start producing these crops closer to the location of consumption.

4.6. Architectural Impact

The different building types that need to be used to produce food together make up a massive portion of the whole building. In the current settings, the plant factory will be almost 2.400m^2, and it is a closed box. That could be positioned in the centre of the building around which most housing and social functions could be placed. A portion of the plant factory can also be placed on top of the building, where it would take away less of the space on the ground floor. The ground floor can then be used for social and educational purposes. The amount of Glasshouse needed to sustain the community is about 1.900m^2 large. This amount of space could be placed on a roof if the building size allows it. If it would not fit, the remaining part could be placed in the public space. For some crops (now selected for plant factories), it would also have been good to grow them in a glasshouse. Crops like potatoes and onions need almost the whole year to develop and rely on a cold period to jumpstart their growth in spring. To simulate this year-round climate in a plant factory might seem futile. However, the yield increase a plant factory brings makes it a viable and effective alternative.

Some of the crops like the trees and large shrubs or vines are now selected to grow in open fields as they grow too large to be stacked, and the yield increase does not outweigh the energy need increase for that crop. These plants, however, can also be used as urban greenery. They can be put on a public picking farm. Here they would not function as crops that provide the community with the essentials but mainly as attractors for the rest of the neighbourhood. They can be cared for collectively.

4.7. Societal and educational impact

Besides the described environmental impacts, urban agriculture can also substantially positively impact society and social structures within. According to a study from 2021, socialisation motivations for urban farming among urban gardeners predict a higher wellbeing impact(Kirby et al., 2021). A couple of urban farms in the US have hired community members with developmental disabilities or different emotional and behavioural needs. They provide them with a place to spend their days, learn, grow personally and make money while under some supervision. Besides this, they are credited with feeding themselves and a part of the community with fresh and healthy food. Some urban farms also engage teenagers or children in farming activities as a part of their education. They learn "hands-on about nutrition, water resource management, efficient land use, climate change, biodiversity, conservation, contamination, pollution, waste management, and sustainable development." (*8 Urban Farms Creating Positive Social Impact*, n.d.) People are usually unaware that all of these topics affect our environment and society daily. It would be hugely beneficial for a community (and the whole world) to become much more aware of the need to change our practices around food production, consumption and waste.

5. Conclusion

The proposal for the community is to grow all necessary food on-site. That would mean that all the CO_2 emitted by transportation will now no longer be emitted. In conclusion: A community of 200 people can lower their carbon emissions by 15,85 million kilos if they would produce the food on-site. If one person sitting on a flight from Amsterdam to New York and back emits 2,11 tonnes of CO_2, this community could save 7.500 of these one-person round trips worth of CO_2. Water usage of the whole community can be reduced by 70.000 Litres compared to traditional farming(77%), and only 7% more energy is required for the Urban Farm. The water needed (20.000L) can be harvested with a surface of 22.000m^2. Besides this, agricultural land use can be reduced by 76% (from 100.000m^2 to 24.000m^2). That means that this community could potentially give back 7,5 hectares of agricultural land worldwide to transform back to natural reserves and habitats. This number could be even higher if the three crops produced 'outside' would be replaced by crops suitable for production in a Plant Factory. The land use could then be reduced to about 5 to 6 thousand square meters. These impacts were calculated from the base point that the diet was already plant-based. As most people around the world do not follow a plant-based diet, the actual effects of this community could be much more significant provided that all habitants follow the plant-based diet.

In conclusion, growing food on-site in Amsterdam can substantially positively impact climate change, soil depletion, and biodiversity. Besides this, it has an immense potential to change neighbourhood dynamics and the value of food experienced through communities.

6. Discussion

Of course, a few nuances in this proposal were not addressed. The packaging, sales and production emissions were not considered, and neither were other greenhouse gasses. These also have a significant impact on the environment. Energy used in the production of the crops was very superficially addressed and can become much more nuanced if more time is spent on it. It would be advised to conduct more research on the selected crops, expand the crop selection and optimise for the best suitable crops for production in the Plant Factory.

7. ARCHITECTURAL PROPOSAL

After proving that growing food within a housing community can have a substantial positive environmental and social impact, It is essential to give an overview of the final proposed community and a program of requirements.

This proposal is made on the presumption that the three crops that had the most significant impact on the earlier proposed diet are eliminated from the composition. Instead, the apples and mandarins are replaced by melons, and Peanuts replace the pistachios. Eventually, this means that the number of Peanuts produced in the proposed community will be doubled. These crops can be grown hydroponically, stacked and in a Plant Factory. To still provide the community with a wide range of fruits, some apple and mandarin trees can be planted in the urban environment and be called a 'public picking farm'. This way, they are not part of the amount of food needed to provide the community with their dietary needs, but they serve a more social purpose for the whole neighbourhood.

Figure 11 shows that the proposed community will have 5 functions: Housing, Urban Farming (Glasshouse and the Plant Factory), a Market and a Classroom.

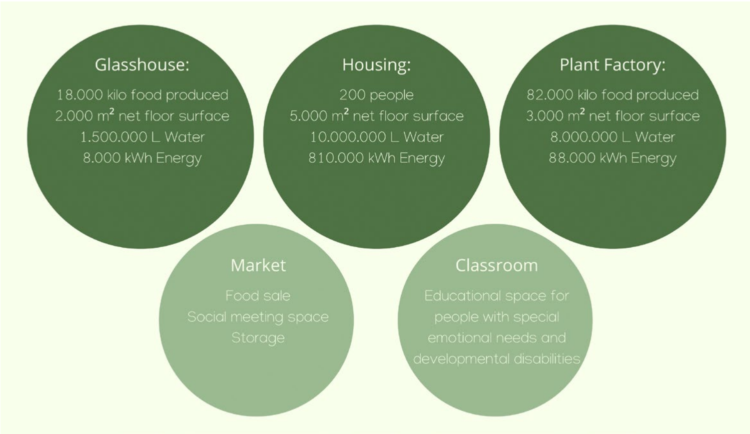

Figure 12: Program of requirements for the proposed community. (own image)

Figure 12 shows how the different functions work together and what resource flows are in between all of them. An enlarged version of this diagram can be found in the appendix on page 35.

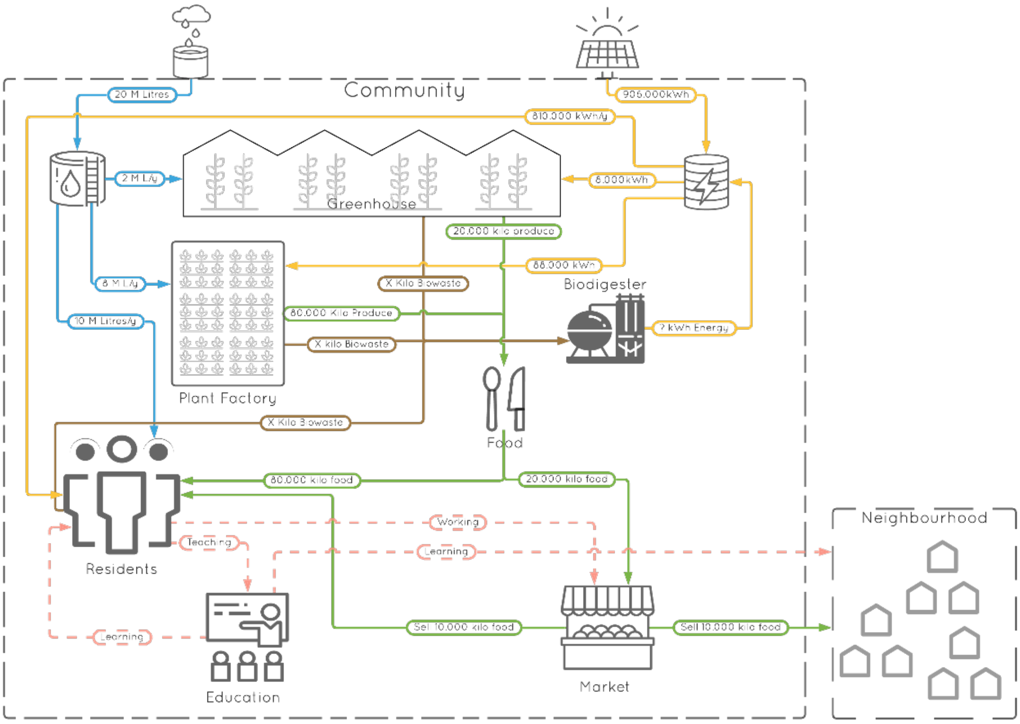

Figure 13: Community Organisational and Flow diagram. (own image)

Figure 13 shows the difference in resource use of how we currently retrieve our food from farms outside the city (or even the country) and how much more land and water they use. Figure 14 then gives us a clear overview of the actual savings of these resources in more tangible or familiar units. These savings are yearly

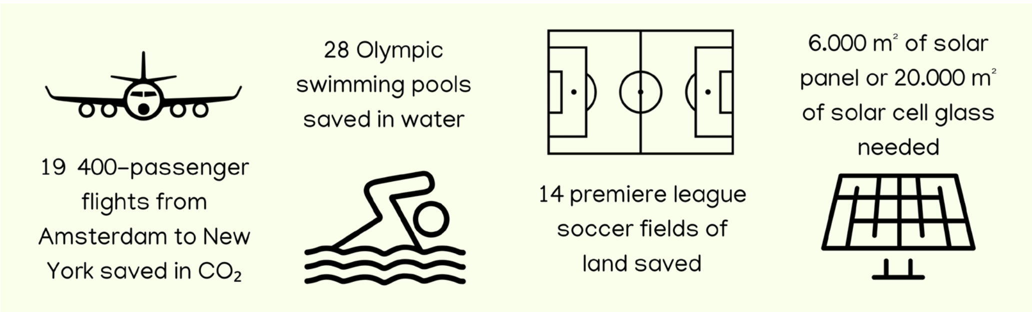

Figure 15: Positive environmental impacts expressed in alternative measurements. (own image)

Traditional Farm:	Proposed Urban Farm:	Resources saved:	
200	200	–	People
100.000	100.000	–	kilos Food
100.000	5.000	95.000	m^2 (Urban) Farm
15.800.000	0	15.800.000	kilos CO_2 from transportation
90.000.000	20.000.000	70.000.000	Liter Water
910.000	920.000	+10.000	kWh Energy extra

