Geo-information Science and Remote Sensing

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The municipality of Amsterdam as a case study

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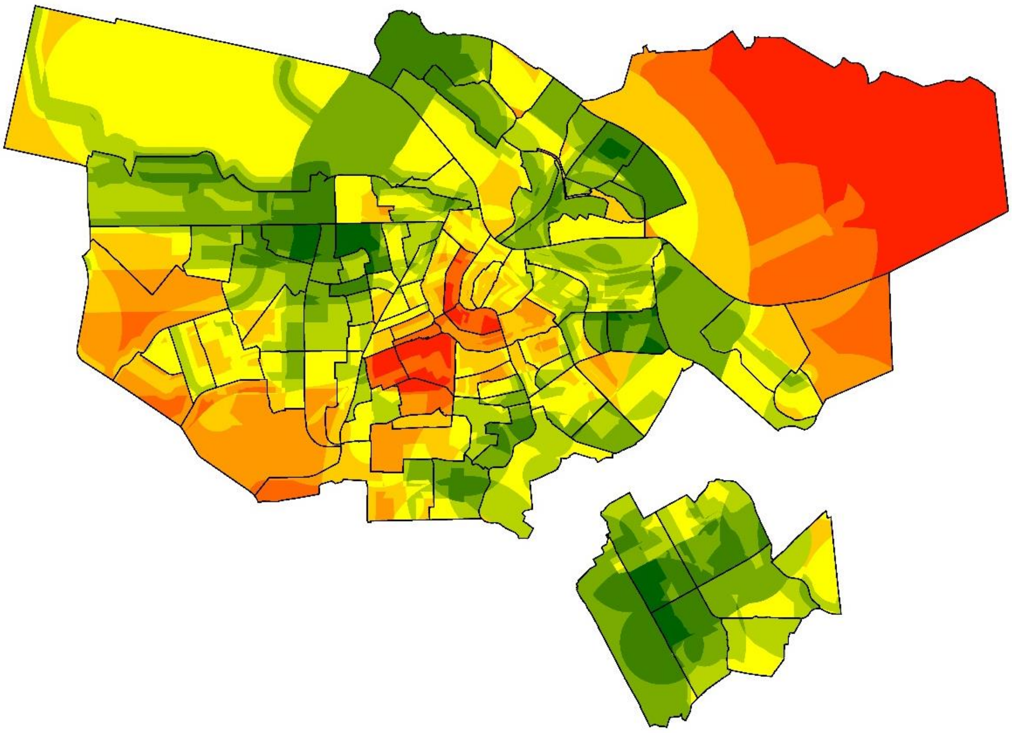

WAGENINGEN UNIVERSITY & RESEARCH

Analysis of the spatial conditions and its context-dependent sensitivity for a vertical farm's location decision

The municipality of Amsterdam as a case study

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Foreword

This thesis is executed as part of the master program Urban Environment Management (MUE) at the Wageningen University and Research. As a track within my studies I chose geo-information science, part of the GIRS chair group in Wageningen. During my studies of MUE at the Wageningen University I specialised in food and agriculture in the urban context. This thesis is an attempt to combine the work fields of urban sustainability, food provisioning and geo-information science. For the work I spend the first half of the thesis work venturing into the field of vertical farming, and the second part of it was focused on taking the findings to the field of geo-information science.

I want to thank Ron van Lammeren as my supervisor and for letting me discuss all aspects of the thesis including the things outside of the domain of geo-information science. I also want to thank John Stuiver for providing insights into the use of different methods to come to a result for my case and for validating my approach on it.

Furthermore, I want to thank the interviewees that were willing to talk with me about the concept of vertical farming and the spatial aspects it might hold. Their input has proven to be essential for the analysis.

I hope my research can contribute to the debate around vertical farming and can provide insights into the importance of spatial conditions for a vertical farm's location decision. Hopefully, it is both an interesting read for those familiar with geo-information science as well as those more affiliated with vertical farming.

Abstract

The rise in urban population and increasing stress on agricultural land in combination with the advancement in technology of indoor farming have sparked the idea of producing food in urban areas in vertical farms. Decision making of vertical farm location is done without a proper consideration of spatial conditions that influences its success. Research on the location, or spatial characteristics of vertical farming is virtually absent. This study is the first endeavour of a location analysis for vertical farming. A literature and interview analysis are performed to examine criteria that are of importance. Twelve criteria were found that are valid in Amsterdam, The Netherlands, and are used as an input for a spatial GIS (Geographical Information System) based Multi-Criteria Analysis (MCA). Five scenarios that can motivate decision-makers were formulated. The MCA led to suitability maps for vertical farming according to the scenarios. Vacant buildings and lots are used exemplary to demonstrate how the suitability maps can help in guiding the decision-making process. The scenarios show how different approaches to vertical farming can lead to a different suitability and decision of a vertical farm's location. Improved understanding of the impact of spatial criteria is achieved and the use of these criteria gives valuable insight into the context-dependent suitability of vertical farms. Applying the same strategy to another study area needs careful re-assessment of the criteria there and their overall validity. Results are affected by the availability and quality of the (spatial) data.

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1 Introduction

1.1 General background

Human population has recently surpassed 7 billion, and it is projected to grow to 9 billion by 2050. In convergence with the current urbanisation rate means this growth is concentrated in cities (King et al., 2017). As an effect, the share of the rural population is declining. Traditionally food production has been associated with and executed by the rural population. In the last century the separation of the rural and urban landscape increased by planning practices in the light of Corbusier and modern urban planning (Pons et al., 2015). However, this strict boundary between the producer and the consumer is fading. The growing (urban) population, increase in urban migration and the stress on agricultural land ask for solutions to increase the amount of food that we can produce while using less land. Currently, the world occupies the size of South America as agricultural land (United Nations, 2014), and there is little extra land available without further damaging existing ecosystems (Lin, Philpott and Jha, 2015). Potentially, part of the solution lies in the urban environment. Of late there has been a trend in urban agriculture (Lin, Philpott and Jha, 2015; Hemenway, 2015). The (urban) citizens want to take responsibility for their own food consumption (Hemenway, 2015). People are more concerned about the origin of their food, and produce food in their backyards and in communal vegetable gardens for personal consumption (Veen, Derkzen and Visser 2014). Cities are looking for alternative ways to feed their population; aiming at sourcing healthy, local and sustainable food and increasing food security (Lin, Philpott and Jha, 2015). Producing food in cities reduces the distance that food needs to travel to their consumer, increases emphasis on seasonal products and a renewed appreciation for local traditional food and recipes (King et al., 2017).

1.2 The emergence of vertical farming

In recent years there has been a rise in the concept of vertical farms after the idea and ideal of Dickson Despommier (2010; VPRO Tegenlicht, 2017). These (high-tech) vertical farms are able to produce large quantities of food on limited acreage and in the middle of a city. Technology has improved to the level that large-scale farming is now being executed in the middle of the city, through vertical farming (Kozai and Niu, 2015a). This technology is constantly advancing and has the potential to become a major alternative food production system (Despommier, 2013).

Farming in an urban environment, an environment with a high population and infrastructure density, does not have to be restricted to small-scale hobby farming anymore (Despommier, 2010). Indoor farming is developing at a fast pace and is making new locations for farming viable. Soilless gardening, or hydroponics was already developed in the 1930s (Gericke, 2010), but the boom in usage only catalysed recently (Despommier, 2010). Moreover, the way light is supplied to allow plants to photosynthesize has changed drastically. Light Emitting Diodes (LEDs) have replaced direct sunlight in indoor farms as the source for plants to photosynthesize and grow. They can be controlled by software together with other factors, like the indoor atmosphere in the farm to create perfect growing conditions. These conditions can be made specifically for a type of plant, or even for a desired nutrient composition of a plant (Shimizu et al., 2015). Moreover, with the right implementation, a vertical farm can play a vital role in controlling the resource flows of cities, both the inflow and waste outflow (Despommier, 2010; Kozai and Niu, 2015a) and integrating agriculture in the city (dos Santos, 2016). Meanwhile, a vertical farm is not a picturesque vegetable garden where every citizen decides individually what they want to grow and harvest. However, important aspects of urban agriculture can be incorporated to make a vertical farm a valuable addition to the socioeconomic landscape of a city. It can make the citizens come into close contact again with the food production. It can offer solutions for food security issues and incorporate social work to the benefit of the community (Besthorn, 2013). Moreover, urban agriculture, and thus vertical farming, in the urban landscape, can connect to the recent surge in interest of food in urban policy (Wiskerke, 2015) and give it more momentum.

Many high-tech farms are currently built in places far away from urban centres. Low land costs make sure the farms can be economically viable (e.g.: Sundrop Farms, South Australia). This also means larger transport routes and less guarantee on the freshness of food (Kozai and Niu, 2015a). Urban vertical farms must compete with these by keeping the price of the product as low as possible. Using the advantages of the city while keeping the land costs at a minimum. An asset they have over their rural counterparts is that they can deliver ultra-fresh (harvested less than an hour before) fruit and vegetables to the consumer (Despommier, 2013) and it has a smaller impact of food transportation on the environment (Benis and Ferrão, 2017).

In line with these developments, the Wageningen University has rolled out a challenge for students to design an urban farm, either a greenhouse or vertical farm, in a Dutch city that started in 2018 ('Design the Ultimate Urban Greenhouse', 2017). This thesis is written concurrently with the arrangements for this challenge and thus focuses on a Dutch city.

1.3 Problem definition

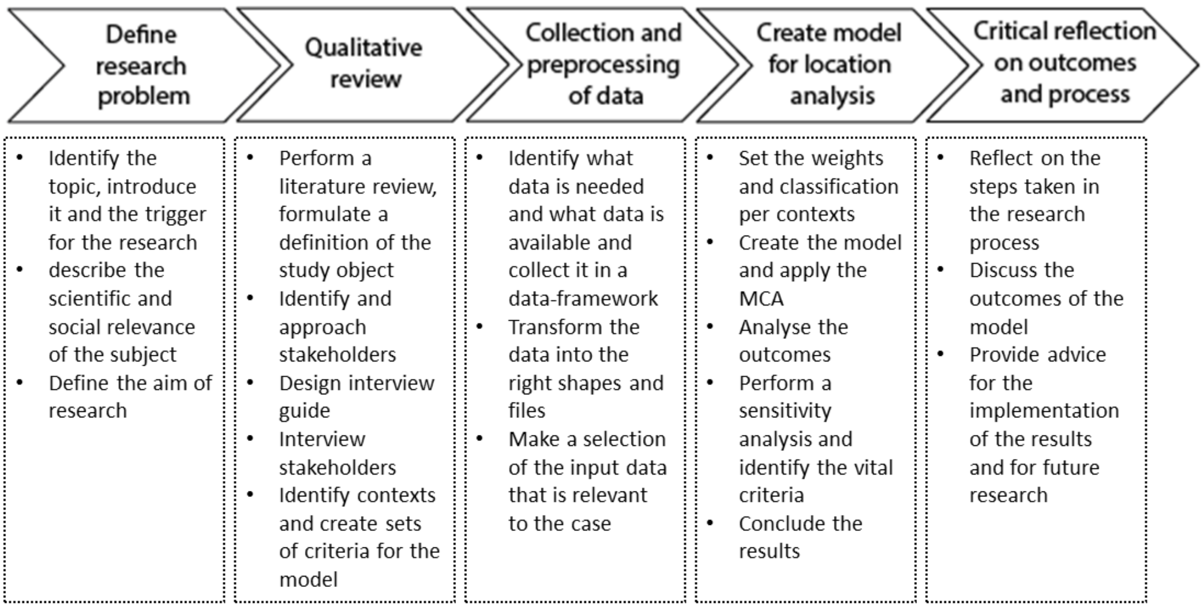
Combining large-scale food production with the inner-city landscape is a novelty, of which the opportunities and challenges are gathering more attention, leading to multiple discussions and research (Al-Chalabi, 2015; Goldstein et al. 2016; Pons et al. 2015; Sarkar, 2015; Specht et al., 2013; Specht and Sanyé-Mengual, 2017). Remote-sensing studies have been performed to evaluate the food-yield potential of urban greenhouses and rooftop gardens (Nadal et al., 2017; Saha and Eckelman, 2017). Research on the location or spatial characteristics of vertical farms in a city is virtually absent, however. The lack of this knowledge means that the decision-making is done more intuitively without a full examination of the constraints and advantages of a location. Or that they are assessed through a different decision method, as was the case for the 'Design the Ultimate Urban Greenhouse'-challenge. Here the location and its spatial assets and constraints were not analysed extensively until the decision was already made. A location analysis can help with examining the possibilities and risks of vertical farms and thus increase its success rate. With the knowledge generated by a location analysis, the decision-making process can be guided (Malczewski, 2006). Through analysing the criteria, valuable information on the vertical farming concept is generated, which can facilitate the advancement of this technology.

The case study in this research is the municipality of Amsterdam, The Netherlands. The research is focused on a spatial-temporal site-selection process for a vertical farm. The problem is divided into two distinct problems with different research angles. Which spatial-temporal criteria determine a vertical farm's location (qualitative) and how can these criteria be used for finding the best location (quantitative). Given the lack of other research on the topic, the research is an explorative endeavour into vertical farms. The first part of the research is a venture for the criteria, whilst the second part focuses on using the criteria found for a location analysis.

1.5 Reading guide

Since this research has a distinct qualitative and a more quantitative phase, the document has been split up accordingly. The overall outline of the research is presented (figure 1.1) and explained. The report started with defining the research problem. Chapter two discusses the qualitative review for the criteria analysis that is done with the help of literature and interviews. First, a definition on vertical farming is given, followed by a brief methodology and study area. The information found in the literature and from analysing the interviews is presented in the criteria analysis review. All criteria considered are discussed here. In conclusion, the criteria that qualify or not are revisited. In chapter three the start is made with the review of the location analysis and a spatial MCA in particular. The review part covers both elements for the pre-processing as well as for the processing. The methodology and execution of these steps are written separately for each step in the process. After the review, the methodology for the data pre-processing is explained: where does the data come from and how is it transformed and standardised. After this is performed, the decisions made are described and the resulting map is shown per criteria. These maps serve as the input for the processing. The steps taken to come to the suitability, i.e. the weighing of the criteria and the potential locations, are explained. Executing these steps leads to the suitability map of Amsterdam and the best locations, given the input. The outcomes are further analysed to give the outcome more depth. Scenarios are constructed to delve into the differences between decision-making contexts in chapter four. The outcomes are compared to each other. Chapter five contains the conclusion of the research. In the final chapter, attention is given to discussion and reflection on the choices made in the research and the uncertainty of the model and last but not least recommendations are given for further research and implementation of results.

Figure 1.1 Outline of the research



2 Criteria Analysis

1.4 Research objectives

The research objective is to find spatial conditions that determine a vertical farm's best location and the sensitivity of context-dependent spatial conditions using Amsterdam as a case example. Spatial conditions are the criteria and their spatial relation with vertical farming. Contexts are different scenarios that can possibly motivate decision makers in their choice of location. To come to this result four questions guide the process and outline of the research.

1. *What (sets of) criteria must be considered when planning a vertical farm's location?*

2. *How can the location criteria for a vertical farm be used in a model to determine the suitability of sites within a study area?*

3. *To what extent can the suitability be used to find the best location for a vertical farm?*

4. *How do context-dependent spatial conditions alter the suitability of a vertical farm's location?*

The research questions facilitate in reaching the main objective. First, the criteria that are important for an urban vertical farm's chance of success are determined. This is consequently used to build a model. Modelling also adds the benefit of re-evaluating your inputs constantly to come to the right procedure. This model combines the different criteria gathered and adds a spatial-temporal dimension to them, the basis for a spatial location analysis. This serves as input for a map scoring the city with least to best suited areas and specific locations according to the parameters of a given context. The last step is to determine the actual sensitivity of the model. MCA's can be sensitive to changes in the parameters or sets of parameters leading to different scores or outcomes. To find out how different interpretations can affect the outcome a sensitivity analysis will be conducted.

2.1 Review motive

As a start of the research, the focus is on the concept of vertical farming. The revival of the term vertical farming was catalysed by the publication of Despommier in 2010. Before this publication, there is little written on vertical farming. Since it has only been less than 8 years from that moment, the amount of literature on the subject is still limited. To get a better understanding of the subject a variety of sources of information, not only scientific, are used and critically examined. Blogs on vertical farming and publications by companies and organisations helped giving shape and context to vertical farming. It also provides with interesting reads on the reasons for success and failures of vertical farms. Soon in the process, it became apparent that different people have different ideas of vertical farming and that it is important to define the study object. In the next paragraph the definition is examined and formulated before the next part of the research can be framed and conducted. Then a brief explanation is given on the different methods of delving into the criteria. Afterwards, the actual review and analysis are presented.