Figure 14: Resource use efficiency of the proposed community compared to traditional farming. (own image)

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8. APPENDIX

8.1. Totals

The totals sheet is divided into different columns and rows. The columns are divided into input and outputs. The outputs are divided into three subjects and the 'other' category. These values (both inputs and outputs) are divided into rows for the urban farm, housing and both combined. This way, it can become very clear from where the numbers originally were.
One of the inputs that might be unclear is the 'module' or 'unit'. These are made purely for future practical purposes. An essential condition for developing a new housing typology is flexibility and simplicity. If the proposed design can also be fitted into an existing neighbourhood or building, it could perhaps be implemented many more times. The current calculation model works as follows: The (only) input is the size of the community. The amount of food needed to provide this many people is calculated using the Schijf for Life, and subsequently, the space for housing and farming are calculated. So are the water demand, the energy demand and the carbon

Inputs

Totals	**Community:**			
Totals	Community size:	200		people
Totals	Max amt of floors:	8		floors
Urban Farm	**UF PF module:**			
Urban Farm	Height of one floor:	3	8,70	meters
Urban Farm	Module width	2	10,00	meters
Urban Farm	Module length	2	10,00	meters
Urban Farm	Module surface:		100	m^2
Urban Farm	**UF GH module:**			
Urban Farm	Height of one floor:	5	5,00	meters
Urban Farm	Module width	2	10,00	meters
Urban Farm	Module length	4	20,00	meters
Urban Farm	Module surface:		200	m^2
Housing	**Housing unit:**			
Housing	Height of Residential floor	1	2,70	meters
Housing	Module width	1	5,00	m
Housing	Module length	1	5,00	m
Housing			25,00	m^2

Built form

Totals	Volume housing:	20.686	m^3
Totals	Volume of Plant Factory	21.221	m^3
Totals	Volume of Glasshouse:	9.394	m^3
Totals	Rough total volume of building:	51.301	m^3
Totals	Rough Building surface:	2.138	m^2
Totals	Width and depth	46,2	
Urban Farm	Available surface for UF	7263	m^2
Urban Farm	Surface PF	2.439,20	m^2
Urban Farm	Surface GH	1.878,80	m^2
Urban Farm	Surface FS	19.700,69	m^2
Urban Farm	PF Modules:	25	
Urban Farm	GH Modules:	10	
Housing	Available surface for Housing	637	m^2
Housing	Amount of households:	103,00	
Housing	m^2 of residential space BVO	7.662	m^2
Housing	m^3 of residential space BVO	20.686	m^3
Housing	m^2 of residential space NVO	4.975	m^2
Housing	m^3 of residential space NVO	13.433	m^3
Housing	Amt of residential modules:	199	
Housing	Amt of modules per floor:	16	
Housing	amt of residential floors:	13	
Housing	Residential height:	39,00	
Housing	m^2 residential per floor	196,45	m^2

Water

Totals	Total water need:	39.104,95	m^3
Totals	Water saved:	52.399,99	m^3
Totals	Surface needed to harvest water:		
Totals	For indoor purposes	21.273,51	
Totals	For outside farming	26.610,11	
Urban Farm	Water need traditional	81.639,16	m^3
Urban Farm	Water needed for farm	29.239,18	m^3
Urban Farm	Water need decrease:	64,18%	
Urban Farm	Water need internal	7.508	m^3
Urban Farm	Water need outside:	21.732	m^3
Urban Farm	Water need PF	6.127	m^3
Urban Farm	Water need GH	1.380	m^3
Urban Farm	Water need FS	21.732	m^3
Urban Farm	Water need per kilo food PF	96,1034585	L/kg
Urban Farm	Water need per kilo food GH	85,9403971	L/kg
Urban Farm	Water need per kilo food FS	1288,71429	L/kg
Housing	Water need housing:	9.865,78	m^3

Energy

Totals	Total energy need:	916.396	kWh
Totals	m^2 of glasshouse on roof	1.879	m^2
Totals	Energy generated in glass panels	93.940	kWh
Totals	Percentage generated in glass	10,3%	
Totals	Solar Panels Needed:	3.666	pcs
Totals	m^2 solar panel needed:	6.048,21	m^2
Totals	Roof surface:	7899,5	
Totals	solar panel as % of roof	77%	
Urban Farm	Energy needed traditional farm:	98.262,55	kWh
Urban Farm	Energy needed Urban Farm:	104.850,53	kWh
Urban Farm	Energy need increase:	107%	
Urban Farm	Energy need PF	87.557	kWh
Urban Farm	Energy need GH	7.972	kWh
Urban Farm	Energy need FS	9.321	kWh
Urban Farm	Energy need per kilo food PF	1,37	kWh/kg
Urban Farm	Energy need per kilo food GH	0,50	kWh/kg
Urban Farm	Energy need per kilo food FS	0,55	kWh/kg
Housing	Total Energy need housing:	811.545	kWh

Other

Totals	Food need:	78.573,55	Kilogram
Totals	Food need + extras	96.681,20	Kilogram
Totals	CO_2 saved:	15.781.163	Kilogram
Urban Farm	CO2 saved:	15.781.163	Kilogram
Urban Farm	Food produced in PF	63.758	Kilogram
Urban Farm	Food produced in GH	16.060	Kilogram
Urban Farm	Food produced in FS	16.863	Kilogram
Urban Farm	CO_2 saved in PF		
Urban Farm	CO_2 saved in GH		
Urban Farm	CO_2 saved in FS		
Housing	CO2 saved:		Kilo

Table 3: Totals: Inputs and outputs (from own calculations)

emissions savings. After having these data

8.1.1. Totals per Crop

The third table shows totals per crop. Here we gain insight into how certain crops' production methods can or cannot be improved. It becomes visible that, for example, apples, mandarins and pistachios cannot be reduced in land use all that much. Therefore, it could be wise to see if they can continue to be grown as they are conventional. In other words, likely in an open field and a percentage being imported.

Crop	Traditional growing space im m^2	Growing space in chosen technique in m2	Space need reduction in m^2	Space need reduction in %	Reduction in % of the whole space needed	Water use reduction in m^3	Water use reduction in %	Energy use (increase) in kWh	Energy use (increase) in %	CO_2 emissions reduction	Saved CO_2 per m2 needed in Amsterdam
Apples	4.342,30	4.342,30	0,00	0,00%	0,00%	0,00	0%	0,00	100%	1.367.800,17	314,99
Raspberries	12.455,41	1.556,93	10.898,48	87,50%	11,10%	2.126,03	64%	937,33	130%	965.890,66	620,38
Mandarins	6.245,82	6.245,82	0,00	0,00%	0,00%	0,00	0%	0,00	100%	3.295.015,14	527,56
Lettuce	1.813,60	1,00	1.812,59	99,94%	1,85%	920,88	97%	70,91	106%	196.313,78	195.473,75
Spinach	1.241,27	0,35	1.240,92	99,97%	1,26%	1.134,59	97%	70,91	106%	444.375,83	1.282.945,06
Kale	1.400,12	3,37	1.396,75	99,76%	1,42%	1.251,16	97%	70,91	106%	728.441,15	216.438,83
Tomatoes	1.117,34	4,14	1.113,19	99,63%	1,13%	831,51	97%	87,11	106%	434.966,58	105.005,32
Bell Peppers	840,83	2,26	838,57	99,73%	0,85%	589,05	97%	34,84	106%	191.319,41	84.560,90
Carrots	404,95	0,66	404,29	99,84%	0,41%	303,08	97%	48,47	106%	179.637,51	271.413,44
Onions	159,64	0,19	159,45	99,88%	0,16%	211,38	97%	16,53	106%	86.074,70	444.496,55
Garlic	213,72	1,48	212,24	99,31%	0,22%	228,86	97%	15,47	106%	43.037,35	29.103,02
Eggplant	537,62	1,82	535,80	99,66%	0,55%	562,63	97%	50,80	106%	134.392,27	73.991,38
Mushrooms	281,67	6,26	275,41	97,78%	0,28%	726,53	70%	0,00	100%	157.051,02	25.090,37
Wheat	7.528,13	836,46	6.691,67	88,89%	6,81%	9.275,11	70%	533,74	106%	2.538.113,56	3.034,36
Potatoes	1.005,85	4,51	1.001,33	99,55%	1,02%	1.338,19	97%	15,78	106%	554.956,74	123.026,11
Sweet potatoes	2.717,64	13,00	2.704,63	99,52%	2,75%	1.190,54	97%	10,52	106%	426.362,16	32.796,56
Peas	8.209,69	69,81	8.139,88	99,15%	8,29%	3.699,08	97%	777,65	106%	696.146,33	9.971,97
Green beans	3.927,73	35,23	3.892,50	99,10%	3,96%	3.487,70	97%	84,16	106%	782.622,43	22.215,19
Peanuts	7.311,52	20,33	7.291,19	99,72%	7,42%	3.242,91	97%	106,75	106%	150.544,90	7.405,19
Pistacchios	9.112,57	9.112,57	0,00	0,00%	0,00%	0,00	0%	0,00	100%	100.077,02	10,98
Flax seed	191,87	4,16	187,70	97,83%	0,19%	128,05	70%	6,52	106%	7.469,41	1.794,13
Coffee beans	8.898,49	529,67	8.368,82	94,05%	8,52%	14.706,93	97%	2124,63	106%	236.985,74	447,42
Grapes	7.209,94	321,87	6.888,07	95,54%	7,01%	4.692,40	96%	905,15	130%	504.646,05	1.567,85
Malt	10.851,35	904,28	9.947,07	91,67%	10,13%	1.680,95	70%	593,04	106%	1.539.992,80	1.703,01
Mint	30,06	0,04	30,02	99,86%	0,03%	22,38	97%	8,92	106%	3.709,47	89.334,19
Basil	41,12	0,04	41,08	99,91%	0,04%	25,02	97%	8,92	106%	11.511,36	298.318,33
Oregano	110,00	0,13	109,87	99,88%	0,11%	25,02	97%	8,92	106%	3.709,47	27.645,17
Total	98.200,24	24.018,69	74.181,55	75,54%		52.399,99				15.781.163,01	

Table 4: Totals per crop (from own calculation)

8.2. Food need

The food need is based on the 'Schijf for life' of Lobke Faassen et al.

Based on these amounts of food needed to feed the community of 200 people, a selection of crops were chosen to represent the calculations made in further chapters.

With the selection of crop growing methods, The amount of kilos per production method is calculated. As can be seen, only about one-sixth is grown in both full soil and the Glasshouse. By far, the plant factory produces the most food in kilos, with almost two-thirds of the food needed (63 thousand kilos a year).

Food type:	One Person Per day	One Person Per day with margin	One Person Per year	Community per Day	Community per Year
	In Kilos	in Kilos	In Kilos	In Kilos	In Kilos
Fruits	0,30	0,33	120,45	66,00	24.090,00
Leafy greens	0,15	0,17	60,23	33,00	12.045,00
Other vegetables	0,15	0,17	60,23	33,00	12.045,00
seaweed	0,00	0,00	1,00	0,55	200,75
whole grain products	0,09	0,10	36,14	19,80	7.227,00
root vegetables	0,10	0,11	40,15	22,00	8.030,00
legumes	0,16	0,18	64,24	35,20	12.848,00
nuts	0,025	0,03	10,04	5,50	2.007,50
flax seeds	0,001	0,00	0,40	0,22	80,30
Total	0,98	1,08	392,87	215,27	78.573,55

Table 5: Food need based on the Schijf for Life.

Food type	Vegetable:	One Person Per day	One Person Per day with margin	One Person Per year	Community per Day	Community per Year	Built form:	Kilos produced outside	Kilos food produced in Glasshouse	Kilos food produced in Plant Factory
		In Kilos	In Kilos	In Kilos	In Kilos	In Kilos				
Fruits	Apples	0,10	0,11	40,15	22,00	8.030,00	Outside	8.030,00	0,00	0,00
	Raspberries	0,10	0,11	40,15	22,00	8.030,00	Glasshouse	0,00	8.030,00	0,00
	Mandarins	0,10	0,11	40,15	22,00	8.030,00	Outside	8.030,00	0,00	0,00
Leafy greens	Lettuce	0,05	0,06	20,08	11,00	4.015,00	Plant Factory	0,00	0,00	4.015,00
	Spinach	0,05	0,06	20,08	11,00	4.015,00	Plant Factory	0,00	0,00	4.015,00
	Kale	0,05	0,06	20,08	11,00	4.015,00	Plant Factory	0,00	0,00	4.015,00
Other vegetables	Tomatoes	0,05	0,06	20,08	11,00	4.015,00	Plant Factory	0,00	0,00	4.015,00
	Bell Peppers	0,02	0,02	8,03	4,40	1.606,00	Plant Factory	0,00	0,00	1.606,00
	Carrots	0,02	0,02	8,03	4,40	1.606,00	Plant Factory	0,00	0,00	1.606,00
	Onions	0,01	0,01	4,02	2,20	803,00	Plant Factory	0,00	0,00	803,00
	Garlic	0,005	0,006	2,01	1,10	401,50	Plant Factory	0,00	0,00	401,50
	Eggplant	0,02	0,02	8,03	4,40	1.606,00	Plant Factory	0,00	0,00	1.606,00
	Mushrooms	0,04	0,04	16,06	8,80	3.212,00	Plant Factory	0,00	0,00	3.212,00
whole grain products	Wheat	0,09	0,10	36,14	19,80	7.227,00	Plant Factory	0,00	0,00	7.227,00
root vegetables	Potatoes	0,06	0,07	24,09	13,20	4.818,00	Plant Factory	0,00	0,00	4.818,00
	Sweet potatoes	0,04	0,04	16,06	8,80	3.212,00	Plant Factory	0,00	0,00	3.212,00
legumes	Peas	0,08	0,09	32,12	17,60	6.424,00	Plant Factory	0,00	0,00	6.424,00
	Green beans	0,08	0,09	32,12	17,60	6.424,00	Plant Factory	0,00	0,00	6.424,00
nuts	Peanuts	0,015	0,02	6,02	3,30	1.204,50	Plant Factory	0,00	0,00	1.204,50
	Pistacchios	0,010	0,01	4,02	2,20	803,00	Outside	803,00	0,00	0,00
flax seeds	Flax seed	0,001	0,00	0,40	0,22	80,30	Plant Factory	0,00	0,00	80,30
Extras	Coffee beans	0,010	0,01	4,02	2,20	803,00	Plant Factory	0,00	0,00	803,00
	Grapes	0,10	0,11	40,15	22,00	8.030,00	Glasshouse	0,00	8.030,00	0,00
	Malt	0,10	0,11	40,15	22,00	8.030,00	Plant Factory	0,00	0,00	8.030,00
	Mint	0,001	0,00	0,40	0,22	80,30	Plant Factory	0,00	0,00	80,30
	Basil	0,001	0,00	0,40	0,22	80,30	Plant Factory	0,00	0,00	80,30
	Oregano	0,001	0,00	0,40	0,22	80,30	Plant Factory	0,00	0,00	80,30
	Total	1,20	1,32	483,41	264,88	96.681,20		16.863,00	16.060,00	63.758,20
								16.863,00	16.060,00	63.758,20
								17,44%	16,61%	65,95%

Table 6: Crop selection based on Schijf for life + percentage of all crops grown per growing method. (from own calculations)

8.3. Land Use

The use of land for each crop was calculated to determine how much arable land we take up per person. Using the diet described by Lobke Faassen in Schijf for Life and with the selected crops within those food groups, a person annually (or generally) takes up about 650m². The whole community of 200 people take up almost 13 hectares. In this calculation, ten people require one soccer field size of farming land. The whole community would take up 20 soccer fields. Imagine a row of houses (of 10 houses each with three people) with three full soccer fields next to them just to provide food. It must be possible to lower the amount of land use.

In the tables below, calculations are made on the land/space used for different farming techniques. Three varying choices for techniques are used: Glasshouse vs Plant factory, In full soil vs Hydroponics, and Vertically stacked or not. Average multiplication factors are used to calculate these numbers. These are averages of numbers mentioned in different articles. The sources can be found in the Calculation numbers sheet, which is explained further in this document.

Finally, with the selection of growing methods for crops, the land use is calculated for the proposed community. (read about the choice of production methods for crops further in this document)

				Not Vertical											
				Full Soil						Hydroponics					
	Traditional Farming			Glasshouse			Plant Factory			Glasshouse			Plant Factory		
	Crop	Land use per person in m²	Land use per Community in m²	Crop	Land use per person	Land use per Community	Crop	Land use per person	Land use per Community	Crop	Land use per person	Land use per Community	Crop	Land use per person	Land use per Community
Apples	Apples	21,71	4.342,30	Apples	10,86	2.171,15	Apples	7,24	1.447,43	Apples	1,94	387,71	Apples	1,29	258,47
Raspberries	Raspberries	62,28	12.455,41	Raspberries	15,57	3.113,85	Raspberries	10,38	2.075,90	Raspberries	2,78	556,04	Raspberries	1,85	370,70
Mandarins	Mandarins	31,23	6.245,82	Mandarins	15,61	3.122,91	Mandarins	10,41	2.081,94	Mandarins	2,79	557,66	Mandarins	1,86	371,77
Lettuce	Lettuce	9,07	1.813,60	Lettuce	0,97	194,03	Lettuce	0,65	129,35	Lettuce	0,17	34,65	Lettuce	0,12	23,10
Spinach	Spinach	6,21	1.241,27	Spinach	0,39	78,56	Spinach	0,26	52,37	Spinach	0,07	14,03	Spinach	0,05	9,35
Kale	Kale	7,00	1.400,12	Kale	0,71	141,35	Kale	0,47	94,24	Kale	0,13	25,24	Kale	0,08	16,83
Tomatoes	Tomatoes	5,59	1.117,34	Tomatoes	0,52	104,39	Tomatoes	0,35	69,59	Tomatoes	0,09	18,64	Tomatoes	0,06	12,43
Bell Peppers	Bell Peppers	4,20	840,83	Bell Peppers	0,48	95,03	Bell Peppers	0,32	63,35	Bell Peppers	0,08	16,97	Bell Peppers	0,06	11,31
Carrots	Carrots	2,02	404,95	Carrots	0,25	50,04	Carrots	0,17	33,36	Carrots	0,04	8,94	Carrots	0,03	5,96
Onions	Onions	0,80	159,64	Onions	0,17	34,16	Onions	0,11	22,77	Onions	0,03	6,10	Onions	0,02	4,07
Garlic	Garlic	1,07	213,72	Garlic	0,43	86,95	Garlic	0,29	57,97	Garlic	0,08	15,53	Garlic	0,05	10,35
Eggplant	Eggplant	2,69	537,62	Eggplant	0,46	91,54	Eggplant	0,31	61,03	Eggplant	0,08	16,35	Eggplant	0,05	10,90
Mushrooms	Mushrooms	1,41	281,67	Mushrooms	0,70	140,84	Mushrooms	0,47	93,89	Mushrooms	0,13	25,15	Mushrooms	0,08	16,77
Wheat	Wheat	37,64	7.528,13	Wheat	18,82	3.764,06	Wheat	12,55	2.509,38	Wheat	3,36	672,15	Wheat	2,24	448,10
Potatoes	Potatoes	5,03	1.005,85	Potatoes	1,14	227,35	Potatoes	0,76	151,57	Potatoes	0,20	40,60	Potatoes	0,14	27,07
Sweet potatoes	Sweet potatoes	13,59	2.717,64	Sweet potatoes	4,91	982,82	Sweet potatoes	3,28	655,21	Sweet potatoes	0,88	175,50	Sweet potatoes	0,59	117,00
Peas	Peas	41,05	8.209,69	Peas	20,52	4.104,84	Peas	13,68	2.736,56	Peas	3,67	733,01	Peas	2,44	488,67
Green beans	Green beans	19,64	3.927,73	Green beans	2,96	591,85	Green beans	1,97	394,57	Green beans	0,53	105,69	Green beans	0,35	70,46
Peanuts	Peanuts	36,56	7.311,52	Peanuts	6,83	1.366,15	Peanuts	4,55	910,77	Peanuts	1,22	243,96	Peanuts	0,81	162,64
Pistachios	Pistachios	45,56	9.112,57	Pistachios	22,78	4.556,29	Pistachios	15,19	3.037,52	Pistachios	4,07	813,62	Pistachios	2,71	542,42
Flax seed	Flax seed	0,96	191,87	Flax seed	0,16	31,22	Flax seed	0,10	20,82	Flax seed	0,03	5,58	Flax seed	0,02	3,72
Coffee beans	Coffee beans	44,49	8.898,49	Coffee beans	22,25	4.449,25	Coffee beans	14,83	2.966,16	Coffee beans	3,97	794,51	Coffee beans	2,65	529,67
Grapes	Grapes	36,05	7.209,94	Grapes	18,02	3.604,97	Grapes	12,02	2.403,31	Grapes	3,22	643,74	Grapes	2,15	429,16
Malt	Malt	54,26	10.851,35	Malt	27,13	5.425,68	Malt	18,09	3.617,12	Malt	4,84	968,87	Malt	3,23	645,91
Mint	Mint	0,15	30,06	Mint	0,02	3,49	Mint	0,01	2,33	Mint	0,00	0,62	Mint	0,00	0,42
Basil	Basil	0,21	41,12	Basil	0,02	4,21	Basil	0,01	2,81	Basil	0,00	0,75	Basil	0,00	0,50
Oregano	Oregano	0,55	110,00	Oregano	0,06	11,27	Oregano	0,04	7,51	Oregano	0,01	2,01	Oregano	0,01	1,34
	Total	491,00	98.200,24	Total	192,74	38.548,24	Total	128,49	25.698,83	Total	34,42	6.883,62	Total	22,95	4.589,08
			98.200,24			38.548,24			25.698,83			6.883,62			4.589,08
			100,00%			39,25%			26,17%			7,01%			4,67%