2.1.1 Vertical farming definition

Before diving into the criteria it is important to think of and define the actual subject of study. The subject is the vertical farm, a concept that is simple in the literal meaning of the words: a farm in which produce is grown vertically instead of (only) horizontally. In practice, there is a large variation in how it is perceived by different companies, and how the vertical element is approached in terms of techniques and use of space. The revival of the concept of vertical farming by Despommier is still fresh and it can thus be the reason that the concept is not yet framed exclusively. He defined the vertical farm broadly:

"A vertical farm is a 2-story or higher high-tech greenhouse and nothing else, ever" – Despommier, 2016

Meanwhile, the scientific interest is mostly toward the practice of vertical farming and not the theory behind it. This has meant a more distinct definition, or specification of the different type of farms that have sprouted in recent years is lacking. When looking for information on vertical farming a lot of different names come up that are linked to vertical farming or used instead: "*Agritecture, vertical farming, urban farming, high rise farming, rooftop farming, rooftop hydroponic greenhouse, high-density farming, skyscraper farming. Building integrated agriculture, facade farming, hydroponicum, interior agriculture, plant factory (with artificial lighting), warehouse farming*" - are just examples amongst many others. They all contain elements of vertical farming. However, they are not all the same. They vary in their technological complexity and require different materials and resources to exist. Moreover, the techniques used within the different concepts can vary a lot and determine the requirements for the farm to function. Techniques that are often mentioned are: *"hydroponics, aeroponics, aquaponics, passive hydroponics, open environment, controlled environment agriculture. Fully LED driven, semi LED-driven, greenhouse style, growing under direct sunlight, fertigation,* *aquaculture",* amongst many others. A farm can make use of multiple, but there are a lot of different 'recipes' on which vertical farms are built. In practice this means not all vertical farms are similar and the term vertical farm does not address one uniform concept. To research the location criteria of a vertical farm it is crucial to set a clear definition for which the location is sought for. The definition set up by the Association for Vertical Farming (AVF) is more specific than the definition of Despommier:

> *"Vertical farming is the practice of growing food and/or medicine in vertically stacked layers, vertically inclined surfaces and/or integrated in other structures. The modern idea of vertical farming uses Controlled Environment Agriculture (CEA) technology, where all environmental factors can be controlled. These facilities utilize artificial control of light, environmental control (humidity, temperature, gases,..) and fertigation. Some vertical farms make use of techniques similar to greenhouses, where natural sunlight can be augmented with artificial lighting". – AVF, 2017a*

Here, other than a vertical farm being a multi-storied greenhouse, it defines some techniques and says something about the environment in which the plants grow. This is regardless of the number of stories in the buildings, something the AVF and Despommier do not agree on (Gordon-Smith, 2016). The Japanese Toyoki Kozai, the author of 'Plant Factory', who has written extensively on farming vertically, addresses the farms and research objective as Plant Factories with Artificial Lighting (PFAL), and defines them by their aim accordingly:

> *"PFALs aim to grow high-value produce (product of the yield and unit value or quality) with maximum Resource Use Efficiency and Cost Performance, minimum vulnerability of yield and quality of produce, and minimum emission of environmental pollutants. However, PFALs are an emerging and thus technically immature production system, so their commercial application is still very limited". – Kozai and Niu, 2015a*

In his definition it is more about the type of produce that a vertical farm can deliver with maximal performance using little resources and minimum amount of money. It must thus be economically viable for its functionality and have limited impact on the environment. He acknowledges that at this moment the development of vertical farming is not at the stage of full implementation yet. It is thus arguably still in the R&D phase of the technology; with negative income from the inputs and a relatively high amount of failures.

All three definitions describe the vertical farm as a high-tech farm, within an enclosed space where produce is grown vertically. For Despommier that is all. The AVF and Kozai specify more about the environment in which the plants grow: a controlled environment. And the source of energy that is needed to let them grow: artificial lighting. The vertical farm's definition that was used in the research included these two aspects: "*A vertical farm is a high-tech farm within a closed, controlled environment where food is grown vertically under artificial lighting".*

To facilitate the research, elements of all definitions mentioned are considered when developing the final research entity. To cover more possibilities in design and purposes of the farm, different contexts in forms of scenarios are created to help with differentiating within the research and covering the heterogeneity of purposes of vertical farms. The interviewees were asked to give the definition of a vertical farm, in their own words, at the start of the interview. This to make sure it was clear what was referred to as a vertical farm in the interviews.

2.2 Criteria analysis – Methodology

The definition of vertical farming is taken to the review of the criteria and used as a reference point for the literature and interviews. Before starting the review the stakeholders are analysed, an interview guide is set up and the case area is framed.

2.2.1 The identification of stakeholders

The aim was to speak to a number of stakeholders that are or have been involved in vertical farms. Their relation could be anything from vertical farmer to researcher and facilitator. To identify the different stakeholders various sources were addressed online, within the university and in the personal network. This resulted in seven interviews. These interviews are numbered A-G, and referred to anonymously in the text. Eventually, three researchers from universities, two companies that are involved in the construction of vertical farming equipment and/or environments, one bank and an advocacy organisation for the horticulture sector were interviewed.

2.2.2 Interviews

The interviews were done in a semi-structured manner. Questions were prepared in a logical order according to areas of interest to the research. In general, the interviews started with a short introduction of the interviewer and the research and an introduction of the interviewee and his or her relation to vertical farming. The actual interview always started by asking what the definition of vertical farming is according to the interviewee's own interpretation. This to make sure that the subject of the interview was clear to all persons present. The answers also helped to verify the vertical farming definition. From there on the interview was guided by the answers of the interviewee. For the interviewer it was important to keep the things that were of interest to him in mind and make sure that all subjects were covered by the end of the interview. The important issues were:

- Location criteria for a vertical farm;
- What typifies a vertical farm to the interviewee;
- What is the current relevance of a vertical farm (profit, research, educational, social awareness etc.);
- What are the techniques used, and what amount of production is possible with these techniques;
- Is there any spatial data associated with the criteria available? (if the interviewee is aware of this).

The complete interview guide including the questions and introductions of the interviewees can be found in appendix A. Interviewees were asked a variety of question, also specific to their expertise or interest not covered by this guide.

A recording was made of interviews for which it was possible to do so. A keyword summary and bio of each person interviewed are available in separate documentation. The interviews give valuable insights into the practice, research and the momentum around vertical farming. Although the subjects all have different interest, many of the same aspects were mentioned and discussed.

2.3 The case of Amsterdam

Before moving on to the actual criteria and the collection of data used to test the model an area or case study had to be determined. The study area of the applied research was set at Amsterdam from early on in the process. A reason for this was that the preparation for the 'Design the Ultimate Urban Greenhouse'-challenge at the Wageningen University was concurrent with the start of this research. The location chosen in the challenge is in Amsterdam. The procedure to come to this decision was not based on anything from this research and the affiliation between the challenge and this thesis faded throughout the months since an actual, specific location was already chosen. However, as the case of this research, the city of Amsterdam is still of interest. It is the capital and largest city of the Netherlands in terms of inhabitants. The municipality of Amsterdam is focusing more and more on sustainability in all aspects of its processes and flows. It has special arrangements for urban agriculture and subsidies to start your own initiatives (Gemeente Amsterdam, 2018). Urban agriculture projects exist in many parts of Amsterdam. With city farms on the fringes and allotment gardens and school gardens scattered over the city (Maps.amsterdam, 2018). There are a few small vertical farms sprouting including mushrooms farmed in containers, hydroponic growing near restaurants for own consumption, an urban greenhouse on top of a newly built hotel (Amstelside hotel) and 'GrowX' a four-layered vertical farm in Amsterdam Zuid-Oost of 250 m^2 (AGF, 2017). Besides these, there are other organisations that directly or indirectly promote or facilitate urban agriculture in the city. The Amsterdam Institute for Metropolitan Solutions (AMS) is a collaboration between many actors including the Wageningen University and the municipality of Amsterdam in research on applied technology solutions for sustainability in the urban context (AMS, 2018). This creates an active environment for innovation. The cultural organisation of Pakhuis de Zwijger is an independent platform for the city of Amsterdam and has had multiple programmes around vertical farming with a high attendance and involvement of the community (Pakhuis de Zwijger, 2017). The subject is thus actively discussed in the city and the community is keen to get to know more about the possibilities and implications of vertical farming. Another important asset of the municipality is the availability of data. The choice of Amsterdam means that a wide variety of geospatial data is readily available through their own portal: 'Maps Data'. This is convenient in the data acquisition phase and saves a lot of time preparing and transforming data relevant to the study. Altogether the city is an interesting case study area, with both initiatives and interest around urban agriculture and a wide availability of data. In the interviews different geographical areas and scales were discussed with Amsterdam and the Netherlands being the focal point. This led to important findings and ideas on the importance of the spatial context in which a farm is being built. This is discussed in the first part of the results.

2.4 Criteria analysis – Review

In this part, all the results from the literature and interviews are presented and analysed. It to a variety of criteria that are important to a vertical farm. Each criterion that was considered and its importance is discussed here. In practice there are numerous conditions and influences that have their role in the production of plants indoors. Only those that are relevant to the *location* of vertical farms were taken into consideration and analysed. The number of criteria mentioned or distilled from the research is large and the feasibility of each criterion has to be critically addressed. It is at times also a critical reflection of the possibilities and importance of each criterion in The Netherlands compared to other countries. The step that follows this analysis is to determine whether the criteria can be spatially characterised.

2.4.1 The crop

In a vertical farm, basically any plant can be grown. If enough space and the right conditions are provided for the specific growth of each plant (interview B). A distinction is made between plants that are suitable for consumption and those that have other potentials (see '*alternative uses'* text box). Since the focus is on feeding the population only crops that can be eaten are considered. Some crops have more potential than others in a vertical farm for various reasons. Maximising space is an important element of the vertical farm, due to the high price of space in urban areas. Ideally the crop:

- can be grown on limited space (Interview B, Agrilyst, 2017, Despommier 2010);
- is in demand so there is a market (interview D);
- is efficient with the current technique (Bright Agrotech, 2017);

Furthermore, it can be advantageous if a high percentage of the crop can be eaten. A lot of the created value can then be sold and it leaves less waste in the production process (Kozai and Niu, 2015). Crops that can be grown and harvested fast minimise liability because the next production can be guaranteed within a short timeframe (Bright Agrotech, 2017) and can generate high revenues (Agrilyst, 2017).

> *Alternative uses*:
> ***Seedlings:*** Some farms that have been set up with artificial lighting are used for growing seedlings (Nunomura et al. 2015). They are then sold to other farms where they are grown further. The business is in providing materials for food production (seedlings instead of seeds) and is not considered in this research. It can, however, be a highly effective form of vertical farming, one however for which a (urban) location is of less importance.
> ***Medicine:*** a second alternative is that of medicine (Sma, 2015). Many essential ingredients of medicine are derived from plants, making them high-value options. Vertical farms solely focused on these plants could reduce the costs and/or availability of medicine to hospitals and pharmacies.

The five main crops types that are used for indoor and vertical farming are leafy greens, tomatoes, herbs, flowers and microgreens (Agrilyst, 2017). Leafy greens account for nearly 60% of the crop in the US. In the Netherlands there are currently two active vertical farms in operation, that are focused on production, and one is expected to start its operations soon. One combines the growth of, mainly, fruit vegetables (tomato and bell pepper) with the cultivation of fish, an aquaponic growing system (De Schilde, Den Haag). The other two both focus on (a variety of) lettuce. GrowX supplies directly to restaurants and hotels in the Amsterdam area. The, currently being developed, 'Vanderstaaygroup' indoor farm in Dronten will supply its lettuce directly to a supermarket chain for its 'ready-made' salads.

Space

In a vertical farm, or any farm really, one of the factors that you need to be taken into account is the space needed for a plant to grow. When seeding, or thinning out the seedlings a decision has to be made on the row width and distance between plants within a row. Maximising the growth potential of individual plant and the number of plants that can be grown. Each specific plant needs different spacing according to the aimed size and shape it needs to get. In the common horizontal greenhouse tomatoes are generally grown along vertical installation, up to 3 meters into the air. Lettuce is grown more horizontally and does not often grow high (figure 2.1).

Figure 2.1 Commercial tomato and lettuce greenhouse farming

If you then want to grow each crop in different horizontal layers stacked on top of each other a certain height can obviously support many more layers of lettuce than tomatoes. Through this, the productivity of lettuce can even match that of tomatoes in terms of kg per m^2 (interview A; B; E). In greenhouses the maximum production per layer is around 90 kg per m^2 for tomatoes and 20 kg per m^2 for lettuce (Vermeulen, 2016). So there is a lot to gain for lettuce when stacking the layers for growth vertically. Of course, tomatoes benefit from stacking as well in terms of land cover. However, there is little advantage per floor to be gained. The average floor height in the Netherlands is between 2,5 and 3 meters. This means one plant covers the whole floor of a building.

Market

Within the European market, the Dutch horticulture industry produces the largest share of the total amount for a number of vegetables. Of all the fresh tomatoes 28%, cucumbers 42%, and bell peppers 54% was produced in The Netherlands in 2016 while using less land per kg produced than that other countries use. For lettuce the Dutch market share in Europe is only 4% (Vermeulen, 2016). So the share of lettuce in the Dutch farming system is relatively low compared to other possible produce. The Netherlands is already producing multiple times the domestic demand for tomatoes, cucumbers and bell peppers. The Dutch innovation (interview E) and planning (interview A) in the greenhouse sector has made it the second biggest exporter of vegetables in the world (interview E; Vermeulen, 2016) especially due to these crops. It has been able to use a limited amount of space to grow a large quantity of food. It is so effective that the cost price is low enough to compete with open field agriculture in countries in Southern Europe (Vermeulen, 2016). A vertical farm in a Dutch city primarily focused on either one of these vegetables is not likely to compete with the current greenhouses. The cost price will be multiple times higher, while the logistic advantages are negligible. The ultra-freshness of these crops is less advantageous, and sought for than that of lettuce because the shelf life is generally longer compared to lettuce. Only a specific market might be interested in sourcing fruit vegetables from a vertical farm. At this moment it is not realistic to produce this in the city at a substantial scale that could serve a substantial percentage of the population (>5%).

Efficiency

Lettuce is arguably the most efficient plant to grow under LEDs. It takes up little space and a large percentage of the harvested plant can be eaten. Subsequently, a lot of the energy that is being used to grow the plant is transformed into the edible material. In research facilities specific cultivars of lettuce have been able to produce up to 30 grams of plants material per mol of light used (interview G). In Japan the cost price of leafy greens has been lowered since the introduction of vertical farms. In 2017 already 150 vertical farms operate in the country and the majority produce lettuce and other forms of leafy greens (Kozai and Niu, 2015a). At Philips, with a specific cultivar of lettuce, they have achieved a production up to 100 kg per m^2 (interview G). This is in terms of growing space and not floor area. So that means you could stack this on top of each other and reach numbers exceeding 100kg per m^2 when using several layers.

Choice

For this study, the main crop that is focused on is lettuce and will be used for calculations on the potential of locations. It can be grown on a limited space, is an attractive crop in terms of ultra-freshness and less cultivated than other crops in The Netherlands, and can be grown effectively in vertical farms. Moreover, almost the whole plant can be eaten. Leafy greens are the most used plants to grow in indoor farming. Because they are valued extra by their freshness, and even while the leaves look green for an extended period, they taste best closer to harvest. Of course, the diet of people does not only consist of lettuce so the impact of others will be taken into consideration as well.

2.4.2 Logistics

The importance of logistics is captured by a statement of a bank that was interviewed: "the main concern of the vertical farm is not to produce the food, but how to get the food to your market" (interview D). For vertical farming this logistics are both the reason vertical farming is an interesting opportunity, as well as the basis of profitability. Both lead to the potential of the vertical farming in the urban landscape. For a vertical farm the importance is in the proximity to the consumer and getting your supplies and produce distributed in and out of the farm.

2.4.2.1 Proximity to the consumer

An asset urban farming, and in particular vertical farming, has over their rural counterparts is that one can deliver ultra-fresh produce to the consumer (Despommier, 2013). And the proximity to your market means the transportation distance is smaller than for farms in rural areas, and a smaller impact of food transportation on the environment as a consequence (Benis and Ferrão, 2017). In the US 75% per cent of all leafy greens (lettuce, spinach etc.) is grown in California (LGMA, 2016, interview G). As a result, these products have to be transported over large distances to supply the inhabitants of the whole country. This has a large impact on the environment. By the time the produce ends up in the supermarket on the east coast, it has travelled close to 5000 kilometres and the freshness can no longer be guaranteed. A lot of these leafy greens are lost in transport (interview E). Vertical farms in the US use this to their advantage by bringing the production closer to the market of the consumer. Especially for produce like leafy greens that have a short shelf life and are most attractive to consumers when bought fresh (interview G). Here the vertical farm is not solely a farm in an urban environment, but also a method to physically shorten the chain from production to consumption. However, comparing this with The Netherlands the distance factor and advantages of vertical farming is much less present. A farm or greenhouse producing fresh food is never further away than a few hundred kilometres at most. Moreover, arguably, by international comparison, a lot of the production of food in the Netherlands can be classified under urban agriculture already and its success is largely due to its excellent logistics (interview A; C; D; E; F). Big greenhouse areas of 'Westland', 'Oostland' and 'Aalsmeer' are all within 20 kilometres of one of the largest municipalities in the country. Moreover, moving from 'cheap' (rural) to 'expensive' (urban) land in The Netherlands is fast and relatively cheap (interview D). Vertical farms in The Netherlands will have to compete with these greenhouses, while the absolute distance from the market to the consumer is not that different, providing limited benefits in terms of extra freshness or lower transport costs. So in The Netherlands, the proximity to the consumer is not the most interesting asset of the concept of vertical farming. However, it is still vital to its functioning. Without good logistics, a farm cannot provide its customers.

2.4.2.2 Where does it come from and where does it go?

One of the reasons The Netherlands is one of the largest exporters of food in the world is for a large part due to the effectiveness of the horticulture industry (Interview B). It has been able to thrive in The Netherlands because of the logistics (interview A). The favourable geographical position of the Netherlands allows for quick distribution of goods within the country and towards others. To compete with the current food producers a vertical farm must make sure it can source its input (nutrients, seeds, energy etc.) efficiently and deliver its produce to the market or consumer quickly (interview A; D; E). According to (interview D) a vertical farm is only interesting if the business plan is focused on getting your produce to the market, whatever the market may be. This means you will need a good location that allows for quick distribution of your products to your specific clientele. The size of the farm has an influence on what logistic conditions are desirable (Agrilyst, 2017). A small farm is most likely interested in supplying local shops, hotels and restaurants, a medium sized farm will be looking at a conglomeration of shops or a regional supermarket, a large farm is most interested in a large supermarket chain (interview A). For the supply of your growth resources different farm sizes have different approaches. If you decide to have your farm on the highest floors of an office space, you have to think of getting the supplies up, without interfering too much with other functionalities in the building. Lawyers and fertiliser sharing the same elevator might be a strange sight (interview E). In conclusion, it means the better accessibility a farm has for input and output of the flows the better. For the location analysis model this is represented by accessibility and proximity.