Table 7: Land use of Traditional farming and non-vertical Urban farming methods. (from own calculations)

The vertically stacked crops have a higher yield. That is calculated by dividing the height of the urban farm by the crop height (with factor, explained in appendix 8, calculation numbers on page 30). That increases the yield per m^2 floor space in the urban farm.

Vertically stacked											
Full Soil						Hydroponics					
Glasshouse			Plant Factory			Glasshouse			Plant Factory		
Crop	Land use per person	Land use per Community	Crop	Land use per person	Land use per Community	Crop	Land use per person	Land use per Community	Crop	Land use per person	Land use per Community
Apples	0,00	0,00	Apples	0,00	0,00	Apples	0,00	0,00	Apples	0,00	0,00
Raspberries	7,78	1.556,93	Raspberries	5,19	1.037,95	Raspberries	0,93	185,35	Raspberries	0,62	123,57
Mandarins	0,00	0,00	Mandarins	0,00	0,00	Mandarins	0,00	0,00	Mandarins	0,00	0,00
Lettuce	0,06	11,41	Lettuce	0,04	7,61	Lettuce	0,01	1,51	Lettuce	0,01	1,00
Spinach	0,02	4,13	Spinach	0,01	2,76	Spinach	0,00	0,52	Spinach	0,00	0,35
Kale	0,24	47,12	Kale	0,16	31,41	Kale	0,03	5,05	Kale	0,02	3,37
Tomatoes	0,26	52,19	Tomatoes	0,17	34,80	Tomatoes	0,03	6,21	Tomatoes	0,02	4,14
Bell Peppers	0,16	31,68	Bell Peppers	0,11	21,12	Bell Peppers	0,02	3,39	Bell Peppers	0,01	2,26
Carrots	0,04	7,15	Carrots	0,02	4,77	Carrots	0,00	0,99	Carrots	0,00	0,66
Onions	0,01	2,28	Onions	0,01	1,52	Onions	0,00	0,29	Onions	0,00	0,19
Garlic	0,09	17,39	Garlic	0,06	11,59	Garlic	0,01	2,22	Garlic	0,01	1,48
Eggplant	0,11	22,89	Eggplant	0,08	15,26	Eggplant	0,01	2,72	Eggplant	0,01	1,82
Mushrooms	0,05	9,39	Mushrooms	0,03	6,26	Mushrooms	0,01	1,20	Mushrooms	0,00	0,80
Wheat	6,27	1.254,69	Wheat	4,18	836,46	Wheat	0,67	134,43	Wheat	0,45	89,62
Potatoes	0,28	56,84	Potatoes	0,19	37,89	Potatoes	0,03	6,77	Potatoes	0,02	4,51
Sweet potatoes	0,82	163,80	Sweet potatoes	0,55	109,20	Sweet potatoes	0,10	19,50	Sweet potatoes	0,07	13,00
Peas	4,10	820,97	Peas	2,74	547,31	Peas	0,52	104,72	Peas	0,35	69,81
Green beans	2,96	591,85	Green beans	1,97	394,57	Green beans	0,26	52,84	Green beans	0,18	35,23
Peanuts	1,37	273,23	Peanuts	0,91	182,15	Peanuts	0,15	30,49	Peanuts	0,10	20,33
Pistachios	0,00	0,00	Pistachios	0,00	0,00	Pistachios	0,00	0,00	Pistachios	0,00	0,00
Flax seed	0,03	6,24	Flax seed	0,02	4,16	Flax seed	0,00	0,80	Flax seed	0,00	0,53
Coffee beans	22,25	4.449,25	Coffee beans	14,83	2.966,16	Coffee beans	3,97	794,51	Coffee beans	2,65	529,67
Grapes	18,02	3.604,97	Grapes	12,02	2.403,31	Grapes	1,61	321,87	Grapes	1,07	214,58
Malt	6,78	1.356,42	Malt	4,52	904,28	Malt	0,97	193,77	Malt	0,65	129,18
Mint	0,00	0,50	Mint	0,00	0,33	Mint	0,00	0,06	Mint	0,00	0,04
Basil	0,00	0,47	Basil	0,00	0,31	Basil	0,00	0,06	Basil	0,00	0,04
Oregano	0,01	1,61	Oregano	0,01	1,07	Oregano	0,00	0,20	Oregano	0,00	0,13
Total	71,72	14.343,39	Total	47,81	9.562,26	Total	9,35	1.869,48	Total	6,23	1.246,32
		14.343,39			9.562,26			1.869,48			1.246,32
		14,61%			9,74%			1,90%			1,27%

Table 8: Land use of Vertically stacked urban farming methods (from own calculations)

The total space needed to provide a community of 200 people with enough food to sustain themselves all year is 2,4 hectares in the proposed urban farming concept. Compared to the 9,8 hectares needed for traditional farming, this is quite an improvement. However, 82% of the land use in the proposed idea is for full-soil agriculture of only three crops: Apples, Mandarins and Pistachios. That can be much improved by simply selecting crops that have a much lower land use demand, such as Berries, melons and peanuts. (as a replacement for the fruits and nuts)

Final Selection							
Crop	Outside, Glasshouse or Plant Factory	Full Soil or Hydroponics	Vertically stacked or not stacked	Total growing space :	Total Outside space	Total Glasshouse space:	Total Plant Factory space:
Apples	Outside	Full Soil	Not stacked	4342,30	4.342,30	0,00	0,00
Raspberries	Glasshouse	Full Soil	Stacked	1556,93	0,00	1.556,93	0,00
Mandarins	Outside	Full Soil	Not stacked	6245,82	6.245,82	0,00	0,00
Lettuce	Plant Factory	Hydroponics	Stacked	1,00	0,00	0,00	1,00
Spinach	Plant Factory	Hydroponics	Stacked	0,35	0,00	0,00	0,35
Kale	Plant Factory	Hydroponics	Stacked	3,37	0,00	0,00	3,37
Tomatoes	Plant Factory	Hydroponics	Stacked	4,14	0,00	0,00	4,14
Bell Peppers	Plant Factory	Hydroponics	Stacked	2,26	0,00	0,00	2,26
Carrots	Plant Factory	Hydroponics	Stacked	0,66	0,00	0,00	0,66
Onions	Plant Factory	Hydroponics	Stacked	0,19	0,00	0,00	0,19
Garlic	Plant Factory	Hydroponics	Stacked	1,48	0,00	0,00	1,48
Eggplant	Plant Factory	Hydroponics	Stacked	1,82	0,00	0,00	1,82
Mushrooms	Plant Factory	Full Soil	Stacked	6,26	0,00	0,00	6,26
Wheat	Plant Factory	Full Soil	Stacked	836,46	0,00	0,00	836,46
Potatoes	Plant Factory	Hydroponics	Stacked	4,51	0,00	0,00	4,51
Sweet potatoes	Plant Factory	Hydroponics	Stacked	13,00	0,00	0,00	13,00
Peas	Plant Factory	Hydroponics	Stacked	69,81	0,00	0,00	69,81
Green beans	Plant Factory	Hydroponics	Stacked	35,23	0,00	0,00	35,23
Peanuts	Plant Factory	Hydroponics	Stacked	20,33	0,00	0,00	20,33
Pistachios	Outside	Full Soil	Not stacked	9112,57	9.112,57	0,00	0,00
Flax seed	Plant Factory	Full Soil	Stacked	4,16	0,00	0,00	4,16
Coffee beans	Plant Factory	Hydroponics	Stacked	529,67	0,00	0,00	529,67
Grapes	Glasshouse	Hydroponics	Stacked	321,87	0,00	321,87	0,00
Malt	Plant Factory	Full Soil	Stacked	904,28	0,00	0,00	904,28
Mint	Plant Factory	Hydroponics	Stacked	0,04	0,00	0,00	0,04
Basil	Plant Factory	Hydroponics	Stacked	0,04	0,00	0,00	0,04
Oregano	Plant Factory	Hydroponics	Stacked	0,13	0,00	0,00	0,13
Total				24018,69	19.700,69	1.878,80	2.439,20
					19.700,69	1.878,80	2.439,20
					82,02%	7,82%	10,16%

Table 9: Final crop growing method with respective land use. (from own calculations)

8.4. Water Use

The water use per technique in this table is calculated by using the conversion factors defined in calculation numbers on page 30. It becomes visible that growing crops using Hydroponics or in a plant factory (or both) can significantly reduce water use.
Vertical farming was not taken into account as it does not affect the water use per kilo produced food.

			Not Vertical							
			Full Soil				Hydroponics			
	Traditional Farming		Glasshouse		Plant Factory		Glasshouse		Plant Factory	
	Per Kilo food in Liters	For the whole community in M³								
Apples	822,0	6600,7	295,0	2369,2	244,6	1964,0	32,0	256,7	26,5	212,8
Raspberries	413,0	3316,4	148,2	1190,4	122,9	986,8	16,1	129,0	13,3	106,9
Mandarins	748,0	6006,4	268,5	2155,9	222,6	1787,1	29,1	233,6	24,1	193,6
Lettuce	237,0	951,6	85,1	341,5	70,5	283,1	9,2	37,0	7,6	30,7
Spinach	292,0	1172,4	104,8	420,8	86,9	348,8	11,4	45,6	9,4	37,8
Kale	322,0	1292,8	115,6	464,0	95,8	384,7	12,5	50,3	10,4	41,7
Tomatoes	214,0	859,2	76,8	308,4	63,7	255,6	8,3	33,4	6,9	27,7
Bell Peppers	379,0	608,7	136,0	218,5	112,8	181,1	14,7	23,7	12,2	19,6
Carrots	195,0	313,2	70,0	112,4	58,0	93,2	7,6	12,2	6,3	10,1
Onions	272,0	218,4	97,6	78,4	80,9	65,0	10,6	8,5	8,8	7,0
Garlic	589,0	236,5	211,4	84,9	175,3	70,4	22,9	9,2	19,0	7,6
Eggplant	362,0	581,4	129,9	208,7	107,7	173,0	14,1	22,6	11,7	18,7
Mushrooms	322,0	1034,3	115,6	371,2	95,8	307,7	12,5	40,2	10,4	33,3
Wheat	1827,0	13203,7	655,8	4739,2	543,6	3928,6	71,0	513,4	58,9	425,6
Potatoes	287,0	1382,8	103,0	496,3	85,4	411,4	11,2	53,8	9,3	44,6
Sweet potatoes	383,0	1230,2	137,5	441,6	114,0	366,0	14,9	47,8	12,3	39,7
Peas	595,0	3822,3	213,6	1371,9	177,0	1137,3	23,1	148,6	19,2	123,2
Green beans	561,0	3603,9	201,4	1293,5	166,9	1072,3	21,8	140,1	18,1	116,2
Peanuts	2782,0	3350,9	998,6	1202,8	827,8	997,0	108,2	130,3	89,7	108,0
Pistacchios	11363,0	9124,5	4078,5	3275,1	3380,9	2714,9	441,8	354,8	366,3	294,1
Flax seed	2270,0	182,3	814,8	65,4	675,4	54,2	88,3	7,1	73,2	5,9
Coffee beans	18925,0	15196,8	6792,8	5454,6	5630,9	4521,6	735,9	590,9	610,0	489,8
Grapes	608,0	4882,2	218,2	1752,4	180,9	1452,7	23,6	189,8	19,6	157,4
Malt	298,0	2392,9	107,0	858,9	88,7	712,0	11,6	93,0	9,6	77,1
Mint	288,0	23,1	103,4	8,3	85,7	6,9	11,2	0,9	9,3	0,7
Basil	322,0	25,9	115,6	9,3	95,8	7,7	12,5	1,0	10,4	0,8
Oregano	322,0	25,9	115,6	9,3	95,8	7,7	12,5	1,0	10,4	0,8
	45.998,00	81.639,16	0,00	29.302,95	0,00	24.290,79	0,00	3.174,49	0,00	2.631,50
	45,998 M³	81639,16 M³	16,51018 M³	29302,95 M³	13,68617 M³	24290,79 M³	1,7886 M³	3174,49 M³	1,48267 M³	2631,5 M³

Table 10: Water use of growing crops using certain techniques (from own calculations)

Crop	Glasshouse/Plant factory	Full Soil/ Hydroponics	Combina	Water use per person	Water use per Community	Water use outside	Water use glasshouse	Water use Plant factory
Apples	Outside	Full Soil	0	33,0	6600,7	6600,7	0,0	0,0
Raspberries	Glasshouse	Full Soil	1	6,0	1190,4	0,0	1190,4	0,0
Mandarins	Outside	Full Soil	0	30,0	6006,4	6006,4	0,0	0,0
Lettuce	Plant Factory	Hydroponics	4	0,2	30,7	0,0	0,0	30,7
Spinach	Plant Factory	Hydroponics	4	0,2	37,8	0,0	0,0	37,8
Kale	Plant Factory	Hydroponics	4	0,2	41,7	0,0	0,0	41,7
Tomatoes	Plant Factory	Hydroponics	4	0,1	27,7	0,0	0,0	27,7
Bell Peppers	Plant Factory	Hydroponics	4	0,1	19,6	0,0	0,0	19,6
Carrots	Plant Factory	Hydroponics	4	0,1	10,1	0,0	0,0	10,1
Onions	Plant Factory	Hydroponics	4	0,0	7,0	0,0	0,0	7,0
Garlic	Plant Factory	Hydroponics	4	0,0	7,6	0,0	0,0	7,6
Eggplant	Plant Factory	Hydroponics	4	0,1	18,7	0,0	0,0	18,7
Mushrooms	Plant Factory	Full Soil	2	1,5	307,7	0,0	0,0	307,7
Wheat	Plant Factory	Full Soil	2	19,6	3928,6	0,0	0,0	3928,6
Potatoes	Plant Factory	Hydroponics	4	0,2	44,6	0,0	0,0	44,6
Sweet potatoes	Plant Factory	Hydroponics	4	0,2	39,7	0,0	0,0	39,7
Peas	Plant Factory	Hydroponics	4	0,6	123,2	0,0	0,0	123,2
Green beans	Plant Factory	Hydroponics	4	0,6	116,2	0,0	0,0	116,2
Peanuts	Plant Factory	Hydroponics	4	0,5	108,0	0,0	0,0	108,0
Pistacchios	Outside	Full Soil	0	45,6	9124,5	9124,5	0,0	0,0
Flax seed	Plant Factory	Full Soil	2	0,3	54,2	0,0	0,0	54,2
Coffee beans	Plant Factory	Hydroponics	4	2,4	489,8	0,0	0,0	489,8
Grapes	Glasshouse	Hydroponics	3	0,9	189,8	0,0	189,8	0,0
Malt	Plant Factory	Full Soil	2	3,6	712,0	0,0	0,0	712,0
Mint	Plant Factory	Hydroponics	4	0,0	0,7	0,0	0,0	0,7
Basil	Plant Factory	Hydroponics	4	0,0	0,8	0,0	0,0	0,8
Oregano	Plant Factory	Hydroponics	4	0,0	0,8	0,0	0,0	0,8
Totaal				146,20	29.239,18	21731,6	1380,2	6.127,38
						21731,6	1380,2	6127,4
						74,32%	4,72%	20,96%

Table 11: : Water use per crop within selected growing technique and built form (from own calculations)

8.4.1. Precipitation

The precipitation in Amsterdam was taken from 3 different sources to calculate the water harvesting capacity. The average rainfall was used. Precipitation in millimetres was converted to harvested litres of water per m^2. That was then used to calculate how many square metres of water harvesting surface is needed to provide enough water for the whole community. That is done separately for only the functions inside: Housing, the Plant factory and the Glasshouse. That was done because Open field farming is already in an open field and might suffice with the surface that it takes up itself.

rainfall:	in milimeters	in milimeters2	in milimeters3	Average
jan	69,00	65,00	68,00	67,33
feb	57,00	50,00	53,00	53,33
mar	58,00	50,00	44,00	50,67
apr	57,00	40,00	49,00	48,67
may	68,00	55,00	52,00	58,33
jun	73,00	65,00	58,00	65,33
jul	88,00	80,00	77,00	81,67
aug	86,00	100,00	87,00	91,00
sep	76,00	85,00	72,00	77,67
oct	70,00	85,00	72,00	75,67
nov	68,00	85,00	70,00	74,33
dec	74,00	80,00	64,00	72,67
Total	844,00	840,00	766,00	816,67

Table 12: Average precipitation in Amsterdam from different sources

Water demand for:	demand in m^3	surface needed to harvest water in m^2	surface needed to harvest water for indoor purposes in m^2
Housing	9.865,78	12.080,54	12.080,54
Plant Factory	6.127,38	7.502,92	7.502,92
Glasshouse	1.380,20	1.690,04	1.690,04
Open Field Farming	21.731,59	26.610,11	0,00
Total		47.883,62	21.273,51

Table 13: Calculated water harvesting surface demand for community of 200 people (from own calculations)

8.5. Energy Need

	Traditional	Glasshouse	Plant factory	Traditional/ community	Glasshouse/ community	Plant factory/ community	building choice	Energy need
	MJ/kilo	MJ/kilo	MJ/kilo	MJ	MJ	MJ		MJ
Apples	1,59	2,07	10,78	12767,70	16605,54	86597,99	Glasshouse	16605,54
Raspberries	1,40	1,82	9,48	11225,94	14600,34	76140,87	Glasshouse	14600,34
Mandarins	1,22	1,59	8,27	9796,60	12741,35	66446,25	Glasshouse	12741,35
Lettuce	5,31	6,90	36,00	21310,47	27716,16	144540,00	Plant Factory	144540,00
Spinach	5,31	6,90	36,00	21310,47	27716,16	144540,00	Plant Factory	144540,00
Kale	5,31	6,90	36,00	21310,47	27716,16	144540,00	Plant Factory	144540,00
Tomatoes	23,60	23,60	160,07	94754,00	94754,00	642676,88	Plant Factory	642676,88
Bell Peppers	36,10	36,10	244,85	57976,60	57976,60	393231,10	Plant Factory	393231,10
Carrots	1,88	2,45	12,75	3019,28	3926,84	20478,52	Plant Factory	20478,52
Onions	1,28	1,67	8,70	1029,49	1338,94	6982,58	Glasshouse	1338,94
Garlic	2,40	3,12	16,28	963,60	1253,25	6535,70	Glasshouse	1253,25
Eggplant	1,97	2,56	13,36	3163,82	4114,83	21458,87	Plant Factory	21458,87
Mushrooms	0,79	0,79	0,79	2543,90	2543,90	2543,90	Plant Factory	2543,90
Wheat	17,80	23,15	120,73	128640,60	167308,60	872515,55	Glasshouse	167308,60
Potatoes	0,20	0,27	1,38	982,87	1278,31	6666,41	Glasshouse	1278,31
Sweet potatoes	0,20	0,27	1,38	655,25	852,21	4444,27	Glasshouse	852,21
Peas	7,54	9,81	51,14	48436,96	62996,60	328527,70	Plant Factory	328527,70
Green beans	0,82	1,06	5,53	5241,98	6817,67	35554,19	Plant Factory	35554,19
Peanuts	5,52	7,18	37,44	6648,84	8647,41	45096,31	Plant Factory	45096,31
Pistacchios	13,69	17,81	92,85	10993,07	14297,47	74561,41	Glasshouse	14297,47
Flax seed	5,06	6,58	34,32	4063,18	5284,53	27558,86	Glasshouse	5284,53
Coffee beans	164,80	214,34	1117,77	132334,40	172112,72	897569,06	Plant Factory	897569,06
Grapes	1,35	1,76	9,16	10840,50	14099,04	73526,59	Glasshouse	14099,04
Malt	15,14	19,69	102,69	121574,20	158118,11	824587,11	Glasshouse	158118,11
Mint	6,92	9,00	46,94	555,67	722,70	3768,89	Plant Factory	3768,89
Basil	6,92	9,00	46,94	555,67	722,70	3768,89	Plant Factory	3768,89
Oregano	6,92	9,00	46,94	555,67	722,70	3768,89	Plant Factory	3768,89
Total				733251,19	906984,86	4958626,79		3239840,89