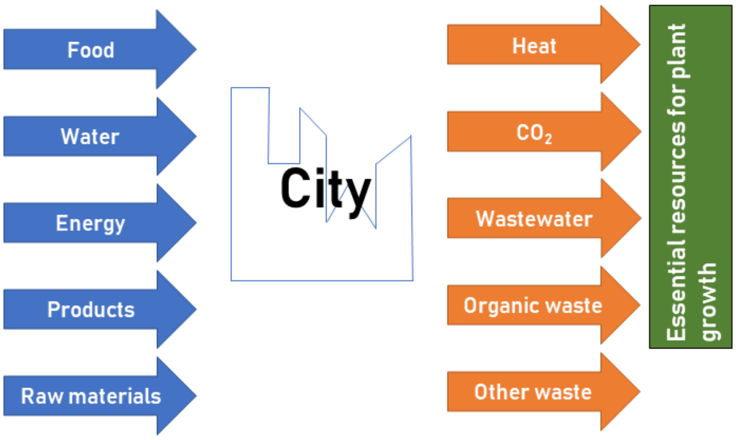
2.4.3 Circularity

Urbanisation has drawn more attention to the issues and consumption patterns of cities (Wiskerke, 2015). While more than 50% of the human population lives in cities, which is expected to grow to 70% by 2050 (UN, 2014). At the same time, they use 75% of all the resources in the world (Madlener and Sunak, 2011). A huge amount of inputs is needed to keep the system of the cities functioning. After they are used they are discarded and moved out of the urban system as waste: the inputs and outputs together form a linear system. Many types of waste contain valuable inputs for specific uses however and can be used again within the urban systems, making the system circular. Vertical farming in an urban environment can use the waste of other urban processes as an input for the growth of products inside and can reuse its own waste within the facility if managed well (Despommier, 2010; Kozai and Niu, 2015a). The Urban Harvest Approach (UHA) (Agudelo-Vera et al., 2012; Leusbrock et al., 2015), offers insight into the possibilities of recovering nutrients from urban resource flows. The strategies of this approach are demand minimisation, output minimisation and multi-sourcing. Urban agriculture has the potential to be a shackle in the chain of urban circularity by making use of the resources available in different (waste) flows in the city (Wielemaker, Weijma and Zeeman, 2018). Resource efficiency is key in optimising the circularity of any system and if applied to a vertical farm it can save costs and reduce the impact on the environment (Kozai and Niu, 2015a; interview A). In practice there are two levels on which the vertical farm can act towards circularity: within the system of the farm and through the urban system it is part of.

2.4.3.1 Circular system - urban level

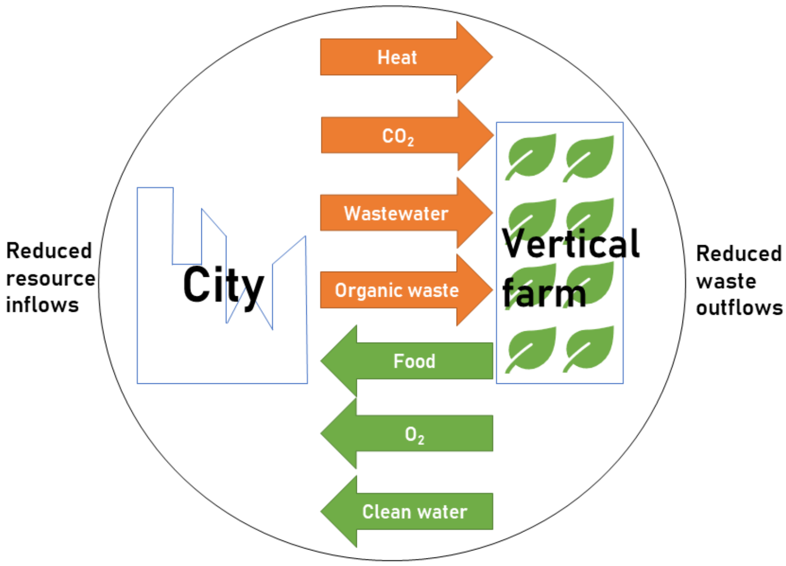
The urban system uses a lot of resources to function and is left with a lot of waste as a result of the urban processes. The resources are food, water, energy, products and raw materials among others. In a linear urban system it ends up in waste like heat, CO_2, wastewater, organic waste and other types of waste (figure 2.2). Of the five main waste streams four contain, or are essential resources for plant growth (Kozai and Niu, 2015a). The opportunity and challenge are to connect these waste flows to the vertical farm and use them as an input for plant growth.

Figure 2.2 Linear urban system



When a vertical farm is placed within the urban system and connected to its flows this benefits both the city and the vertical farm and creates circularity in the system (figure 2.3). Connecting the waste outflows of other processes to a vertical farm allows them to be (re-)used to grow plants. It reduces the overall inflow of resources in the city and the waste outflow. The products of the vertical farm (i.e. food, oxygen and clean water) are resources for other urban processes yet again, minimising the demand in the city of outside resources. It keeps resources flowing through the city, without leaving the system. Linking them together results in a more circular system. The possibilities are dependent on the size of the farm, the availability of resources nearby and the level of development of the required technology. There is a lot of research at this moment on reusing waste flows in the cities for other processes. The opportunities are evident, as shown by the above example. However, the technology or legislation is limiting the feasibility for some streams at this moment (Wielemaker, Weijma and Zeeman, 2018). In the model, the waste streams that have potential to act as resource input are taken as criteria. At this moment, with the current technology this is only (partially) possible for 'CO_2', 'Energy' and 'Heat'. Per waste stream an explanation is given:

Figure 2.3 Circular urban system with the addition of a vertical farm



CO_2

In the horticulture industry, CO_2 has long been used to increase the plant growth. Without adding this an indoor farm cannot function properly (Kozai and Niu, 2015a; interview B; E; F). It is a vital ingredient for the photosynthesis of plants, and without adding more it will slowly diminish since it is used up in the process. CO_2 enriched air, higher than the outside average, actually increases your yield and is one of the reasons indoor farming is more effective than outdoor farming. At a CO_2 level of 1350 ppm, it is up to 40% more effective compared to the outside value of 350 ppm. The increase reduces when the light and CO_2 levels become higher (Vermeulen 2014; Vermeulen, 2016; Nederhoff 1994). Moreover, in vertical farms CO_2 use can be reduces by up to 92% compared to greenhouses in The Netherlands (Graamans et al., 2018). It can be supplied to the plants in different ways; from outside sources or for instance as a result of processes within a farm that produce CO_2. In the Westland horticulture area in The Netherlands, the greenhouses are connected with oil refineries in the Rotterdam harbour area that produce excessive CO_2 that would otherwise be left unused and end up in the earth's atmosphere. Locating a vertical farm near a source of CO_2 and connecting them reduces the demand for resources and the farm's impact on the environment. Proximity to sources of CO_2 is taken as a criterion in the model.

Energy

When conducting interviews with various organisations involved in vertical farming also Philips Lighting was visited. At the time they were refurbishing all the LEDs in their research facility with the newest models developed by them. However, they had had to wait for this to happen, because their clients wanted the product as well and were given priority on the first batches of production. The research on plant growth could only later benefit from the better lamps that were available (interview G informal). In a way, the short lifetime of the LEDs is both a hurdle and a reason for its great innovation. A hurdle because every few years new investments have to be made in these lamps, at the same time the rate of development means it is worthwhile to invest in new lamps every few years because it means a farm will be able to produce food more efficiently, increasing its productivity (interview A). The LEDs are probably the most important part of the vertical farm, and potentially of any indoor farm (interview G), and is the next innovation in farming (interview G). The location of the farm is irrelevant for the lights itself, but rather for the costs and source to power them. Lighting is approximately 80% of the total electricity cost (Kozai and Niu, 2015a). Using the light efficiently has great consequences on the growth of plants and/or the production costs. The amount of light needed to grow plants is measured in light use efficiency (gram per mol of light) or energy efficiency (gram per joule). Vertical farms outperform even the most efficient greenhouses in energy efficiency. They need less energy (MJ) to grow a kg of plant material (Graamans et al., 2018). Greenhouses however, are designed to use (free) solar energy directly for photosynthesis and are not solely reliant on LEDs to provide energy (Graamans et al., 2018). The total costs of energy for a vertical farm thus exceeds that of a greenhouse regardless of its efficiency. Others thus argue that when you remove the use of natural sunlight in the farm the production cost regarding energy use and greenhouse gas emissions becomes too high (Molin and Martin, 2018). Regardless of the impact, growing indoors, without the use of direct sunlight will require a large amount of energy to produce the plants. Theoretically, this does not have to pose any (environmental) issues as long as the energy required can be sourced sustainably. The amount of energy needed to produce one kg of lettuce is approximately 10 kWh. It is likely that this will become less in the near future at around 5 kWh (Kozai and Niu, 2015b). In order to facilitate this in a sustainable business model, potential green energy sources are included in the analysis to provide the farm with enough sources of green energy to grow plants. The energy requirement of the potential farms is directly derived from the energy need per kg of production in the model.

(Waste-)water

A vertical farming's advantage is the potential reduction of use of water. Up to 96% less than in traditional farming. Moreover, wastewater from urban sources could be used to provide the plants with both nutrients and water. Yellow, grey and black wastewater contain valuable resources for plant growth; namely P (phosphorus) and N (Nitrogen). Ideally, the vertical farm collects the wastewater and the plants filter the water, by taking up the nutrients they need and clean it in the process (Despommier, 2010). As a result, the plants grow and the wastewater is cleaned and is suitable to use for other purposes. However, at this moment the reuse of wastewater for agricultural purposes is restricted to specific countries. In The Netherlands, the content of heavy metal, micro-pollutants, pharmaceuticals and pathogens in the wastewater disallows the use of it for growing food, as the risks are uncertain (Interview F). More research is needed on improving the technology to clean the wastewater of undesirable content and on safety measures that ensure no harm is done to humans and the environment, and opening up legislation in favour of reuse of wastewater (Wielemaker, Weijma and Zeeman, 2018). Moreover, at this point, it is also hard to determine the exact amount of plant matter that can be grown on wastewater of a given amount of people. Different forms, yellow and black for instance, have to be combined to 'match' the nutrient composition a plant ideally gets as fertiliser (interview F). Since the use of this is restricted in The Netherlands at this moment, wastewater reuse is not taken as a criterion. With technology and legislation changing in the future, it can become a vital component and asset of a vertical farm. The criterion is covered to some extent by adding weight to the proximity to large quantities of people. Places with more people present consequently produce more wastewater with nutrients, increasing the potential for nutrient collection in the future (interview F). If the technology improves and legislation becomes favourable for the reuse of wastewater, a farm nearby a cluster of people could tap into the resources more easily.

Purification of grey water

Despommier (2010) states as one of the advantages of vertical farming the potential to purify grey water through the growth of plants. The grey water waste streams of the city are used to grow the plants on. The plants take the nutrients from the water the excess water is than transpired by the plants into the atmosphere. Dehumidifying the air inside the farm provides the city (relative) clean water back into the urban system (Despommier, 2010). However, as argued before the plants that grow on these waste streams are in the Dutch situation, and many other countries, not allowed to be sold for consumption. The sole purpose of this farm is then to clean grey water through plants. The plants could then be used as biofuel, however at this moment doing this profitable is unrealistic and not in any way environmentally conscious.

Heat

Greenhouse production relies on heating to keep the growing conditions for plants ideal in winter. In Urban areas, there is a potential in the reuse of waste heat produced by factories, data centres and offices. Even low temperature sources, can be combined if in abundance and effectively raise the temperature with heat pumps (Kozai and Niu, 2015a). Meanwhile, one of the (by)products of lighting and photosynthesis is also heat. So the vertical farm also produces excessive heat at times, potentially of use to other processes. Proximity to sources of waste heat is included as a criterion, serving both aims of circularity and cost reduction.

Organic waste

Urban areas produce large quantities of organic waste. This waste can be used and applied to agriculture. It contains vital ingredients for plant growth through support that it gives to the microorganisms that increase the uptake of nutrients of the plant (Kozai and Niu, 2015a). Policies and laws are in many places preventing the utilisation of this waste stream (AVF, 2017b). In Amsterdam, there is no large-scale active policy on collecting organic waste from households. A huge transition is needed to enable it, not only for the municipality but also in the practices of the inhabitants (Het Parool, 2016). To do this is at a large enough scale for an operating vertical farm is perhaps too ambitious now. Moreover, it is only a minimal amount of the total costs of a vertical farm (<3%, Kozai and Niu, 2015a), and sourcing it from households is not immediately cheaper. Actively advocating change in the existing system around collection and reuse of organic waste to use it in a vertical farm is not reasonable at this point. The time and money efforts without a prospect of saving substantial money are not worth it for an entrepreneur. If policies and practices in the city of Amsterdam change, incorporating organic waste into the system will become more interesting. As a spatial criterion, it is hard to include this waste stream without any assurance of feasibility. So organic waste is not included in a criterion in any way.

2.4.3.2 Circular system - indoor level

One of the principal advantages of vertical farming is the possibility to control the whole growth cycle of the plant from seed to harvest in an enclosed space (Despommier, 2010). So-called controlled-environment agriculture. This allows the farmer to control variables in temperature, humidity, CO_2, light, nutrient concentration and acidity. A large part of the potential of the vertical farm is resource efficiency (interview A; B). When done properly this raises the possibility to close the cycle of the resources (Spruijt et al., 2015). For instance, with the current systems, water use can be reduced by 95% of the current use in greenhouses in the Netherlands (Graamans et al., 2018) and theoretically the water use efficiency could be 100% (Kozai, 2013b). The plants transpire and this natural phenomenon affects the humidity in the building, that can consequently be controlled again and be recovered from the air if too much is being transpired (AVF, 2017b; interview E). Similarly, other flows can be designed in such a way to reduce the waste to the outside of the farm and maximise the reuse of materials. This is done by installing proper insulation, design the building to accommodate natural airflow and maximise light use of the plants. These options are not confined generally to the location of the farm. However, the structure of the building can be a determining factor. For the research, the indoor circularity of the farm is considered as the responsibility of the design and the farmer's practices. It is a condition rather than a criterion; it is assumed that the farm is aiming for circularity with the processes of the vertical farm. Other than the criteria discussed above, there are no other spatial criteria taken in terms of indoor circularity.

2.4.4 Labour

Labour is an essential part of any company and compromises a large part (25%) of the costs of a vertical farm (Kozai and Niu, 2015a). It is vital for its success and enough labour should be available. Some vertical farms have failed because there were not enough people with the correct knowledge of farming (interview B; E; Kozai and Niu, 2015a). "The first question we ask when we are involved with a vertical farm overseas is: 'who is in charge, and what is his or her experience with farming?'" (interview E). At the same time, a lot of the activities are repetitive and do not require much experience or high skilled labourers. The activities inside a vertical farm differ from those of traditional farms. Data can be obtained through sensors telling the farmer essential information about plant growth. The data requires analysation and the atmosphere needs to be controlled accordingly for maximum efficiency. The workforce is thus ideally a combination of skilled and manual labourers, who are relatively cheap. In the model this is captured by the average income of neighbourhoods and the number of skilled labourers around, assuming that in Amsterdam the proximity to enough labourers is met at any location.

2.4.5 Consuming market

Although vertical farming is propagated as a solution for the expanding global and urban population (Despommier, 2010), its current stage of development and initiation costs means it is most profitable when it aims for niche markets (interview D). In Japan, the success of vertical farms is partially due to the focus on high-profit crops (Innoplex, 2014). Aiming for the absolute top of the market where consumers are willing to pay up to five dollars for a single strawberry (Farm 4.0, 2017). For a bank, new vertical farm initiatives need to be able to show that they are going to supply to a market that is still growing, or where they can compete in with superior products or lower prices (interview D). The vertical farms in The Netherlands that exist now do this to a large extent. 'De Schilde' in The Hague is focused on gaining knowledge and showing the visitors what is possible. They are selling a story rather than just a product (interview C; E). 'GrowX' in Amsterdam has made contracts with restaurants and hotels in the city to which it can deliver its produce. The restaurants have larger margins on their food and can afford to buy more expensive ingredients for their dishes in return for deliverance guarantees and an innovative story around the source of their food (interview C; D; E). In Dronten 'StaayFoodGroup' is building a vertical farm that is going to produce large quantities of lettuce for the Aldi Süd supermarket chain in Germany. The lettuce is going to be part of their ready-to-eat salads. The costs of producing this lettuce here will be significantly more expensive per head of lettuce, but it is only one of the many ingredients of the whole product (interview B). The constant and exact supply together with a guaranteed absence of diseases or vermin means this is seen as a more profitable way of production in the long run (interview B; E). The prices can be kept relatively low because 'StaayFoodGroup' is a wholesaler and comprises a large part of the supply chain of the product. In acting as both a producer, distributor and wholesaler to Aldi Süd it can directly supply to the shops without involving any other companies that want a piece of the pie (interview D). This is a solid business model, and vertical farms should perhaps not (try to) compete with current greenhouses and farms but play on another level (interview G). To capture this with a spatial criterion or data is hard. It is key for a new vertical farm to have an idea of what market it wants to address regardless of the exact location it is built. Location is crucial though for your market and determines whether the 'niche' targeted is accessible to your market. The study focuses on feeding a part of the population of Amsterdam with food from a vertical farm and sees the market here as homogenous, although it is understood that it is not in reality. The market is captured here by population density and logistics. Getting as much produce to as many people as smoothly as possible.