Table 14: Energy use per crop per technique, first per kilo crop, then per community, and finally only the selected technique (from own calculations)

	MJ	kWh	Solar panels:	m^2 Solar panels
Traditional	733.251	203.681	814,72355	1344,293856
with farming method selection:	3.239.841	899.956	3599,8232	5939,70829
% increase	441,85%			

Table 15: Energy need increase of proposal opposed to traditional. then the need for solar panels in amount and m^2 (from own calculations)

8.6. Transportation CO_2 emissions

8.6.1. Cultivation centres

Grams of CO_2 per tonne	Grammes CO_2
per kilometre sea transport	35,00
per kilometre train transport	64,50
per kilometre truck transport	150,00

Table 16: CO_2 emissions per tonne Kilometer for different transportation means

CO_2 emissions of transport to Amsterdam from specific cultivation centre

Cultivation Centre	Central port	Reg, nr	Distance in Kilometers	Means of Transportation	CO_2 emission per Kilo food in grammes
Chinese-Japanese Region	Shanghai	1	19.603,42	Sea	686.120
Indochinese-Indonesian Region	Singapore	2	15.560,50	Sea	544.618
Australian Region	Adelaide	3	2.770,59	Sea	96.971
Hindustani Region	Mumbai	4	11.893,54	Sea	416.274
Central Asian Region	Bandar Abbas	5	11.517,59	Sea	403.116
Near Eastern Region	Mersin	6	6.322,73	Train	407.816
Mediterranean Region	Augusta	7	4.607,78	Sea	161.272
African Region	Douala	8	8.432,16	Sea	295.125
European Siberian Region	Moscow	9	2.418,30	Train	155.980
South American Region	Lima	10	11.558,33	Sea	404.542
Central American and Mexican Region	Mazatlan	11	12.791,76	Sea	447.712
North American Region	Avg of LA & NY	12	10.654,56	Sea	372.910

Table 17: CO_2 emissions of transport to Amsterdam from specific cultivation centre

CO_2 emissions from transport of crops to Amsterdam from provinces in NL where they are produced most

Province:	Central city	Reg nr	Distance in Kilometers	Means of Transportation	CO_2 emission per Kilo food in grammes
Drenthe	Assen	1	185	truck	27.750
Flevoland	Lelystad	2	57	truck	8.550
Friesland	Leeuwarden	3	140	truck	21.000
Gelderland	Arnhem	4	101	truck	15.150
Groningen	Groningen	5	180	truck	27.000
Limburg	Maastricht	6	212	truck	31.800
Noord-Brabant	Den Bosch	7	88	truck	13.200
Noord-Holland	Haarlem	8	32	truck	4.800
Overijssel	Zwolle	9	111	truck	16.650
Utrecht	Utrecht	10	50	truck	7.500
Zeeland	Middelburg	11	171	truck	25.650
Zuid-Holland	Den Haag	12	64	truck	9.600
Niet bekend	Utrecht	13	50	truck	7.500

Table 18: **CO_2 emissions from transport of crops to Amsterdam from provinces in NL where they are produced most**

8.6.2. Final CO_2 emissions

	Food Import						Dutch grown Food					Totals for whole community			
Crop	Percentage imported	Imported Kilos	Cultivation region number	Species used	Shipping distance	CO_2 Emission imported food	Percentage dutch grown	Dutch grown kilos	Location in NL	Distance From AMS	CO_2 emission dutch grown	CO_2 emission import in tonnes	CO_2 emission Dutch grown in tonnes	Total CO_2 emission	CO2 emission per kilo
			see 'C centers'		Kilometers	Kilos CO_2 per kilo transported food			see 'C centers'	Kilometers	Kilos CO_2 per kilo transported food	In Kilos	In Kilos	In Kilos	
Apples	40,00	3.212,00	5	Malus Sylvestris	11.517,59	403,12	60,00	4.818,00	4	101,00	15,15	1.294.807,47	72.992,70	1.367.800,17	170,34
Raspberries	75,00	6.022,50	9	Rubus Idaeus	2.418,30	155,98	25,00	2.007,50	7	88,00	13,20	939.391,66	26.499,00	965.890,66	120,29
Mandarins	75,00	6.022,50	2	Citrus Aurantifolia	15.560,50	544,62	25,00	2.007,50	13	50,00	7,50	3.279.958,89	15.056,25	3.295.015,14	410,34
Lettuce	25,00	1.003,75	9	Latuca Sativa	2.418,30	155,98	75,00	3.011,25	7	88,00	13,20	156.565,28	39.748,50	196.313,78	48,90
Spinach	25,00	1.003,75	5	Spinacea Oleracea	11.517,59	403,12	75,00	3.011,25	7	88,00	13,20	404.627,33	39.748,50	444.375,83	110,68
Kale	25,00	1.003,75	1	Brassica Oleracea	19.603,42	686,12	75,00	3.011,25	7	88,00	13,20	688.692,65	39.748,50	728.441,15	181,43
Tomatoes	25,00	1.003,75	10	copersicon Esculentu	11.558,33	404,54	75,00	3.011,25	12	64,00	9,60	406.058,58	28.908,00	434.966,58	108,34
Bell Peppers	25,00	401,50	11	capsicum annuum	12.791,76	447,71	75,00	1.204,50	12	64,00	9,60	179.756,21	11.563,20	191.319,41	119,13
Carrots	25,00	401,50	6	Daucus carota	6.322,73	407,82	75,00	1.204,50	7	88,00	13,20	163.738,11	15.899,40	179.637,51	111,85
Onions	25,00	200,75	5	Allium Cepa	11.517,59	403,12	75,00	602,25	2	57,00	8,55	80.925,47	5.149,24	86.074,70	107,19
Garlic	25,00	100,38	5	Allium Sativa	11.517,59	403,12	75,00	301,13	2	57,00	8,55	40.462,73	2.574,62	43.037,35	107,19
Eggplant	25,00	401,50	8	iolanum Macrocarpo	8.432,16	295,13	75,00	1.204,50	7	88,00	13,20	118.492,87	15.899,40	134.392,27	83,68
Mushrooms	25,00	803,00	9		2.418,30	155,98	75,00	2.409,00	7	88,00	13,20	125.252,22	31.798,80	157.051,02	48,90
Wheat	85,19	6.156,33	6	Triticum aestivum	6.322,73	407,82	14,81	1.070,67	11	171,00	25,65	2.510.650,96	27.462,60	2.538.113,56	351,20
Potatoes	23,20	1.118,01	10	Solanum Tuberosum	11.558,33	404,54	76,80	3.699,99	1	185,00	27,75	452.282,05	102.674,68	554.956,74	115,18
Sweet potatoes	25,00	803,00	11	Ipomoea Trifida	12.791,76	447,71	75,00	2.409,00	1	185,00	27,75	359.512,41	66.849,75	426.362,16	132,74
Peas	25,00	1.606,00	6	Pisum Arvense	6.322,73	407,82	75,00	4.818,00	2	57,00	8,55	654.952,43	41.193,90	696.146,33	108,37
Green beans	25,00	1.606,00	11	Phaseolus Vulgaris	12.791,76	447,71	75,00	4.818,00	7	88,00	13,20	719.024,83	63.597,60	782.622,43	121,83
Peanuts	25,00	301,13	10	Arachis Hypogaea	11.558,33	404,54	75,00	903,38	6	212,00	31,80	121.817,57	28.727,33	150.544,90	124,99
Pistacchios	25,00	200,75	5	Pistacia Vera	11.517,59	403,12	75,00	602,25	6	212,00	31,80	80.925,47	19.151,55	100.077,02	124,63
Flax seed	25,00	20,08	8	Linum Usitatissimum	8.432,16	295,13	75,00	60,23	11	171,00	25,65	5.924,64	1.544,77	7.469,41	93,02
Coffee beans	100,00	803,00	8	Coffea Arabica	8.432,16	295,13	0,00	0,00				236.985,74	0,00	236.985,74	295,13
Grapes	25,00	2.007,50	9		2.418,30	155,98	75,00	6.022,50	6	212,00	31,80	313.130,55	191.515,50	504.646,05	62,85
Malt	25,00	2.007,50	1	Hordeum Vulgare	19.603,42	686,12	75,00	6.022,50	5	180,00	27,00	1.377.385,30	162.607,50	1.539.992,80	191,78
Mint	25,00	20,08	9	Mentha Spicata	2.418,30	155,98	75,00	60,23	12	64,00	9,60	3.131,31	578,16	3.709,47	46,20
Basil	25,00	20,08	2	Ocimum Basilicum	15.560,50	544,62	75,00	60,23	12	64,00	9,60	10.933,20	578,16	11.511,36	143,35
Oregano	25,00	20,08	9	Origanum Vulgare	2.418,30	155,98	75,00	60,23	12	64,00	9,60	3.131,31	578,16	3.709,47	46,20
Total												14.728.517,24	1.052.645,77	15.781.163,01	

Table 19: CO2 emission by transportation of crops. (own calculation)

As becomes visible in this scheme, the shipping distance is determined for both the imported and the Dutch grown food. It also determines what percentage is imported and produced in the Netherlands. The distance is determined by locating a cultivation centre, see Table 14 and Table 15 The distance is multiplied by an amount of CO_2 emission for a particular transportation means. Multiplied by the amounts of kilos imported and Dutch grown, a total CO_2emission is calculated.