2.4.6 Social embedding

Farming in the cities is commonly done on a small scale: on rooftops, in community gardens amongst others. Alternative food networks are gaining interest with consumers when it comes to sourcing food. While it can be argued that vertical farming is a next step in the further industrialisation and intensification of the agriculture (interview G), it is also a possibility to bring large-scale production closer to the society of urban dwellers and alleviate social concerns and demands (Kozai, 2013a). Urban agriculture, in general, can have a possible positive social contribution in terms of living joy, recreation, lowering crime, the creation of jobs for manual labour, reactivating unemployed workers and a positive influence on the health effects of the local population (Spruijt et al., 2015). Meanwhile, social acceptance of the change of this technology is key (interview A). This is even more important in a city than in rural places. Simply because the production is brought closer to the consumer, also means it has more possibilities to come into contact with these same consumers. They can form an opinion on the concept of vertical farming or a specific farm, both positive and negative, and have an effect on the functioning of the farm through it. If the public opinion is negative around vertical farming it will be hard to find grounds for embedding the farm in the neighbourhood and serving your produce to the market here. Thus, the system should be safe and provide a pleasant working environment in which environmental health and profit come together (Kozai and Niu, 2015a). The activities inside the farm are ideal places to create opportunities for employment of different levels. The image of farming vertically is much more high-tech and attracts a different kind of employee. Especially in East-Asian countries where farming is generally looked down upon it could revive the ageing sector (interview B; E; G). Vertical farming has great potential in terms of circularity but should incorporate this before it can be seen as a sustainable form of food production. In the Netherlands local and sustainable food is a growing market, but the conditions of these must be met by vertical farms before advertising as them. Convincing the consumer why food from a vertical farm is better, and worth a higher price, than other produce is not evidently easy. Altogether the amount of research on the social aspect and power of a vertical farm is lacking. Advocators of the vertical farm (Despommier 2010; Kozai and Niu, 2015) make statements about the clear advantages of vertical farming for social issues and community empowerment, but they are not backed up by convincing evidence. Urban agriculture has seen a variety of studies that focus on the benefits; including increased food access, job creation and educational opportunities and green space (Reynolds, 2014). Vertical farming in a city is a form of urban agriculture but does not necessarily have the same benefits to its people. Vertical farming studies in this respect are virtually absent. The main social aspect that is covered by research is that of food security problems and food deserts (e.g. Besthorn, 2013). These issues are relevant in some countries where vertical farms could be a solution. In The Netherlands, however, local food insecurity and food deserts are not common problems found. The best example of social embedding for vertical farms is that of educational opportunities. Some farms allow visitors to come for a tour of the facility and a taste of the produce. De Schilde in The Hague combines this within its business model and also hosts other activities in his facility (UrbanFarmers, 2018) to actively promote and embed the farm in the locality. Embedding the vertical farm into the neighbourhood and into the community can enhance the sense of place and its value and thus serve as a tool for place-making. Furthermore, it determines whether the facility can attribute to the social sustainability of a place. The local demographic and social characteristics thus affect the feasibility of a project (Yung and Chan, 2012).

2.4.7 Political parties

To make sure the development of a vertical farm is backed by the community the political 'colour' of the neighbourhoods could provide insight. Green political parties are interested in urban agriculture due to the sustainability aspects of this type of farming. Other political parties could be more interested in the social or economic benefits of urban agriculture. Almost all parties in The Netherlands (and the 2018 municipal elections in Amsterdam) have been involved in urban agriculture, or have a position on it. To get a better understanding of their position on vertical farming; political parties and staff members of the government were addressed to talk about the vertical farm and its potential for the city. The willingness to talk was absent. In recent years there have been multiple governmental documents to explore the potential of urban agriculture (e.g. 'green deal stadslandbouw' and 'Stadslandbouw: Een verkenning van groen en boer zijn in en om de stad'). These were however not clearly politically coloured and do not report on vertical farming specifically. A closer look at the viewpoints of the political parties in The Netherlands shows overall positivity towards urban agriculture. Some (smaller) political parties lacked standpoints in this domain. Altogether specific opinions on *vertical farming* are lacking, and there is not enough diversity among the standpoints of political parties on urban agriculture to base the potential of the development of a vertical farm on it. In the future, when there has been more discussion, also in politics, around this topic this data is an interesting layer for the decision-making criteria.

2.4.8 Rental prices

The prices in urban areas for land are generally soaring compared to agricultural land in rural areas. Vertical farms, however, can be built on plots that are not suitable for traditional crop cultivation. Shaded spaces, non-fertile soil and idle land do not affect the possibilities of a vertical farm negatively. Around 1% and 10% of the land equivalent is needed to produce the same amount of lettuce as in open fields or greenhouses respectively (Kozai and Niu, 2015a). The development of a vertical farm requires a large initial investment. After a location is found a design is needed for the new farm and constructed or the current building must be redesigned and refurbished. Hardware is needed to construct the different layers for plants to grow in, including growing trays and LED lights and others.

These expenses have to be made and will be higher than those of open field farms and greenhouses - regardless of the specific choices made - and form a large part of the total costs (Kozai and Niu, 2015a). To keep the total costs of production minimal it is important to look for a location where the land price is low. When land prices are low it is easier to compete with open field agriculture and greenhouses that are built on low-cost land in rural areas. Current prices of rural farmland in The Netherlands for around 10-20 euro per m2 (Vermeulen, 2016). The lowest prices you can find in Amsterdam are around 1250 euro per m2 and rising higher than 6000 euro per m2 (Maps.Amsterdam, 2018). Even when the product is not marketed against the currently available crops, low land costs still mean less overall costs and a potentially lower cost price of the product, and a stronger market position. The extra cost of land in urban areas has to be compensated by a higher yield or market value of the product.

2.5 Criteria analysis - Conclusions

Although the vertical farm, or any indoor farm for that matter, operates as an enclosed space in which the inside atmosphere and conditions are controlled, the location has a significant impact on the viability of the farm. The possible advantages of the vertical farm are abundant and widely shared by literature and experts, yet not all achievable at this moment (Table 2.1). Most farms operating at this moment are not environmentally sustainable. They use too much energy to cultivate the plants. Technology is not developed far enough to provide the vertical farm with enough 'green' resources. Circularity with a farm in the city system can only be achieved up to a certain level with a few streams at this moment: heat, CO_2 and energy (electricity).

The most important factor of the location is logistics. Resources must be able to reach the facility easily, and even more important is that the product must reach the consumer quickly to guarantee the (ultra-)freshness of the food. Labour is a combination between high-skilled and manual, and preferably cheap. To be able to compete with greenhouses in The Netherlands it is essential to look for low rental prices for the facilities. They form a high percentage of the cost price of the product. To sell the product, specific markets must be found, allowing a higher cost price product to sell. The potential of the vertical farm for social issues in cities is marketed well by advocates and farms itself, however strong evidence of this is lacking, especially in the Dutch case. The political parties do not provide with a diverse standpoint either on which the potential of development can be based. At this moment a vertical farm biggest potential for the community is that of job creation to a variety of labourers; potentially minimising the unemployment rates. The next step is to take these criteria, collect the spatial data that is related to them and add them together in a multi-criteria analysis. The outcomes are locations in Amsterdam that are most suited for the development of a vertical farm here according to the criteria established. To do this successfully a set of criteria, or themes are distinguished. They are dependent on the availability of the data and the findings in this review. Four main themes can already be distinguished. The criteria found in the review can roughly be categorised in logistics, environmental, social and economic criteria. First, the data must be collected and analysed so that the remaining criteria can be linked to each of these four themes.

Table 2.1 Qualified criteria

Criteria	**Valid?**
Logistics	Yes
Heat	Yes
CO_2	Yes
Wastewater	No
Organic water	No
Other waste	No
Clean water	No
Energy	Yes
Labour	Yes
Consuming markets	Yes
Social embedding	Yes
Political colour	No
Rental prices	Yes

3 Location analysis

In this chapter, the steps are taken to come to an actual location analysis. This is done with a spatial MCA. A method that is first introduced in a review and then divided into two steps. Preparing the data (pre-processing) and executing the MCA (processing). The method for the pre-processing is first explained and then for each criterion the choices made are explained and the resulting map is presented. This pre-processed data is then ready for the execution of the MCA. The method of weighing the criteria for the analysis is discussed and standardisation of the suitability is explained. The result will be a suitability map that can be used in various ways; foremost to find the potential location for vertical farms in Amsterdam.

3.1 Review location analysis

The location analysis is done in two steps. First, all the data is collected, analysed, transformed and standardised (pre-processing). Secondly, all this data is combined as input for the MCA to create a suitability map for vertical farming, that can be used to find suitable vertical farm locations (processing). Both are done using the criteria found in the criteria analysis. The software used is ArcMap, a GIS (Geographical Information System) software package. The result will be a map with different 'scores'. With the best scoring locations, using the parameters set, highlighted. As an additional outcome, the individual score of each criterion can still be linked to the locations. Thus, allowing for a further research into the strengths and weaknesses of each location. This can help improve certain locations that have already been chosen or that have the preference of decision makers. The first part discusses the use of MCA for spatial decision making. This affects both the pre-processing and the processing. Afterwards, the methodology and execution of these two steps are split apart. The choices made and methods used are explained individually. The choices made in the data-processing phase determines the quality and outcome of the MCA.

3.1.1 MCA for spatial-temporal decision making

Spatial decision problems, in this case, a location analysis, deal with a large variety of criteria, sometimes clashing and not always easily proportioned. An MCA in combination with spatial-temporal attributes can help with structuring the criteria. Furthermore, it is a process that transforms and combines geographical data with the preferences of a decision maker; with the purpose to gain knowledge to make the actual decision (Malczewski, 2006). GIS-based models are ideal for advanced site-selection studies *(*Wang et al., 2009; Malczewski, 2004). To investigate the suitability of locations GIS can be combined with a multi-criteria analysis (Malczewski, 2006). These techniques make use of a suitability index to evaluate the potential of a complete study area. There are a variety of methods to do this in practice (Malczewski, 2004). In this study, the Analytical Hierarchy Process (AHP), developed by Saaty (1980) is used in combination with a 'weighted sum model'. With an AHP the complex issue of the site-selection is divided into several simpler problems. This is ideal when a location needs to meet multiple or even competing objectives (Wang et al., 2009) and has been used many other site-selection procedures (Malczewski, 2006; Uyan, 2013) and also with the involvement of expert stakeholders (Watson and Hudson, 2015). Many studies use a pairwise comparison (Saaty, 1980). Pairwise comparison is generally done by multiple inputs of experts. All individual criteria are compared to each other, regardless of its subject or theme, and the weight is based on a relative weight of one criterion towards the other. To prepare for the MCA spatial data has to be found for each of the criteria and then standardised to make sure each has the same unit of comparison (Eastman, 1999; Voogd, 1980)

3.1.2 Soft and hard criteria

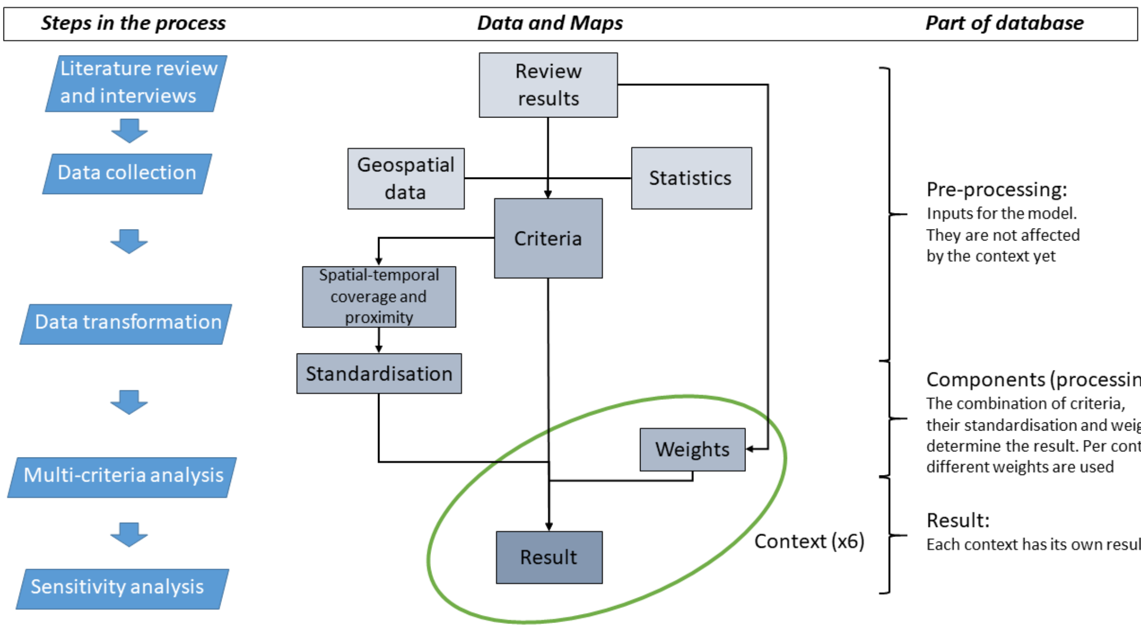
In the process of weighing and classifying the criteria, all individual criteria can be divided into criteria with hard and soft limits. Criteria with hard limits exclude certain locations, for example lacking a certain amount of people within a 5-km radius of the location. This can be captured by a constraint layer (Watson and Hudson, 2015) to eliminate areas that cannot be used for the allocation of your desired land use (Gómez-Delgado and Tarantola, 2006). In this case, the resulting suitability map will be used as an input for current vacant lots and buildings to be assessed. The assumption is made that each building or lot is positioned in a place that exists and that the land use and the soil of the area do not interfere with the possibilities of developing a vertical farm. In other words; water areas, or roads, for example, are automatically excluded because buildings and lots are not in the same location as these land uses. They are weighed and standardized to be able to compare them with each other, as the input for the MCA. Soft constraints are useful if there is no clear boundary of where the object is possible or not. Constraints are more often than not artificial boundaries and not properly including and excluding the right areas (Eastman, 1999). For this method, only the soft criteria are relevant and are used. The vertical farm is not restricted by spatial constraints in this case, as is normal to most spatial multi-criteria analyses (Watson and Hudson, 2015)

3.2 Methodology – pre-processing

The pre-processing is an essential part of the research and covers the data collection, transformation and standardisation for each criteria (figure 3). All these steps are taken with the eventual MCA in mind. The data has to be relevant to the subject (vertical farming) and to the case study (Amsterdam). The processing of the MCA (§3.4 & §3.5) and the sensitivity analysis (§ 4) are covered later in the report.

The use of an MCA in combination with spatial data to determine the potential location for a vertical farm is explorative. No precedent with a set methodology is available yet and thus a number of assumptions are made throughout the pre-processing to deal with the uncertainties of the approach. Calculations are based on a number of assumptions and standardisations based on the available data and the knowledge obtained from the criteria analysis and are explained at each criterion if applicable.

Figure 3 Overall steps and methods overview



3.2.1 Software package for the analysis

To conduct the actual location analysis, built a model for it and determine the sensitivity of it Geographical Information System (GIS) software was used. In this research, the pre-processing of the data and the execution of the spatial modelling of the research was done in ArcMap version 10.6. Excel was used to transform some of the data into formats suitable for ArcMap. Python scripts are used to simplify modelling and decrease the number of steps needed in ArcMap to come to results. The standard type of file ArcMap uses are shapefiles. When collecting the data from the online sources all the files were directly converted to the right format using Mapshaper.org, to allow them to function properly. The reference system of RD new was used. All steps taken in ArcMap are done to eventually come to a suitability map for vertical farming. Many decisions are made during this stage and changes are constantly needed until the right procedure is constructed. To do this in a structured manner and make this step repeatable the model builder of ArcMap is used.

3.2.2 Data collection

In the case of Amsterdam, the data was gathered from multiple sources. First, the criteria found in the earlier phase were translated into spatial data that could represent them. Subsequently, the spatial data was sought for using freely available online databases, accessible to any person who likes to make use of this spatial or other kinds of data. This means anyone could reproduce this research without special access to certain data. If the analysis succeeds this means this information is available to anyone wishing to delve into the spatial characteristics of a vertical farm. A specific origin of each map can be found in the data-framework. Main sources include the PDOK (Publieke Dienstverlening op de Kaart) through the 'Nationaal Georegister', 'Maps.Amsterdam' (the geoportal of the municipality of Amsterdam), OIS (Amsterdam Statistics) and 'OpenStreetMap'. For each map, table or dataset it was identified what purpose it serves and which criterion or criteria (discussed in the review (table 2.1)) it can represent in the analysis (table 3.1). Different origins mean that the files come in different formats and with different extents. The reference systems were also not uniform. In the next step, all maps were set to the same reference system (RD_new), mostly at the extent of the municipality of Amsterdam.