The proposal for the community is to grow all necessary food on-site. That would mean that all the CO_2 emitted by transporting it will now no longer be emitted. In conclusion: A community of 200 people can lower their carbon emissions by 15,85 million kilos if they would produce the food on-site. Of course, there are a few nuances in this. The packaging, sales and production emissions were not taken into account, and neither were other greenhouse gasses which also have a significant impact on the environment.

8.7. Housing

Household type	amount	Percentage
One-person households	3.079.778,00	29,0%
More-person households without children	2.302.921,00	21,7%
More-person households with children	2.615.101,00	24,6%
Married pair with children	1.577.842,00	14,9%
Not married pair with children	447.284,00	4,2%
One-parent families	589.975,00	5,6%
Total	10.612.901,00	

[1]

Table 20: Average dutch household types [2]

	Percentage of community	Amount of these households	Amt of People in these households	People in one household	Square meters per person	Total square meters of household	Amt of modules	Total Square meters NVO	Water use per person	Water use for whole household	Water use for this household type	Energy use per person	Energy use for whole household	Energy use for this household type
					in m²	in m²		in m²	in m^3	in m^3	in m^3	in kWh	in kWh	in kWh
Single Starters	14,5%	29	29	1	25,0	25,0	1,0	725,0	52,0	52,0	1509,0	5741,7	5741,7	166509,1
Couples	7,2%	7	14	2	25,0	50,0	2,0	350,0	49,5	99,0	716,1	4441,1	8882,2	62175,2
Young Family	14,6%	10	29	3	25,0	75,0	3,0	750,0	48,3	145,0	1408,8	3500,0	10500,0	105000,0
Medium Family	14,6%	7	29	4	25,0	100,0	4,0	700,0	47,8	191,0	1391,8	3045,3	12181,3	85268,9
Large Family	14,6%	6	29	5	25,0	125,0	5,0	750,0	47,4	237,0	1381,6	2607,6	13037,8	78226,6
Elderly 1p	14,5%	29	29	1	25,0	25,0	1,0	725,0	52,0	52,0	1509,0	5741,7	5741,7	166509,1
Elderly 2p	7,2%	7	14	2	25,0	50,0	2,0	350,0	49,5	99,0	716,1	4441,1	8882,2	62175,2
One parent family 3p	2,8%	2	6	3	25,0	75,0	3,0	150,0	48,3	145,0	268,7	3500,0	10500,0	21000,0
One parent family 4p	2,8%	1	6	4	25,0	100,0	4,0	100,0	47,8	191,0	265,4	3045,3	12181,3	12181,3
Co housing non related 3p	7,2%	5	14	3	25,0	75,0	3,0	375,0	48,3	145,0	699,2	3500,0	10500,0	52500,0
Total		103	200					4975,0			9865,8			811545,3

Table 22: Households in community, square meters and water usage in households. (from own calculation)

Amount of people in household		Total use per household:	In litres		in m^3	Total use per person	In litres		in m^3
1,0	Person household	52000,0	liter	52,0	m^3	52000,0	liter	52,0	m^3
2,0	Person household	99000,0	liter	99,0	m^3	49500,0	liter	49,5	m^3
3,0	Person household	145000,0	liter	145,0	m^3	48333,3	liter	48,3	m^3
4,0	Person household	191000,0	liter	191,0	m^3	47750,0	liter	47,8	m^3
5,0	Person household	237000,0	liter	237,0	m^3	47400,0	liter	47,4	m^3

[3]

Table 21: Household water use.

Amount of people in household		Total use per household:	In kWh	Total use per person	In kWh	increase opposed to 1 pers household
1,0	Person household	5741,7	kWh	5741,7	kWh	100,00%
2,0	Person household	8882,2	kWh	4441,1	kWh	154,70%
3,0	Person household	10500,0	kWh	3500,0	kWh	182,87%
4,0	Person household	12181,3	kWh	3045,3	kWh	212,15%
5,0	Person household	13037,8	kWh	2607,6	kWh	227,07%

Table 23: Household Energy use.

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[1] Volksgezondheidenzorg.Info, Bevolking - Cijfers & Context
[2] Waternet, 'Gemiddeld waterverbruik van onze klanten'
[3] Gasloos Nederland Magazine. Gemiddeld stroomverbruik gasloze woning.

8.8. Calculation Numbers

	In full soil/outside in the NL	Glasshouse farming	Plant Factory	Hydroponics	Vertical Farming (tray stacking)	Height of crop plant in cm	Height of stack in soil:	Height of stack in hydroponics:	Chosen stack height:	Grow cycle length	Yield increase because of multiple grow cycles
Apples	1	0,8	0,3	0,5	0	674	1482,8	1078,4	1482,8	365	1,00
Raspberries	1	1	0,8	0,5	0,3	141	310,2	225,6	310,2	182,5	2,00
Mandarins	1	0,8	0,3	0,5	0	658	1447,6	1052,8	1447,6	365	1,00
Lettuce	1	1	1	1	1	23	50,6	36,8	36,8	71	4,67
Spinach	1	1	1	1	1	20	44	32	32	42	7,90
Kale	1	1	1	1	1	100	220	160	160	67	4,95
Tomatoes	1	1	1	1	1	180	396	288	288	62	5,35
Bell Peppers	1	1	1	1	1	100	220	160	160	75	4,42
Carrots	1	1	1	1	1	55	121	88	88	82	4,05
Onions	1	1	1	1	1	25	55	40	40	142	2,34
Garlic	1	1	1	1	1	70	154	112	112	270	1,23
Eggplant	1	1	1	1	1	90	198	144	144	113	2,94
Mushrooms	1	0	1	0	1	25	55	40	55	331,8181818	1,00
Wheat	1	1	1	0	0,5	100	220	160	220	331,8181818	1,00
Potatoes	1	1	1	1	1	88	193,6	140,8	140,8	150	2,21
Sweet potatoes	1	1	1	1	1	60	132	96	96	240	1,38
Peas	1	1	1	1	1	77	169,4	123,2	123,2	331,8181818	1,00
Green beans	1	1	1	1	0	200	440	320	320	100	3,32
Peanuts	0,5	1	1	1	1	66	145,2	105,6	105,6	124	2,68
Pistacchios	0,5	0,3	0	0	0	800	1760	1280	1760	331,8181818	1,00
Flax seed	1	1	1	0	1	75	165	120	165	108	3,07
Coffee beans	0	1	1	1	0	325	715	520	520	331,8181818	1,00
Grapes	1	1	0	1	0,3	252	554,4	403,2	403,2	331,8181818	1,00
Malt	1	1	1	0	1	92	202,4	147,2	202,4	331,8181818	1,00
Mint	1	1	1	1	1	51	112,2	81,6	81,6	77	4,31
Basil	1	1	1	1	1	40	88	64	64	68	4,88
Oregano	1	1	1	1	1	54	118,8	86,4	86,4	68	4,88

This table collects different calculation numbers needed to calculate other things more accurately. The first five columns indicate whether a particular crop would be suitable to grow in that respective technique or built form. A zero or a low number indicates that it would not or not easily be possible. A higher number or a '1' suggest that it would be more feasible or entirely feasible.
The crop height was needed to determine how many trays could be stacked in the plant factory height. The growing cycle length was used to calculate a yield increase due to the closed system. In a Glasshouse or Plant Factory, multiple grow cycles for one crop can be completed in a year. That increases the yield as opposed to open-field agriculture.

Table 24: Suitability ratings of crops in different farming methods, crop heights, vertical farming stack heights, growth cycle length, amount of growth cycles in a year. (from own calculations)

Not vertically stacked

	Full Soil			Hydroponics	
	Traditional	Glasshouse	Plant Factory	Glasshouse	Plant Factory
Yield	1	1,10	1,30	3,30	3,90
Land use	1	0,91	0,77	0,30	0,26
Water Use	1	0,36	0,03	0,04	0,00
Electricity use	1	1,30	6,78	Does not apply	Does not apply
Herbicides/ pesticides/ insecticides	1	0,97	0,00	0,44	0,00

Table 25: Calculation factors based on multiple sources

Water use reduction from different sources:

hydroponics	*glasshouse*	***hydroponic Glasshouse***	***Plant factory***	***Plant Factory opposed to Glasshouse***	***Source:***
-		0,25	0,0667		https://www.rockwool.com/group/about-us/our-thinking/sustainability-and-circularity/water-management/
0,1					https://www.boldbusiness.com/infrastructure/hydroponics-methods-water-conservation/
0,05					https://blog.zipgrow.com/water-use-efficiency-hydroponics-aquaponics/
0,2					https://www.greenhousemag.com/article/hydroponics-provides-major-water-savings/
-	0,11	0,075	0,02		https://www.researchgate.net/publication/47866259_Water_use_efficiency_of_tomatoes_-_in_greenhouses_and_hydroponics from table 2
-	0,19379845				https://www.researchgate.net/publication/47866259_Water_use_efficiency_of_tomatoes_-_in_greenhouses_and_hydroponics from table 3
-	0,25				https://www.researchgate.net/publication/47866259_Water_use_efficiency_of_tomatoes_-_in_greenhouses_and_hydroponics tekst
0,1					https://www.powerhousehydroponics.com/innovative-water-saving-methods-in-hydroponics/
0,05					http://help.upstartuniversity.net/en/articles/941911-how-efficient-is-water-use-in-hydroponics-aquaponics
-		0,08			https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4483736/
-	0,39				https://www-sciencedirect-com.tudelft.idm.oclc.org/science/article/pii/S1877705816323207
0,15	0,67				https://www.researchgate.net/publication/342397217_WATER_USE_EFFICIENCY_IN_GREENHOUSE_SYSTEMS_AND_ITS_APPLICATION_IN_HORTICULTURE
-	0,64516129				https://www.greenhousemag.com/article/gm0911-selective-shading-water-efficiency-greenhouse/
-	0,3				https://ieeexplore.ieee.org/document/6970300
-				0,02	https://www.researchgate.net/publication/338557118_Plant_factories_in_the_water-food-energy_Nexus_era_a_systematic_bibliographical_review
-			0,01		https://www.mdpi.com/2071-1050/12/11/4640/htm
-				0,05	https://www.actahort.org/books/1004/1004_2.htm
-				0,025	https://www.sciencedirect.com/science/article/pii/B9780128017753000044
-	0,3125				https://www-sciencedirect-com.tudelft.idm.oclc.org/science/article/pii/S2214317315000463
-				0,05	Kozai, Toyoki, and Genhua Niu. 'Conclusions'. In Plant Factory, 395–99. Elsevier, 2016. https://doi.org/10.1016/B978-0-12-801775-3.00028-7.
0,108333333	**0,358932467**	**0,135**	**0,032233333**	**0,03625**	**Average**