Table 3.1 Availability and source of spatial data for criteria

Criteria	Spatial data	Available	Source	Year
Logistics	Roads public transport	Yes Yes	OpenStreetMap Maps.Amsterdam	No date 2017
Heat	Piping infrastructure (waste) Heat sources	No Yes	 Nationaal Georegister	 2014
CO_2	Waste CO2 streams (electricity plant)	Yes	Nationaal Georegister	2014
Energy	Solar potential Wind potential Energy use	No Yes No	 Maps.Amsterdam	 2014
Labour	Average income Skilled labour	Yes Yes	OIS.Amsterdam OIS.Amsterdam	2017 2017
Consuming markets	Population density Restaurants & Hotels Supermarkets	Yes Yes Yes	OIS.Amsterdam Maps.Amsterdam Maps.Amsterdam	2017 2017 2017
Social embedding	Unemployment rate	Yes	OIS.Amsterdam	2016
Rental prices	Property value	Yes	OIS.Amsterdam	2017

The criterion 'Piping infrastructure' is available as Web Map Service, but not for use in ArcMap. The 'Energy use' and 'Solar potential' were not suited for the whole area of Amsterdam and did only score individual buildings. Aggregating the buildings did not lead to any uniformity in the data.

3.2.3 Data transformation

All maps are collected and added to the database as raw data. For the location analysis for a vertical farm, a number of steps have to be taken to create a variety of criteria that serve as an input for the (MCA) model, together with the weights and classification. This is determined in the next step where the MCA and the decisions made are explained. Data transformation is part of pre-processing. All steps taken in the transformation phase serve to create uniformity of the data and prepare it for the actual analysis. For these, the context had no influence on the choices made for altering the data. The main transformations were among others:

Covered in §3.3:

- Select the elements of maps relevant to certain criteria (iterative)
- Clip the input data to the (relevant) extent
- Give statistics a spatial reference
- Create buffers around objects
- Identify, isolate and standardise the criteria (method §3.2.4)

Covered in §3.5:

- Add weight to the criteria (method §3.4.3)
- Determine suitability per scenario (method §3.4.5)

3.2.4 Standardisation of criteria

For each criterion in the data processing stage a determination of the score of the range of values is made and standardised accordingly. The ranking is done intuitively, resulting in qualitative scores (de Voogd, 1982) that are based on the findings of the executed literature and interview review, and if applicable backed by other research or literature. For the criteria that work with supply and demand of resources, the time frame is set in years (e.g. amount of CO_2 per year). The choice was made to standardise all values between 1 and 9 using only the odd numbers. The reasoning behind this is that there are both criteria that justify a five-score distribution (1, 3, 5, 7, 9) and a three-score distribution (3, 6, 9). In the first, the lowest value is nine times less stronger than the highest value, whilst the difference between the lowest and highest is only a factor three in the latter. In any case, all criterion scores have a positive accumulation. The higher the score the higher the suitability for a vertical farm for this criterion. The calculations are done with python scripts that return a score between 1 and 9 based on (the range of) the values in the criterion. The basic python algorithm that was created is shown below (python algorithm 1). For each criterion the algorithm was adapted to produce the correct outcomes relevant to that criterion.

Python algorithm 1: Reclassifying criteria (e.g. unemployment)

```
def Reclass(unemployment):
    if (unemployment <= 5):
        return 3
    elif (unemployment > 5 and unemployment <= 10):
        return 6
    elif (unemployment > 20 and unemployment <= 100):
        return 9
```

3.3 Data pre-processing

For each of the twelve criteria pre-processing was done to create all the layers for the MCA. For each criterion the steps taken are discussed here and the result shown. Also, the target features, the vacant lots and buildings, were pre-processed. The twelve different spatial datasets that were linked to criteria (table 3.1) are connected to the four themes derived from the review (§2.5). The data came from different sources, with different formats and references. All data is given a spatial component and projected to the 'RD_new' projection. The majority of the work was done in ArcMap. The spatial datasets that came in formats not supported by ArcMap were converted to shapefiles by Mapshaper.org and FME software. The statistical data was first prepared in Excel before importing it as .csv files and joined to the administrative (spatial) component. The steps taken are done using the model builder in ArcMap, allowing revisiting the choices made and altering the values of inputs and parameters. The standardisation was mostly done with the use of python scripts or other forms of calculation.

3.3.1 Circularity

The potential of a vertical farm in circularity is evident. However, not a lot of it can already be met. The lack of development and legislation around some (cleaning of wastewater, and using nutrients from wastewater) and the lack of quality data for others (sun potential, energy use (label) of buildings). The analysis is done with criteria that are available and applicable to a vertical farm in the present day: CO_2 and Energy (wind and heat).

3.3.1.1 CO2

The first is CO_2, which can be applied to a farm in multiple ways. Some farms have installations that burn fuel and capture the CO_2 produced by it and pump this into the cultivation rooms. CO_2 is also a by-product of many (urban) processes and is more often than not released into the atmosphere Through this, it impacts the environment as a greenhouse gas. Plants use CO_2 to grow and ideally a vertical farm is connected to a CO_2 production site so that both the plants have a constant supply of this resource and that less CO_2 is released into the atmosphere.

Waste CO2 streams

In and around Amsterdam there are a variety of facilities that produce CO_2 and can potentially be connected to farms, in a similar fashion as the 'Westland' is connected to the Rotterdam harbour for CO_2 supply. The data was sourced from the 'Nationale Energieatlas' through the 'Nationaal Georegister'. All sites within 10 km of Amsterdam where selected.

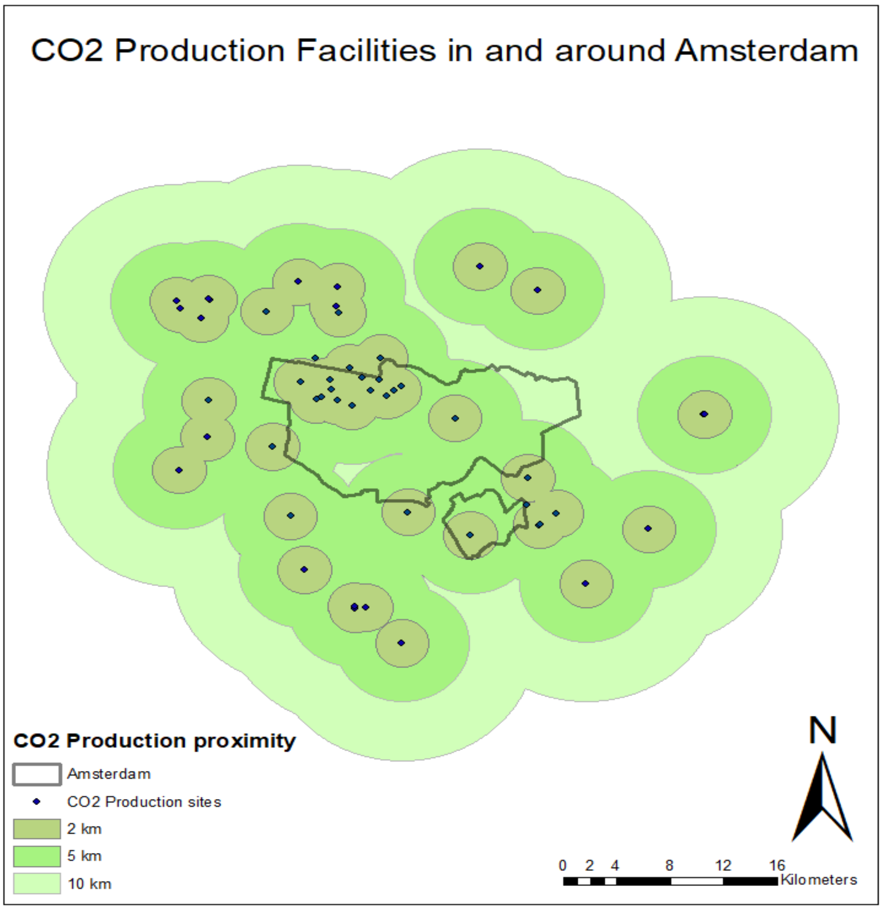
The amount of CO_2 need is calculated for the minimum vertical farm size of 1000 m^2. Because 6 layers of lettuce are grown this means the greenhouse equivalent is around 6000 m^2 and 0,6 ha. For the production of lettuce KWIN (2017) averages the use of natural gas around 80 m^3 per hour per ha. 1 m^3 of natural gas produces around 1,8 kg of CO_2 (Vermeulen, 2014). The minimum kg of CO_2 that is needed for a vertical farm is thus:

$$\text{Kg of CO2} = m3\ natural\ gas\ per\ hour\ per\ ha \times amount\ of\ ha \times kg\ of\ CO2\ per\ m3 \times hours\ in\ a\ year$$

$$= 80 \times 0{,}6 \times 1{,}8 \times 8760 = 756.864\ kg$$

The first selection is then those facilities that produce more than this per year. The data is an average per year based on a five-year measurement. Possible fluctuations of supply from year to year, or in periods during a year are not covered in this data. To reduce costs to infrastructure and make the use of CO_2 from alternative sources viable a higher proximity to these sources is desired. According to Vermeulen (2014), a distance of less than 10km to a source of CO_2 is critical. Buffers were computed around the facilities of 2, 5 and 10 kilometres and the given standardisation values of respectively 9, 6 and 3. The lower the distance the higher the value. The result is shown in figure 3.1. Many facilities are located around and in north-western Amsterdam.

Figure 3.1 waste CO_2 production facilities in and around Amsterdam



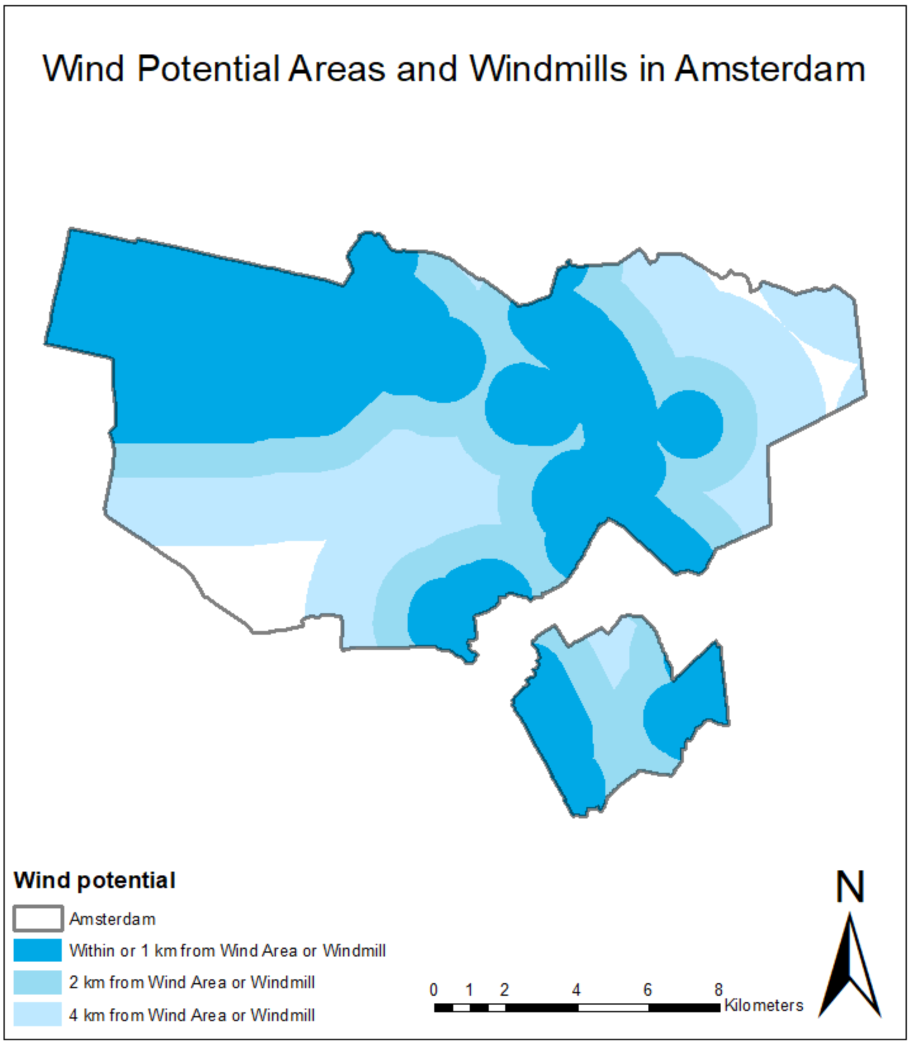
3.3.1.2 Energy

A vertical farm uses a lot of energy to grow crops. The majority of all energy is used for the LEDs that allow the plants to photosynthesise within a closed environment. Besides, also the atmosphere needs to be controlled amongst others. Three criteria were found viable and available: Wind, Heat and Geothermal. The last two could both serve as inputs to control the atmosphere, and the first also as a source for the LEDs. Since this is the most essential part of the whole system, the weight will be higher in the model.

Wind potential

The municipality of Amsterdam has issued the areas within the municipality that have a potential for wind energy development ('wind vision areas'). Other than that numerous windmills already exist in Amsterdam and in its vicinity. Locations directly within or close to wind areas and windmills get the highest score and those furthest away the lowest (figure 3.2). Three buffers were created, then the wind vision areas were erased from the buffers and then the result merged again with the existing wind vision areas. This was done to prevent double scoring the wind vision areas. Both from a buffer and the polygon itself. The resulting polygons were given standardisation scores (9, 6, 3) with the use of python.

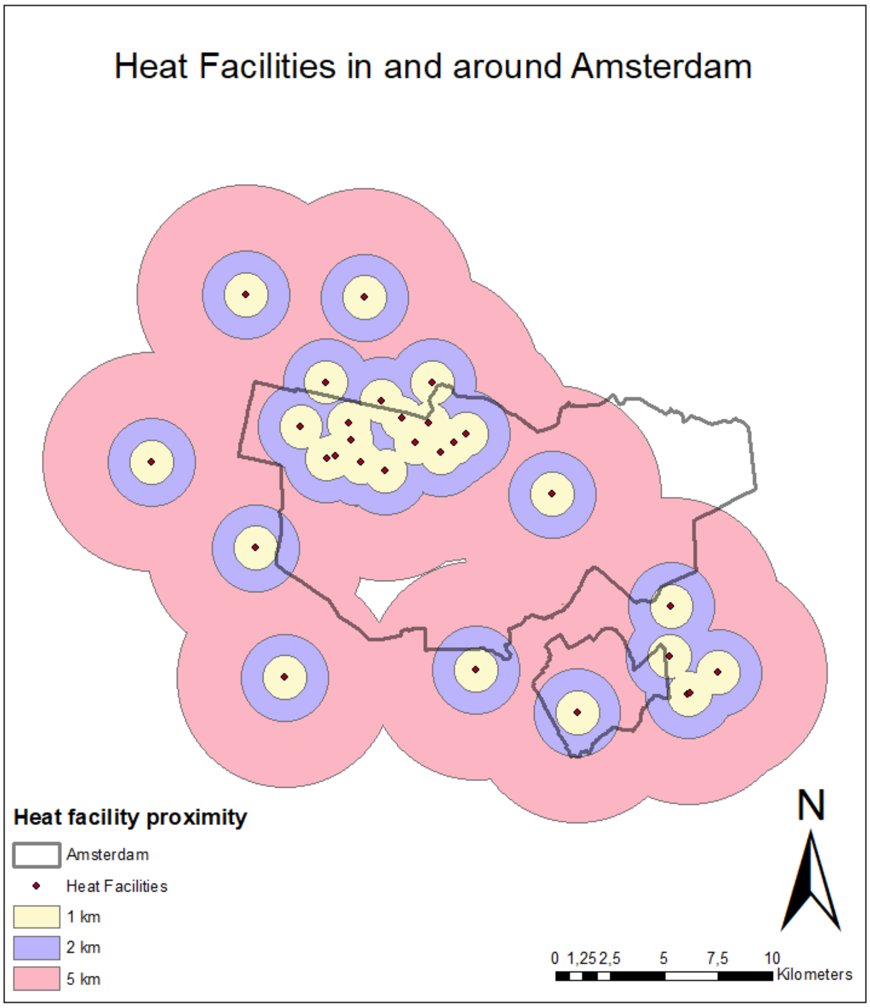
Figure 3.2 Wind potential



Heat sources

There are several facilities that produce excess heat that is usable by other processes in Amsterdam. The reuse of heat for growing is only relevant within 5 kilometres of the heat source (Vermeulen, 2014). Moreover, a portion of the heat is lost during transport. For that reason, the closer the better. Buffers were computed around the facilities of 1, 2 and 5 and the given standardisation values of respectively 9, 6 and 3 (figure 3.3). The lower the distance the higher the value. Compared to greenhouses vertical farms need much less heat for production. The weight of the heat criteria is kept minimal due to the small impact on the whole production.

Figure 3.3 Heat facility buffers



3.3.2 Logistics

The second overarching criterion is 'Logistics'. Logistics are crucial for any business to want to deliver its goods to its customers. The success of the horticulture industry in The Netherlands can for a large part be accredited to the favourable logistic positioning of the country and the horticulture areas within in. For produce in a vertical farm, it is vital that it can be distributed and supplied to the clients swiftly. If done properly the freshness of the product can be guaranteed and the location near the market is justified and adds value to the farm and its produce. Two main criteria that are important for logistics were identified: 'transport' and 'consuming markets'.