Fertiliser use reduction

hydroponics	Glasshouse	Hydroponic Glasshouse	Plant factory	Plant Factory opposed to Glasshouse	source:
0,6					https://www.boldbusiness.com/infrastructure/hydroponics-methods-water-conservation/
0,4					https://www.greenhousemag.com/article/hydroponics-provides-major-water-savings/
0,5	0,745				https://www.researchgate.net/publication/342397217_WATER_USE_EFFICIENCY_IN_GREENHOUSE_SYSTEMS_AND_ITS_APPLICATION_IN_HORTICULTURE
-				0,1	https://www.researchgate.net/publication/338557118_Plant_factories_in_the_water-food-energy_Nexus_era_a_systematic_bibliographical_review
-			0,2		https://www.mdpi.com/2071-1050/12/11/4640/htm
-	0,78170940				https://www-sciencedirect-com.tudelft.idm.oclc.org/science/article/pii/S2214317315000463
-				0,5	Kozai, Toyoki, and Genhua Niu. 'Conclusions'. In Plant Factory, 395–99. Elsevier, 2016. https://doi.org/10.1016/B978-0-12-801775-3.00028-7.
0,5	0,763354701	#DIV/0!	0,2	0,3	Total

Energy use increase

Glasshouse	**Plant Factory**	**Plant Factory opposed to Glasshouse**	**Source:**
-			https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4483736/
-		1,19047619	https://www.researchgate.net/publication/338557118_Plant_factories_in_the_water-food-energy_Nexus_era_a_systematic_bibliographical_review
1,300589391			https://www-sciencedirect-com.tudelft.idm.oclc.org/science/article/pii/S2214317315000463
-		0,454545455	Kozai, Toyoki, and Genhua Niu. 'Conclusions'. In Plant Factory, 395–99. Elsevier, 2016. https://doi.org/10.1016/B978-0-12-801775-3.00028-7.
	6,782583058		
		14	
1,300589391	**6,782583058**	**5,215007215**	**Total**

Pesticide use reduction

Hydroponics	Glasshouse	Hydroponic Glasshouse	Plant Factory	Plant Factory opposed to Glasshouse	source
0,45					https://www.researchgate.net/publication/342397217_WATER_USE_EFFICIENCY_IN_GREENHOUSE_SYSTEMS_AND_ITS_APPLICATION_IN_HORTICULTURE
-			0		https://www.mdpi.com/2071-1050/12/11/4640/htm
-				0	https://www.actahort.org/books/1004/1004_2.htm
-	0,97				https://www-sciencedirect-com.tudelft.idm.oclc.org/science/article/pii/S2214317315000463
-				0	Kozai, Toyoki, and Genhua Niu. 'Conclusions'. In Plant Factory, 395–99. Elsevier, 2016. https://doi.org/10.1016/B978-0-12-801775-3.00028-7.
0,45	**0,97**	**#DIV/0!**	**0**	**0**	**Total**

8.9. Selection of growing methods for crops

	Glasshouse or Plant Factory	In Soil or Hydroponics	Not stacked or stacked
Apples	Glasshouse	Full Soil	Not stacked
Raspberries	Glasshouse	Full Soil	Stacked
Mandarins	Glasshouse	Full Soil	Stacked
Lettuce	Plant Factory	Hydroponics	Stacked
Spinach	Plant Factory	Hydroponics	Stacked
Kale	Plant Factory	Hydroponics	Stacked
Tomatoes	Plant Factory	Hydroponics	Stacked
Bell Peppers	Plant Factory	Hydroponics	Stacked
Carrots	Plant Factory	Hydroponics	Stacked
Onions	Glasshouse	Hydroponics	Stacked
Garlic	Glasshouse	Hydroponics	Stacked
Eggplant	Plant Factory	Hydroponics	Stacked
Mushrooms	Plant Factory	Hydroponics	Stacked
Wheat	Glasshouse	Full Soil	Stacked
Potatoes	Glasshouse	Hydroponics	Stacked
Sweet potatoes	Glasshouse	Hydroponics	Stacked
Peas	Plant Factory	Hydroponics	Stacked
Green beans	Plant Factory	Hydroponics	Stacked
Peanuts	Plant Factory	Hydroponics	Stacked
Pistachios	Glasshouse	Full Soil	Not stacked
Flaxseed	Glasshouse	Full Soil	Stacked
Coffee beans	Plant Factory	Hydroponics	Not stacked
Grapes	Glasshouse	Hydroponics	Stacked
Malt	Glasshouse	Full Soil	Stacked
Mint	Plant Factory	Hydroponics	Stacked
Basil	Plant Factory	Hydroponics	Stacked
Oregano	Plant Factory	Hydroponics	Stacked

Table 26: Selection of growing methods for crops (from own calculations)

The selection methods are based on data gathered in the calculation numbers sheet on page 30. The first choice between glasshouse and Plant factory is made by determining which number in the table on page 30 (in columns 2 and 3) is the largest. If the rating for Glasshouse is higher than that for the plant factory, the Glasshouse is chosen. If the number for the plant factory is higher or equal to that of the Glasshouse, the plant factory is chosen.

The same goes for the choice between full-soil and Hydroponics. However, here "Hydroponics" is selected if the number in the table on page 30 in the fifth column is higher or equal to 0,5. If the number is the lowest, It will say "Full soil".

Whether a crop is stacked or not depends on the height of the crop. The crop height is multiplied by a factor to account for the height of the stack and the space needed between the growing lights and the crop itself. This factor is lower if the crop is grown with Hydroponics because that would require only a very shallow tray to flow water in. When the crop height is multiplied, and this number is lower than the height of one farm floor (defined in totals: inputs on page 17), the crop can be stacked vertically.

8.10. Community: Organisational diagram and flow scheme

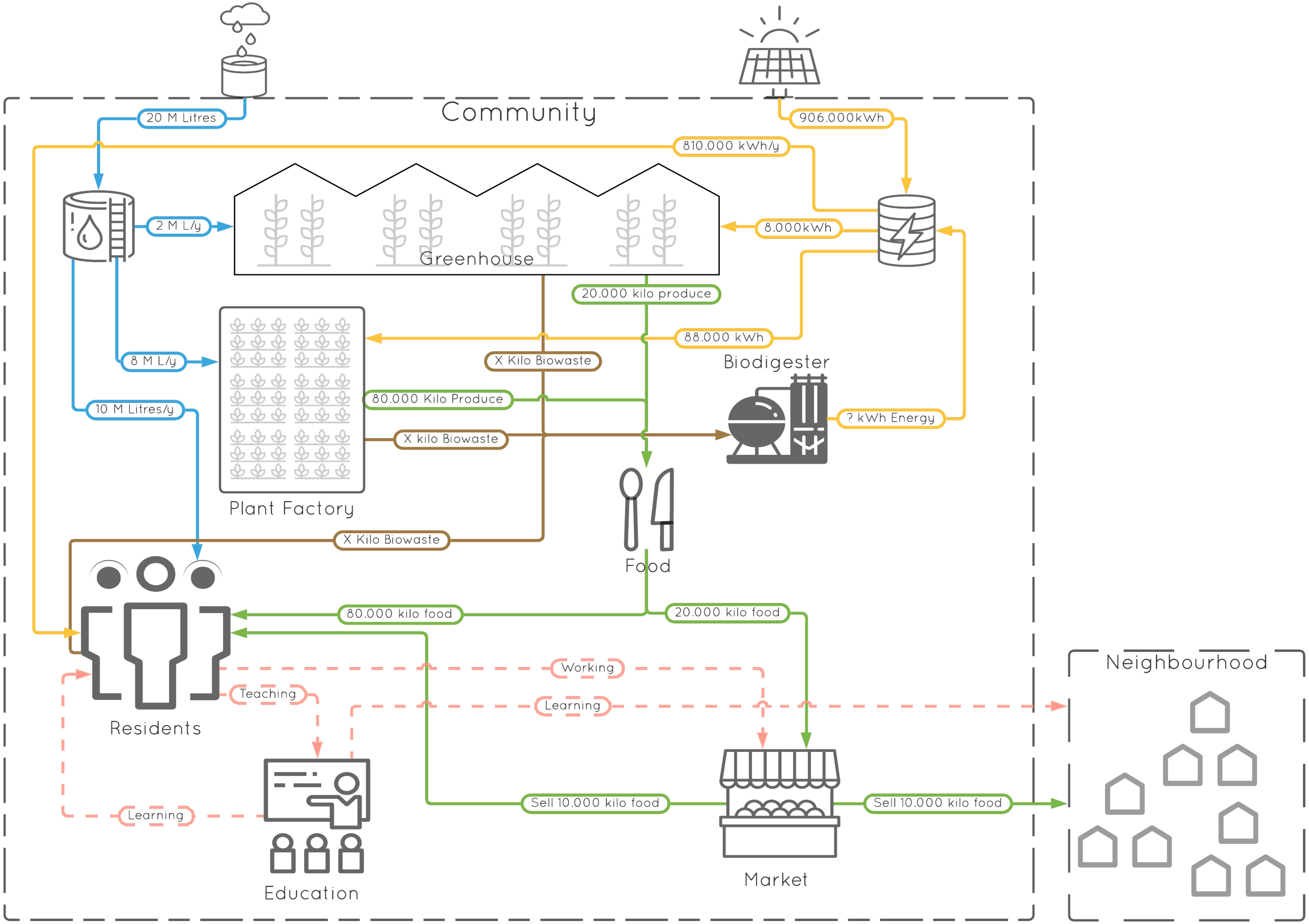

Figure 16: Community Organisational and Flow diagram. (own image)