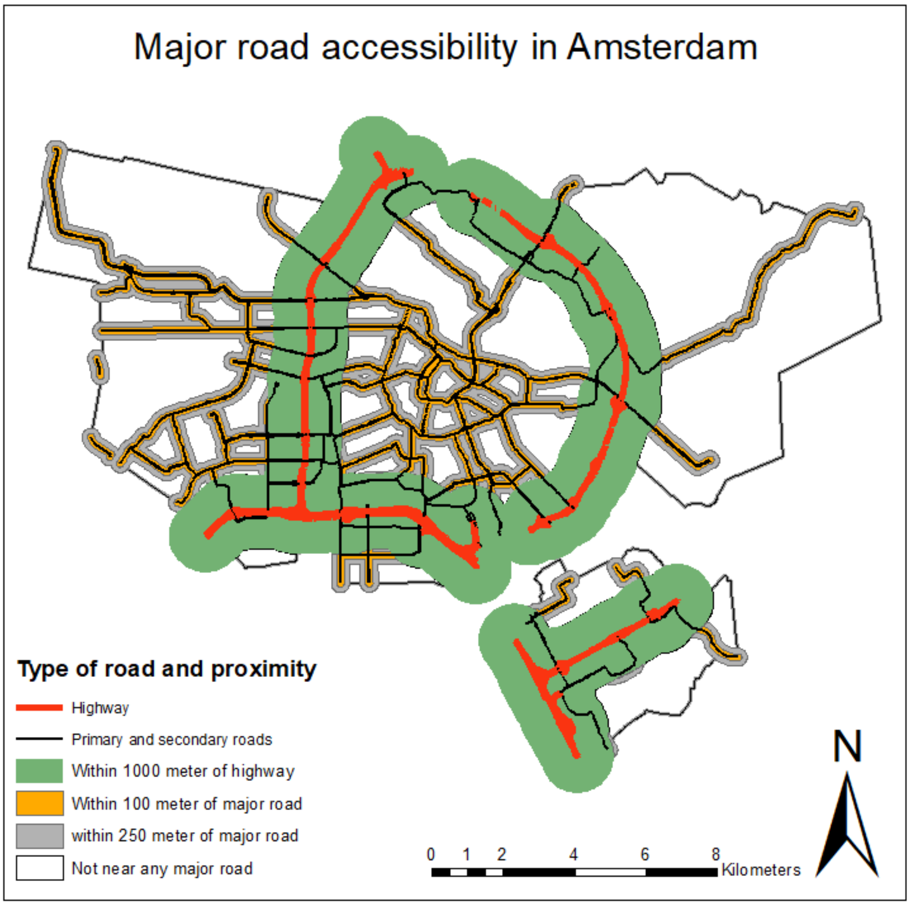
3.3.2.1 Transport

Transport covers the criteria are derived from the physical infrastructure of the city. The proximity of major roads for distributing the products effectively and to a lesser extent for the commuting employees and visitors. Secondly, also the connection with public transport is taken. This mainly functions as a mode for employees and other people to travel to the facility. The impact of this is less than that of roads on the vertical farm's location.

Roads

To compute the distance of the locations to major roads and use this as a criterion to show accessibility of the location the choice was made to use buffers. The buffers were made around both highways and primary and secondary roads combined (figure 3.4). areas within 1000 meters of a highway were standardised to a score of 9. For major roads buffer of 100 meters and 250 meters were used. Assuming that most buildings are built close to roads the buffer size is determined so that locations next to these roads or just of side streets are included and given a value. The standardisation is done with the value 6 for the locations within 100 meters and 3 within 250 meters. The buffer around the highway was erased and then merged to the smaller road buffers so double value or not possible and the proximity to a highway is favoured to that of other roads.

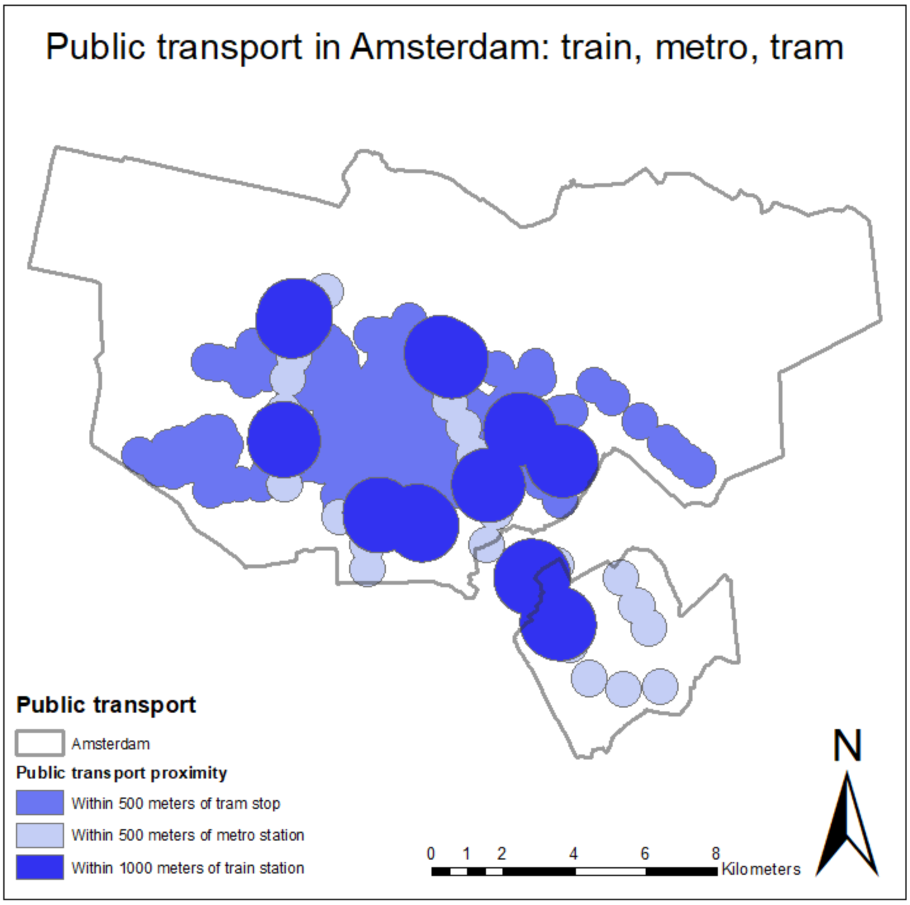
Figure 3.4 Major roads accessibility in Amsterdam



Public transport

Offices are worth more and better accessible when close to train station (V&W, 2010). The average people walk from train stations and other modes of transport vary slightly. The mean distance from train stations is around 1 km and from other modes around 500 meters according to Burke and Brown (2007). This research was conducted in Brisbane, Australia. No similar research was found for The Netherlands, but it is assumed that walking behaviour is similar and that also here people are willing to walk further from train stations. The data was derived from multiple maps of the municipality of Amsterdam (figure 3.5). Bus stops are not provided by them. Buffers with a distance of 500 meters were computed around metro and tram stations. Train stations were given a 1000-meter buffer. The assumption is made that in general the quickest mode of travel is favoured over the others so that these get the highest score. The area around train stations is standardised to 9, metro stations 6 and tram stops 3. The overall weight on transport is lower than that of roads since it is mainly for the accessibility of people and not of goods and produce.

Figure 3.5 Public transport buffers in Amsterdam



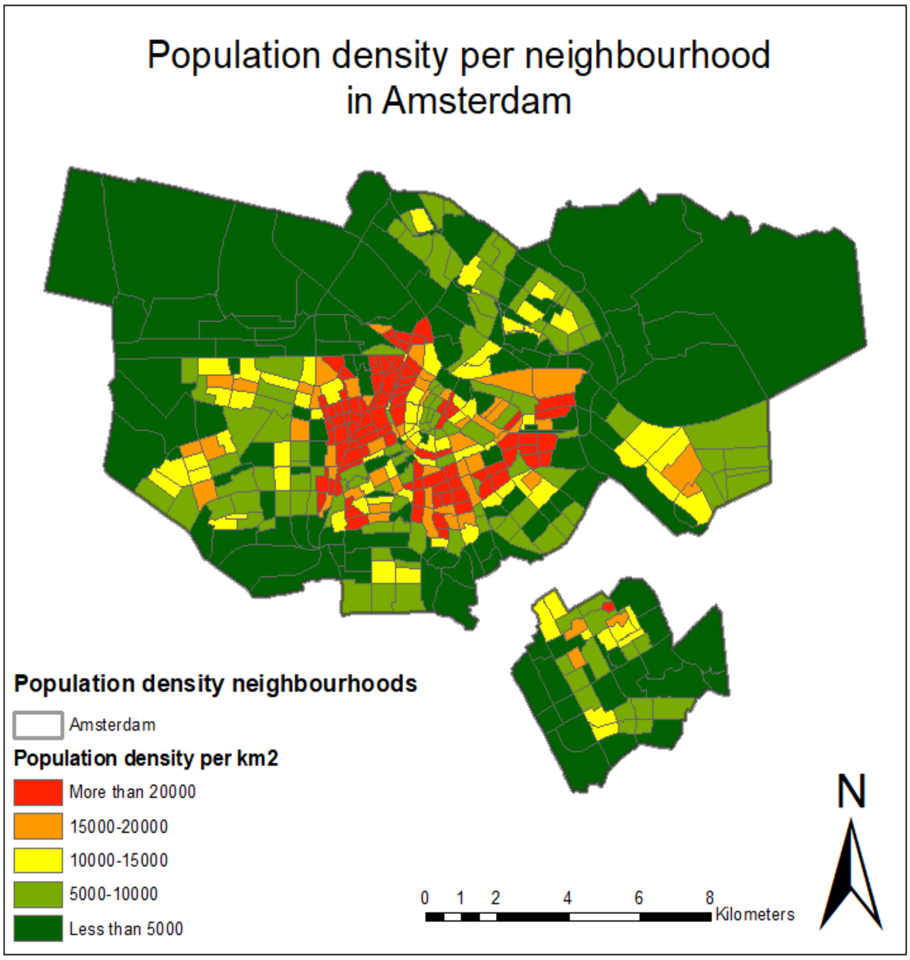
3.3.2.2 Consuming markets

The other important aspect of logistics is consuming markets. What potential customers does the vertical farm have in its vicinity, and what businesses are nearby that it can supply to? Three criteria were added to capture this. The population density, the number of supermarkets (retail), and the number of hotels and restaurants (hospitality).

Population density

The population density is obtained from the statistics bureau of the municipality of Amsterdam OIS ('Onderzoek, Informatie en Statistiek'). The data has no spatial component. To use this data in the model it was added to a layer containing the neighbourhoods of Amsterdam. The neighbourhood level is the smallest administrative unit for which this data is available (figure 3.6). The density was classified into 5 groups and given standardisation scores from 1 to 9. The higher the density the more potential costumers nearby and a higher score.

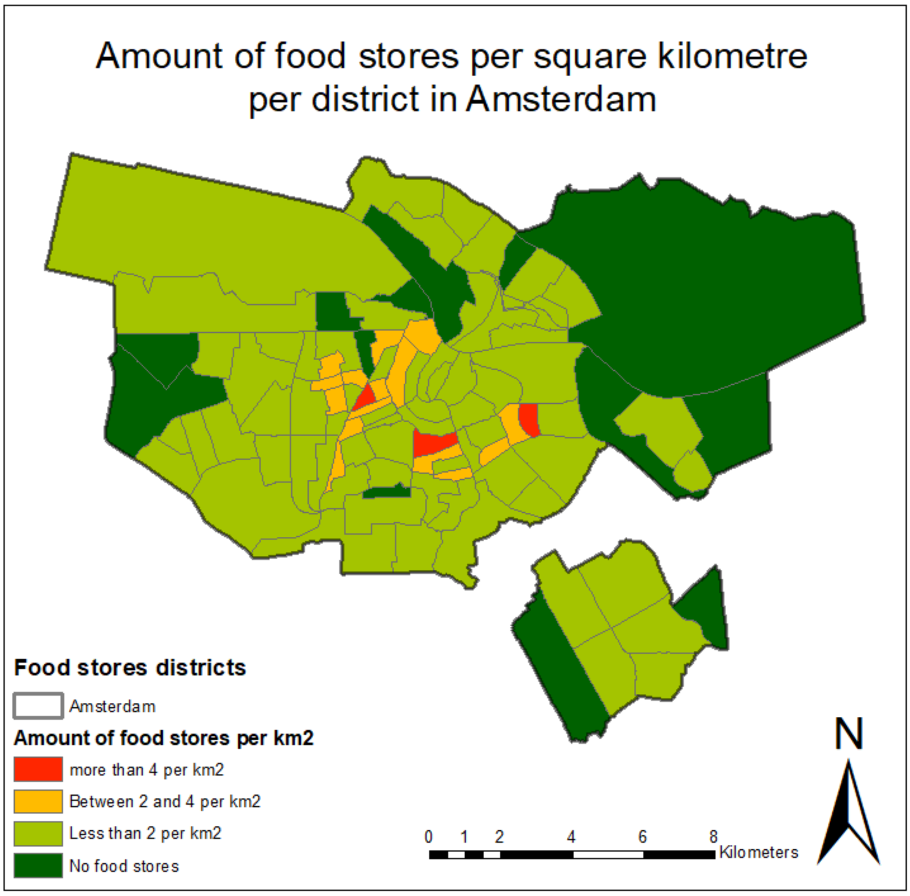
Figure 3.6 Population density



Supermarkets

For the supermarkets, a selection is made on all buildings in Amsterdam that contain retail. Then the selection was set to ‘supermarkets’ and ‘grocery stores’. After comparing the results, the choice was made to spatially join the results to the districts of Amsterdam and not the neighbourhoods. The neighbourhoods are too small to represent the distribution of stores according to their service area. When the stores are spatial joined to the districts they are automatically counted. The number of stores per districts is then known. Because the districts are not identical in size the number of food stores per square kilometre per district is then calculated (figure 3.7). The results were standardised accordingly. More than four stores per square kilometre is given a score of 9, between two and four a score of 6 and those with less than 2 a score of 3. The districts that have no food stores at all are given a score of 0.

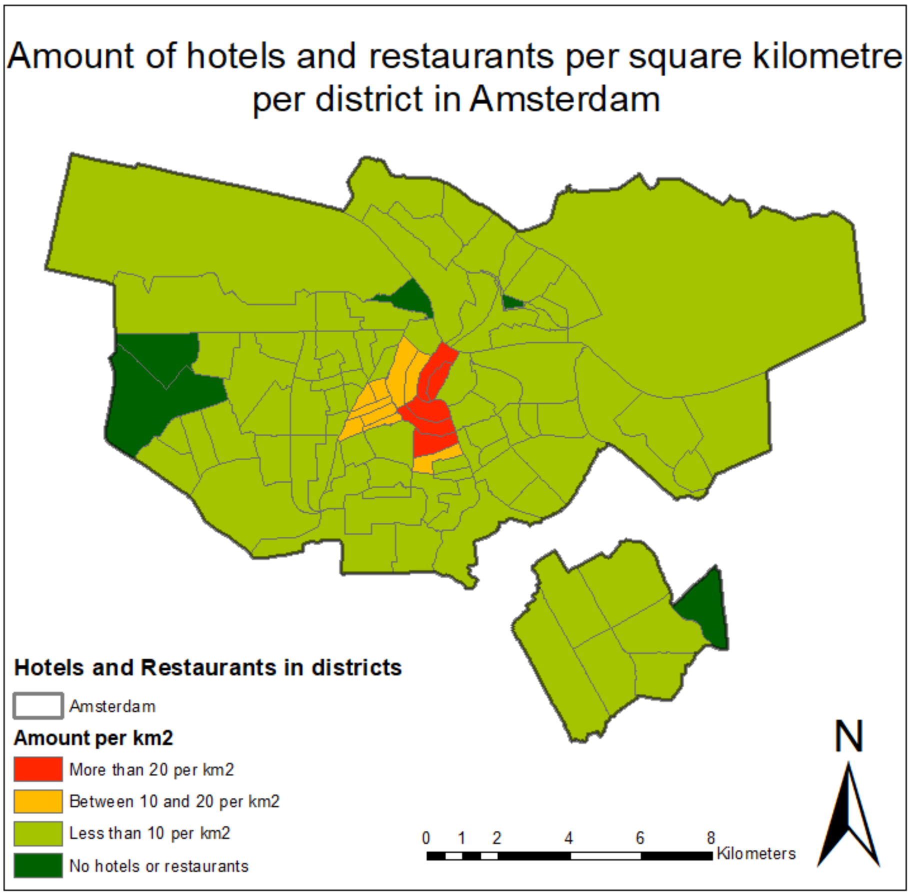
Figure 3.7 Food stores



Hotels and restaurants

The score map for hotels and restaurants was made in a similar way as the supermarket map. Selections were made to those buildings that contain a function that can be qualified as a restaurant or a hotel (figure 3.8). These can function as a direct customer for a vertical farm, without the interference of any distributors. Again, the amount was calculated per district and per km2. More than 20 per square kilometre was standardised to the score of 9, between 10 and 20 to 6, less than 10 to 3 and none to 0.

Figure 3.8 Hotels and restaurants



3.3.3 Economic

The next two criteria are both related to the economic aspect of a vertical farm. The main advantage of vertical farming is the possibility to do this close to your customers, and in this case in the urban area of Amsterdam. This comes at a cost, however, and that is the rental price of the facility. The price per square metre is much higher than the rural equivalent. In order to keep the prices down and cultivate plants for a competitive market price, the costs of the facility are to be kept at a minimum. Secondly, also the average labour costs of areas are added. There is a significant variety of income in Amsterdam and locations where the labour costs are low are more favourable towards the operating costs.

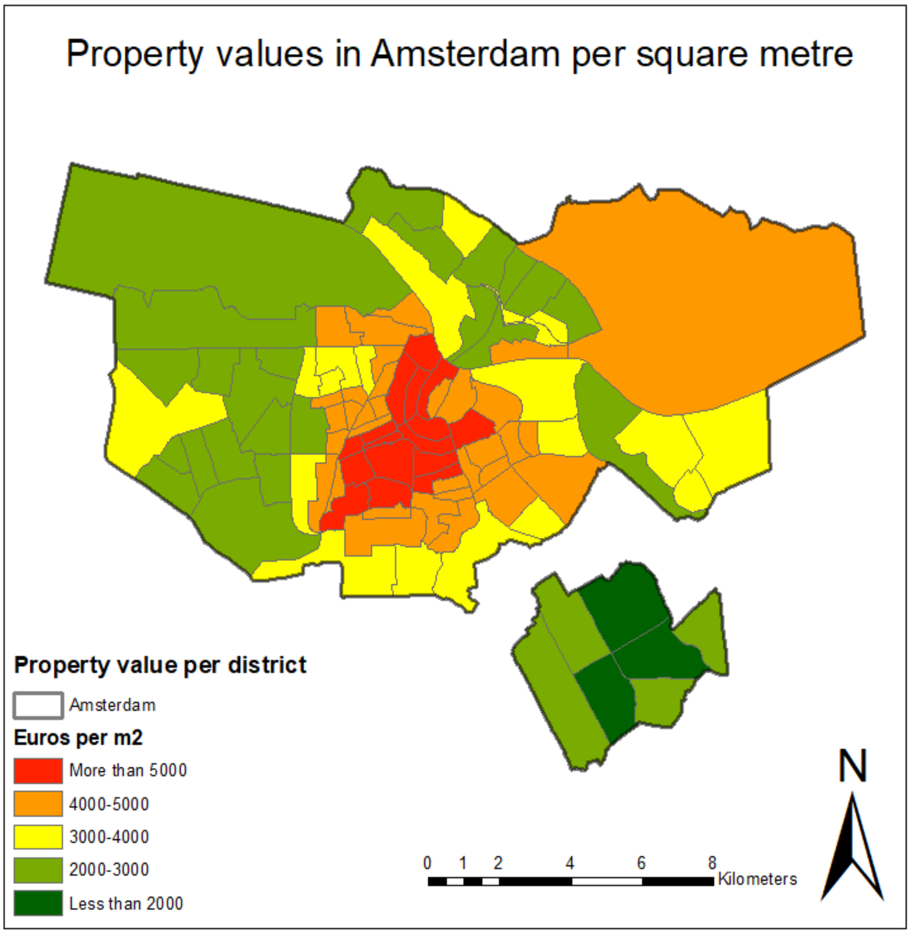
3.3.3.1 Rental prices

The municipality of Amsterdam publishes map data that contains the property value per square metre and how this has changed over the past years. Unfortunately, this data is projected on the buildings that it represents and does not cover Amsterdam in its entirety.

Property value (WOZ)

The OIS however also publishes the WOZ (Wet waardering onroerende zaken)- value per districts (figure 3.9). This is the tax value of properties. The average per districts gives an idea of the distribution of property costs in Amsterdam and the related rental prices per square metre. In and around the city centre the prices rise up to more than 5000 euro per square metre on average. In 'Zuidoost' there are areas in which it is lower than 2000 euro on average. The range is standardised again to scores of 1 to 9 in 5 classes, in which the lowest price per metre gets the highest score.

Figure 3.9 Property value (WOZ)



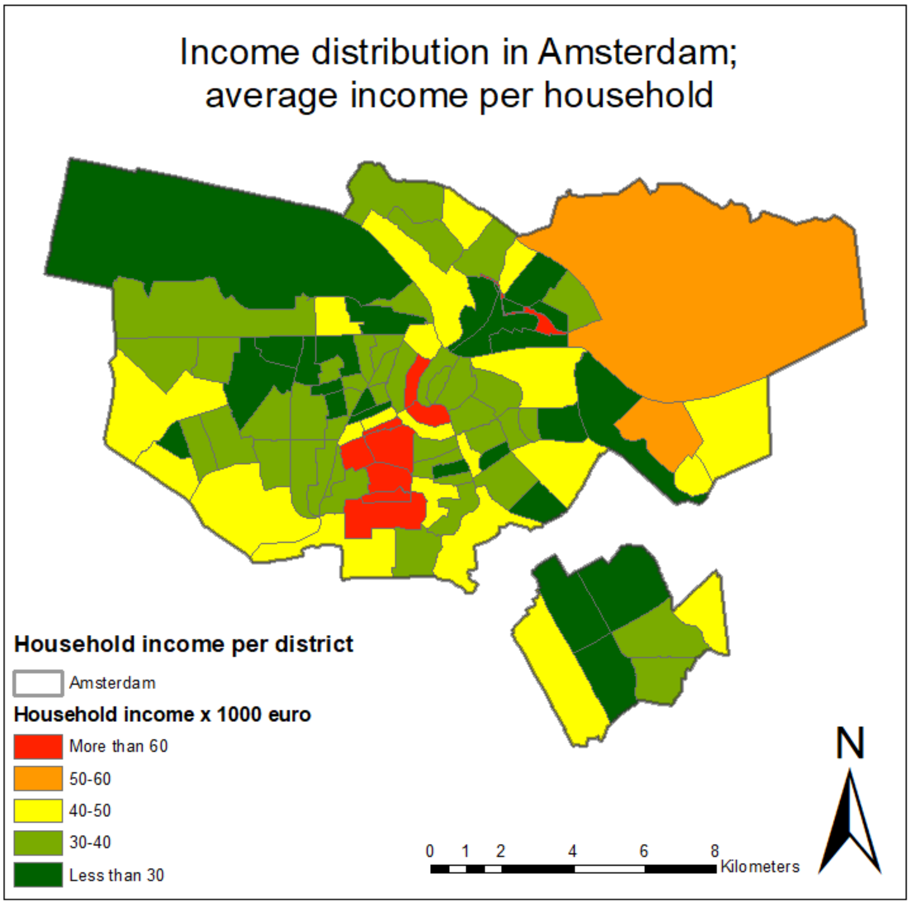
3.3.3.2 Labour (cost)

The labour cost is an important criterion. Vertical farming is a labour-intensive business. Keeping the costs of your personnel low means translates to lower cost prices of your products. There is a variety of data available.

Average income

The assumption is made that the products of the vertical farm are ingredients for meals and that thus the customers are not only persons but also households, providing for their entire home. Instead of the personal income, the average income per household is taken. This data is available through the OIS per district. This is then added again to the dataset and portrayed (figure 3.10). The distribution is divided into 5 classes and standardised to values between 1 and 9.

Figure 3.10 Average income



3.3.4 Social

The last theme is 'Social', which captures two aspects of labour: inclusion and availability. Inclusion reflects the unemployment rate and the possibility of the vertical farm to be an asset to the area by providing work to the population. Availability entails the workforce of the area and the social composition. A mix of labour is required for the functioning of the farm.

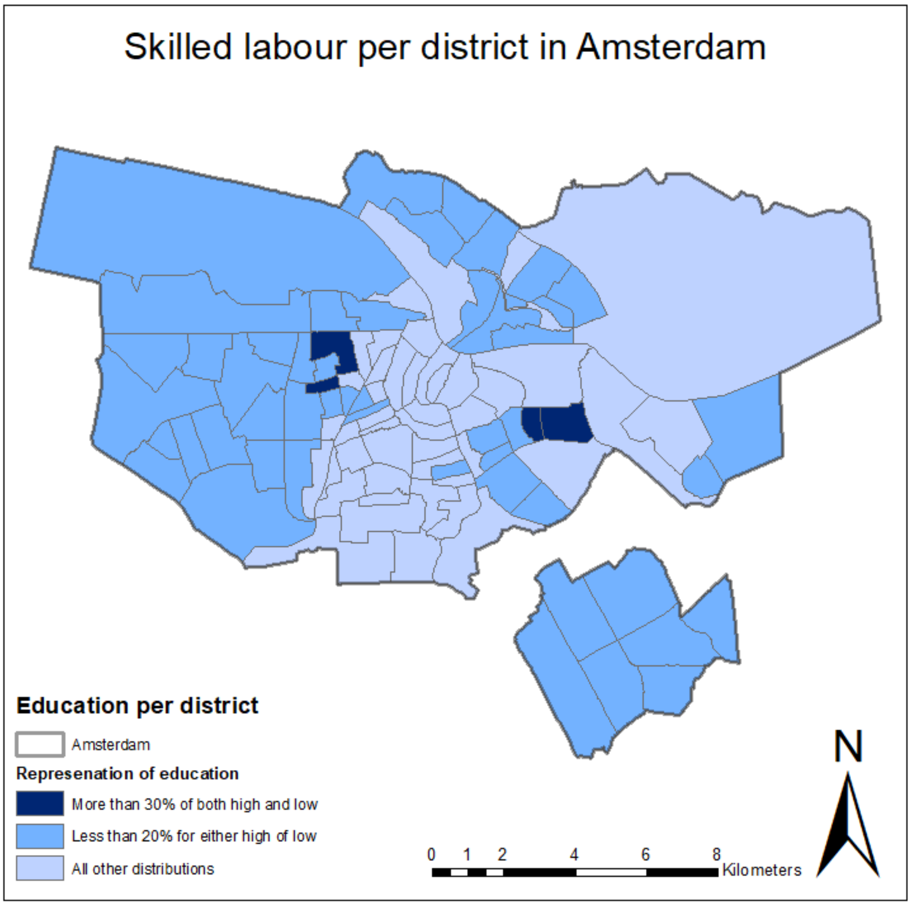
3.3.4.1 Labour (availability)

One of the things that came out of the review was the necessity of both high skilled labour for the monitoring, management and operational design of the farm as well as manual labourers for all work related to the seeding of plants, harvesting amongst others.

Skilled labour

The data is gathered from OIS Amsterdam and provided per district. The data contained the percentage of people that have a low, middle or high education qualification. To capture both types of labour in this criterion, without having to make multiple layers a script was written that scored the areas that had both more than 30% of the people with a high education and more than 30% with a low education. This way it is guaranteed that the right mix of labourers is present in the area. These districts were standardised to a score of 9. If either high or low educational qualification is represented by less than 20% of the population it is standardised to 3, all other areas are given a score of 6 (figure 3.11).

Figure 3.11 Skilled labour



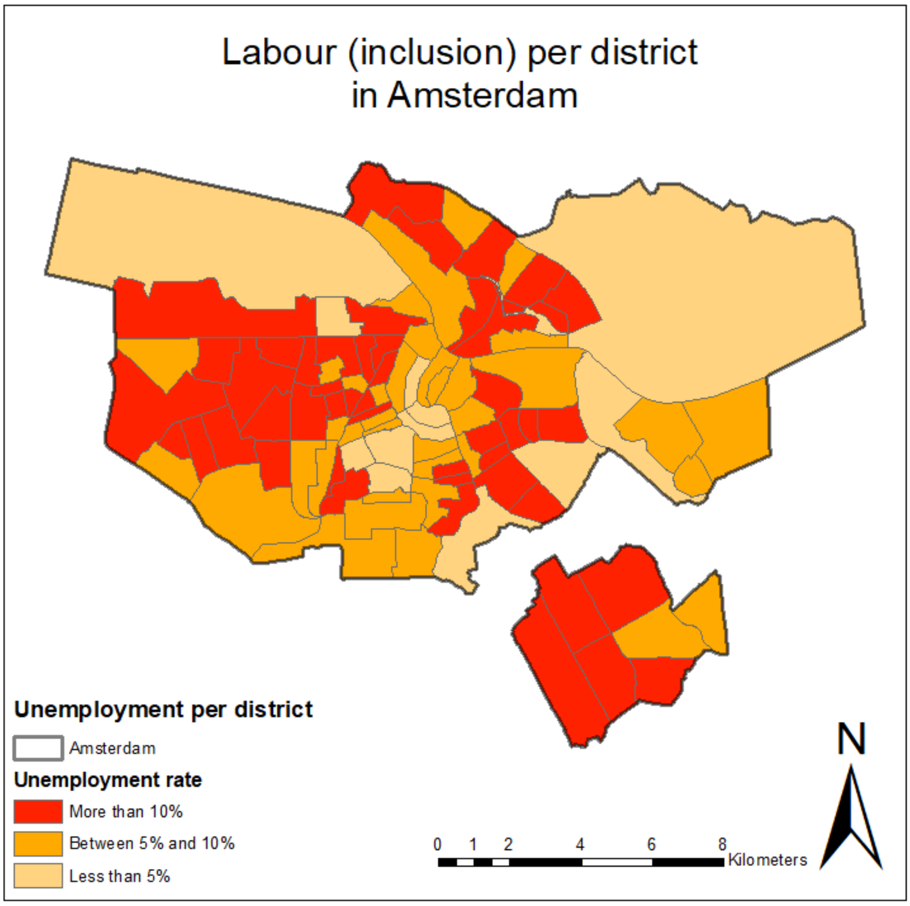
3.3.4.2 Labour (inclusion)

A decent size vertical farm provides jobs for people of all qualifications. The development of the business in an area can boost the creation of jobs and lower activate the unemployed people. In regions where high unemployment rates are an issue the farm can act as a catalyst for workforce activation but also providing simple jobs for people with distance to the job market, as is done in many other urban farming initiatives.

Unemployment rate

The municipality of Amsterdam registers the unemployment rate per district through OIS. For some districts the data is not provided, then the unemployment rate of the higher administrative division is taken. The higher the unemployment rate, the bigger the potential for the vertical farm to be a positive contributor to the social welfare of the area, by reducing the unemployment rate and activating the workforce. If this impact is clearly visible in and to the community the vertical farm becomes embedded here and could have a broader function than only growing food. Standardisation is done again (figure 3.12). The districts with an unemployment rate above 10% are scored with a 9, between 5% and 10% with a 6 and lower than 5% with a 3.

Figure 3.12 Unemployment rate



The selection of valid criteria and the transformation are essential steps towards full implementation of the model. All criteria are spatially determined and are classified using the same unit and scale. Now that all the criteria are pre-processed the next step is to combine them into an MCA.

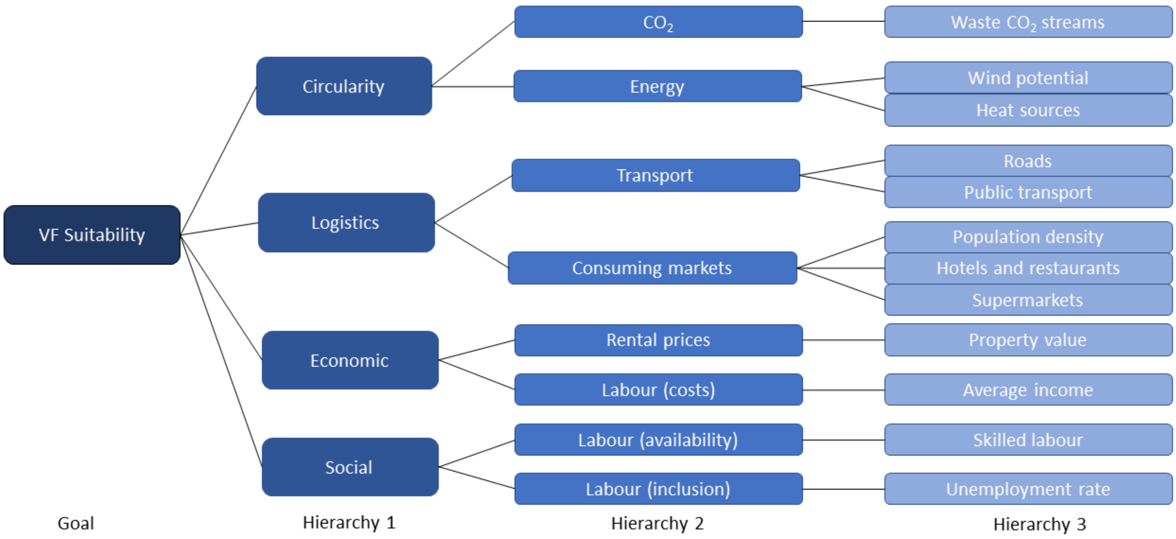
3.4 Methodology – Processing

In this section, the approach to the MCA in combination with spatial data is described. An introduction is given to the use of scenarios to create different outcomes for the model and the weighing of the individual criteria is done. All these serve as inputs for the MCA that is

3.4.1 Analytical Hierarchy Process

As described earlier there are various ways to combine an MCA with spatial data. Here, the Analytical Hierarchy Process (AHP) is used with a subject-specific alteration. The AHP and the associated weights of the individual criteria are used to create a suitability map. In this study, the approach to the AHP is slightly different than how the method is usually prepared. Here it is a comparison, or impact analysis, of the individual criteria that make up a specific hierarchy (figure 3.4). The criteria are then not compared to each other but rather towards their overarching theme. The implementation of different scenarios allows a different relation of the themes, and thus the individual criteria, towards the goal: the suitability of vertical farms. Ideally, the location makes sure the farm is economically viable, environmentally sustainable (circular), integrates well in existing landscapes and infrastructures (logistics) and also in addition to the neighbourhood and its community (social). These factors are represented in the main characteristics: Circularity, Logistics, Economic and Social. With a hierarchy model, each one of them is distributed into multiple other variables (figure 3.13).

Figure 3.13 Analytical hierarchy model



The combined impact of each hierarchy is 100%, however the number of criteria that make up the goal (vertical farm suitability) increase with each addition of a hierarchy. The use of this process allows for the development of different scenarios, using the four main themes (circularity, logistics, economic and social) without having to change the weight of the individual criteria that make up these themes respectively. If the weight of 'Circularity' is increased, automatically all criteria that are associated with 'Circularity' have an increased weight. Moreover, the amount of criteria that make up another hierarchy, does not mean a higher impact of this overarching hierarchy. This characteristic forms the basis of the sensitivity analysis in the next chapter. The different weight distributions of the themes are used to find the effect of different scenarios on the outcome of the model.

3.4.2 Scenario application

Different scenarios are executed with parameters set according to the identity of each scenario as is shown in table 3.2. In the AHP all the four themes are given different weights according to a scenario, while the criteria in 'Hierarchy 2' and 'Hierarchy 3' remain the same power of weight towards 'Hierarchy 1'. The impact of criteria thus changes with the power of the theme it represents. The results are always determined by the scores of the individual criteria and the corresponding weight. This weight is a result of the evaluation and the height of the impact of its overarching theme. And this can be changed through the application of scenarios (see table 3.2 and Appendix B)). In the analysis, the hierarchies of figure 3.4 are referred to as themes (1), sub-themes (2) and criteria (3).

Table 3.2: Distribution of power for the scenarios

Themes	All Equal	Reviewed
Circularity	25%	25%
Logistics	25%	40%
Economic	25%	25%
Social	25%	10%

The first scenario attributes the same weight to each of the four themes ('All Equal'). This scenario is used as a test for the model and a comparative tool to the other possible scenarios. The choice was made to make this the null-scenario instead of a scenario in which all individual criteria were given the same weight. As was shown in figure 3.4 some themes have more criteria than others. By choosing this distribution of weights of the themes for the null-scenario, no themes are favoured that consist of more criteria than others. Since this is also the thought behind the use of an AHP and scenarios is it more accurate to compare the results of possible scenarios relative to the 'All Equal' scenario. The 'reviewed'-scenario is based on the findings in the literature and interviews. And is the scenario that will be used as an input for further analysis of best locations and use of this sort of data for decision making. Almost all interviewees mentioned the importance of logistics as the success factor of any farming operation, and it is expected that this is as or more important to a vertical farm, which is not restricted to any soil type. The guarantee that a vertical farm can deliver (ultra-)fresh produce with a consistent quality is what makes it competitive over other types of farms. If it wants to deliver on this, it will have to have favourable logistics to the market it wants to serve. Circular and economic factors are considered as equally important. The vertical farm has the potential to play a vital role in the sustainable food transition, but can only do this if the business model is also economically sustainable. The impact of a production sized farm on the social wellbeing, or community empowerment of the neighbourhood is a nice potential addition of its value. However, both in the literature and in the interviews, this is not mentioned as a substantial influencer and contributor to vertical farms at this moment, certainly not in The Netherlands. The importance is perhaps more in the acceptance of the vertical farm in the neighbourhood rather than the benefits it brings to the community itself. The acceptance is not covered by the criteria in the social theme in this research due to unavailable or unusable data (election results).

3.4.3 Weighing of the individual criteria

Each scenario must be executed without changing its individual criteria. To do this properly, choices have to be made about the relative weight of each individual criterion. This way, scenarios can be implemented without having to re-examine each criterion again. In table 3.3 the weight distribution of the criteria can be found (in this case the 'All Equal'-scenario). Here it represents a scenario where all themes are given the same weight (0.25) for the goal. If these change, the relative weights of the sub-themes and criteria will change accordingly. Weights per criterion for all scenario are listed in appendix B

Table 3.3 Weight distribution of themes, sub-themes and criteria ('All Equal'-scenario)

Goal	Themes	% of goal	weight	Sub-themes	% of theme	weight	Criteria	% of sub-theme	weight
VF suitability	**Circularity**	25%	0,25	CO_2	25%	0,063	Waste CO_2 streams	100%	0,063
(All Equal)				Energy	75%	0,188	Wind potential	75%	0,141
							Heat sources	25%	0,047
	Logistics	25%	0,25	Transport	50%	0,125	Roads	75%	0,094
							Public transport	25%	0,031
				Consuming markets	50%	0,125	Population density	50%	0,063
							Hotels and restaurants	20%	0,025
							Supermarkets	30%	0,038
	Economic	25%	0,25	Rental prices	60%	0,150	Property value	100%	0,150
				Labour (cost)	40%	0,100	Average income	100%	0,100
	Social	25%	0,25	Labour (availability)	50%	0,125	Skilled labour	100%	0,125
				Labour (inclusion)	50%	0,125	Unemployment rate	100%	0,125
total			1,000			1,000			1,000

The weight of each sub-theme and consequently each criterion is determined by the relative influence of it on its predecessor. For circularity, CO_2 and Energy are both serious contributors. The impact on the whole system, and especially on the relevance towards it is different, however. If a business can source its energy sustainably it has a greater impact on the environment since it is the most essential resource. CO_2 is in that regard of lesser importance. The impact it can make is marginal compared to sourcing energy sustainably. Hence, the distribution is made: 'Energy' (75%) and 'CO_2' (25%). 'Energy' is yet again divided in wind (75%) and heat (25%) components. As mentioned earlier heat is primarily used for heating the farm and contributes only to a small percentage of the total energy requirements. The need for electricity for the LEDs is much higher.

'Logistics' is equally divided among 'Transport' (50%) and 'Consuming markets' (50%). Both being accessible as a location itself as having access to the market is an important aspect of the vertical farm. Within transport, the emphasis is on 'Roads' (75%). Roads are used to access the farm, but also to distribute the produce to the customer and consumer. Public transport is mainly used for commuting employees and potential visitors. The most important criterion within consuming markets is population density (50%) and determines it to a large extent. Moreover, the number of hotels and restaurants and supermarkets in the neighbourhood are most likely also correlated with the population density. The size criterion for the vertical farms is set at more than 1000 square meters. The production (at least 700kg per day) is then more suitable for supermarkets than just hotels and restaurants. The weight of supermarkets (30%) is set higher than that of hotels and restaurants (20%).

For the 'Economic' theme both the rental prices and labour costs are found to be important. Keeping both low is essential for having a solid business model in which you can have a competitive cost price of your product. The differences between the different areas of Amsterdam vary greatly for both. All in all the impact of a high rental price is hard to cover up by other factors, whilst the labour cost of the area could be negated by hiring personnel from other areas. The impact of the rental price (60%) is thus weighted slightly higher than the labour costs (40%).

The 'Social' aspects of the vertical farm are both weighted equally (50%). No evidence was found to support a bigger impact of the availability of labour or the inclusion of people currently unemployed.

3.4.4 Standardisation of the suitability outcome.

To add the weights to all locations, first, the 12 maps are combined to form the basis of the suitability map. This is done with the 'union'-tool in ArcMap. The result is a map containing an assembly of all boundary areas. Each of these areas should in a later stage still reflect the scores from all 12 criterion maps. The suitability map will use the pattern that is created by this map regardless of the scenario. The table that contains this assembly of areas is exported to Excel. When all criteria are standardised in the pre-processing and weights are attributed to each criterion in a weighing table, the MCA can be executed to calculate the suitability of locations. Different weights per scenario give different outcomes for the MCA. The calculations are done with the following summation and are standardised to value between 1 and 100 for easier result projection and interpretation:

$$suitability_{scenario} = \sum w_i C_i$$

$$S_{suitability} = \frac{suitability_{scenario}}{C_{max}} \times 100$$

Where:

$suitability_{scenario}$	= Suitability of each scenario
w_i	= Weight of criterion
C_i	= Standardised score of criterion
$S_{suitability}$	= Standardisation of suitability
C_{max}	= Maximum standardisation score of the criteria = 9

3.4.5 Suitability per district

Since this map always uses the same boundaries, that are a direct consequence of the choices made in the pre-processing another approach is also investigated. For a decision maker, the polygons that are created with the analysis and union in ArcMap might not be of interest. Their boundaries are determined by the parameters set in the model and in reality, might not be as hard as they appear in the projections of the outcome. Another way of looking at the data is to combine all scores per a given area, for instance: administrative areas in Amsterdam. The resulting map gives an idea of the suitability per district and provides the comparison between the existing localities in Amsterdam. To do this each polygon's size is measured. Then the relative size of the polygon within the district is taken. A weighted average suitability can then be calculated. Not doing this would mean the district's suitability is determined by the average of all polygons, disregarding the size of the polygon. The size percentage of each polygon of a district is then multiplied by the suitability score, in this case it is done for the 'Reviewed'- scenario. In the last step, the polygons are dissolved based on the district they are in. The relative sore of all polygons is simultaneously calculated through a sum in the statistics field.

3.4.6 Method assumptions

Many new vertical farms in the world are built in abandoned buildings like warehouses and offices. When transforming these buildings, the physical infrastructure of the building is already present and less initial investments are needed (or are at least expected). Whatever the motivation, somewhere vacant space is needed to develop. Either in an existing building or in open spaces. The municipality publishes all currently (partially) vacant buildings and lots. This is a wide variety of properties and possibilities of which not all are suitable for the construction of a vertical farm. In practice each building does have specific characteristics, qualifying them for the purpose of a vertical farm or not. Inspections are necessary to determine to what extent each building is actually suitable. In this study, it is chosen to perceive each building with the same potential and characteristics. No field investigation was done on each separate location, due to the lack of manpower and relative size of the study. The location and the available floor space are the criteria that are used in order to find out its potential. The sizes of the buildings and lots differ to such an extent that the development of an actual farm is likely to be focused on other markets for the smaller spaces than the largest. Consequently, the criteria are also affected by the purpose and market of the proposed size of the farm. With an actual case, this distinction can be made more clearly and the considerations in the model should be made accordingly. Here, all locations are perceived with the same perspective of a vertical farm that produces to its maximum capacity given its size, regardless of the market its size is most suited for. In line with this, the assumption is made that the vertical farm is also a direct distributor to its clients, without the intervention of and wholesalers are other third parties. It directly supplies to hotels, restaurants and supermarkets.

3.4.7 Location selection, qualification and its production capability

The datasets are obtained from Maps.Amsterdam (undated). There is one of both vacant buildings and vacant lots. Only locations that are allocated as businesses, offices and commercial buildings are used. If a suitability map for Amsterdam is created and the vacant locations are identified a closer look can be given to the potential of each location for vertical farming. The location of the vacant building determines to what extent they are suitable for vertical farming, given the criteria used and the weights set. All the locations were scored according to the polygon with scores they occupy. This is done with an identity tool in ArcMap after the suitability of each scenario is edited back into the attribute table.

Other than the ranking locations according to their suitability also the actual practical potential of the locations is interesting. How many people can be fed if the facility is turned into a vertical farm? The production amount is determined by the type of crop that is grown, the amount of floor space and the number of tiers a floor can hold. Kozai and Niu (2015a) have created a simple equation to calculate how much can be produced in a plant factory (see text box). This is derived from the Japanese growing practices and slight modifications are necessary for the Dutch system. According to the interviewees (A, B and G), a vertical farm can produce as much as a greenhouse at maximum production, per tier or layer. The amount of lettuce farmed in greenhouses in The Netherlands is, depending on the system, around 20 kg per m^2 or 99 pieces of 200 grams per year (Vermeulen, 2016). The calculations are done by taking a floor height of 2,6 meters (the minimum according to Dutch law). The average height of a shelf is taken at 40 centimetres for lettuce (Kozai and Niu, 2015a)(not shown in the figure). The assumption is made that in vacant buildings a maximum tier height of 6 can be reached per floor. Other than that, the effective floor space is derived from Kozai and Niu (2015a) at a ratio of 0.5. This ratio is lower than that of greenhouses. In vertical farms, more spacing is needed between rows of crops for production. To be able to reach each tier manually a vertical farm needs more room for movement (interview B; Kozai and Niu, 2015a). The ratio of the saleable plant is kept at 0.9 as well because their study also focused on lettuce. The amount of people that can be fed is then derived from the production, based on the daily intake advise of 250 grams of vegetables

> ***Kozai and Niu Calculation method:*** *"The annual PFAL production capacity can be calculated as follows: 20 plants/m^2 (culture bed area) × 15 tiers × 20 (harvests/year) × 0.9 (ratio of saleable plants to transplanted plants) × 0.5 (effective floor ratio of tiers to the total floor area). The other 50% of the floor area is used for the operations room, walkway, seedling production, and equipment". (Kozai and Niu, 2015a)*

(Voedingscentrum, 2018). This results in the following equations for 'vertical farm production' and 'amount of people fed':

$$\textbf{Vertical farm production in kg per year} = floorspace \times number\ of\ tiers \times saleable\ plant\ ratio_{\ Type\ of\ crop} \times floorspace\ ratio \times kg\ per\ year\ per\ m^2{}_{Type\ of\ crop}$$

$$\textbf{Amount of people fed by farm} = \frac{vertical\ farm\ production\ in\ kg\ per\ year}{days\ in\ a\ year \times daily\ intake\ per\ person}$$

Where (for lettuce):

$floorspace = determined\ by\ floorspace\ of\ vacant\ building\ or\ lot$

$number\ of\ tiers = 6$

$saleable\ plant\ ratio_{\ Lettuce} = 0.9$

$floorspace\ ratio = 0.5$

$kg\ per\ year\ per\ m^2{}_{Lettuce} = 99\ pieces \times 200\ grams = 19{,}8\ kg$

$daily\ intake\ per\ person = 250\ grams\ or\ 0{,}25\ kg$

For the selection of sites the floor space is set at more than 1000 square metres. The means a greenhouse equivalent of at least 6000 m^2 or 0,6 ha. This is the lower limit, ensuring a decent sized farm, capable of feeding a little less than 600 people.

3.5 Results – Suitability of vertical farming in Amsterdam

3.5.1 Suitability of Amsterdam

The suitability maps are a result of combining the twelve criteria and calculating the suitability per scenario (figure 3.14). The attribute table containing the scores per criteria of the 2431 individual polygons of the map is then exported to Excel. Here the scores of the individual criteria are multiplied by their weights, depending on the scenario and then standardised (see method §3.4.4). All suitability data for the six scenarios are calculated and then edited back into the map containing all the unique polygons. Now, this attribute table contains suitability data for each scenario, and it can be examined and projected accordingly. The first scenario is the 'All Equal'- scenario. The result is an averaged outcome without any bias towards any theme (25% each). This scenario is created to function as a test scenario to check the functioning of the model and to get a first indication of the impact of the individual criteria on the overall suitability. In figure 3.15, this suitability map is portrayed in a red to green spectrum with nine classes and intervals set representing suitability. The symbology is set with natural breaks and ranges from red (unsuitable) to green (suitable). Thus, the greener an area the more suitable the location is according to the criteria and weights set. The main highway corridors around the city centre, and in Amsterdam Zuidoost are clearly visible, with higher suitability scores. Other buffers around objects also show their impact.

Figure 3.14 Combined criteria map

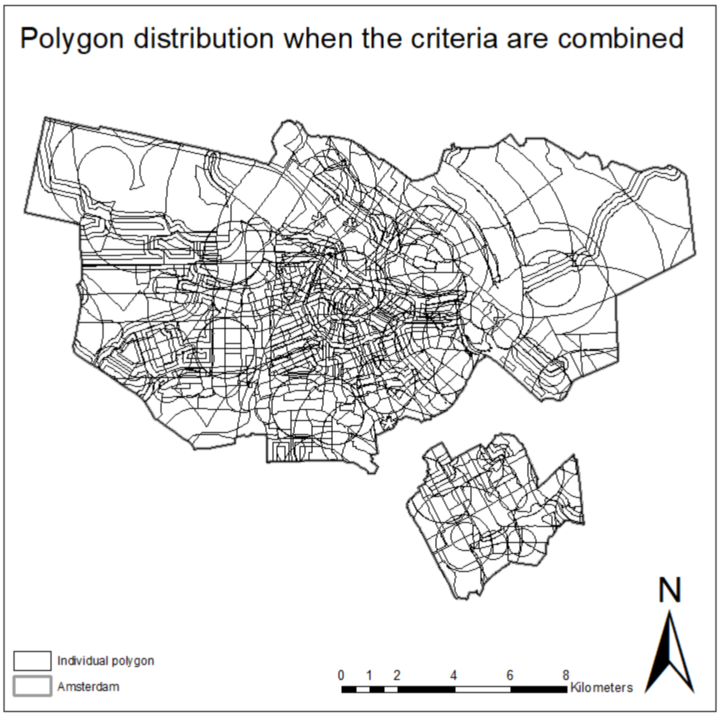
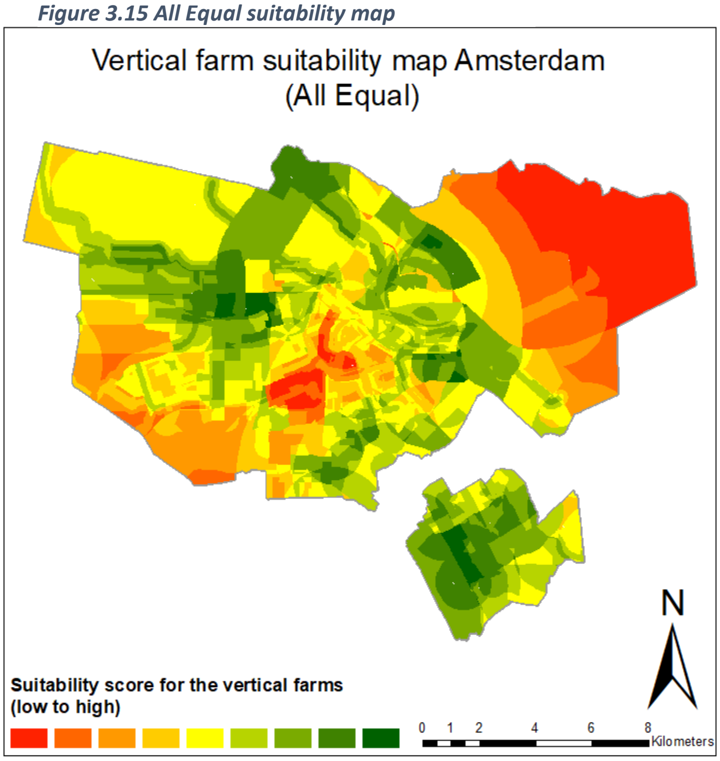


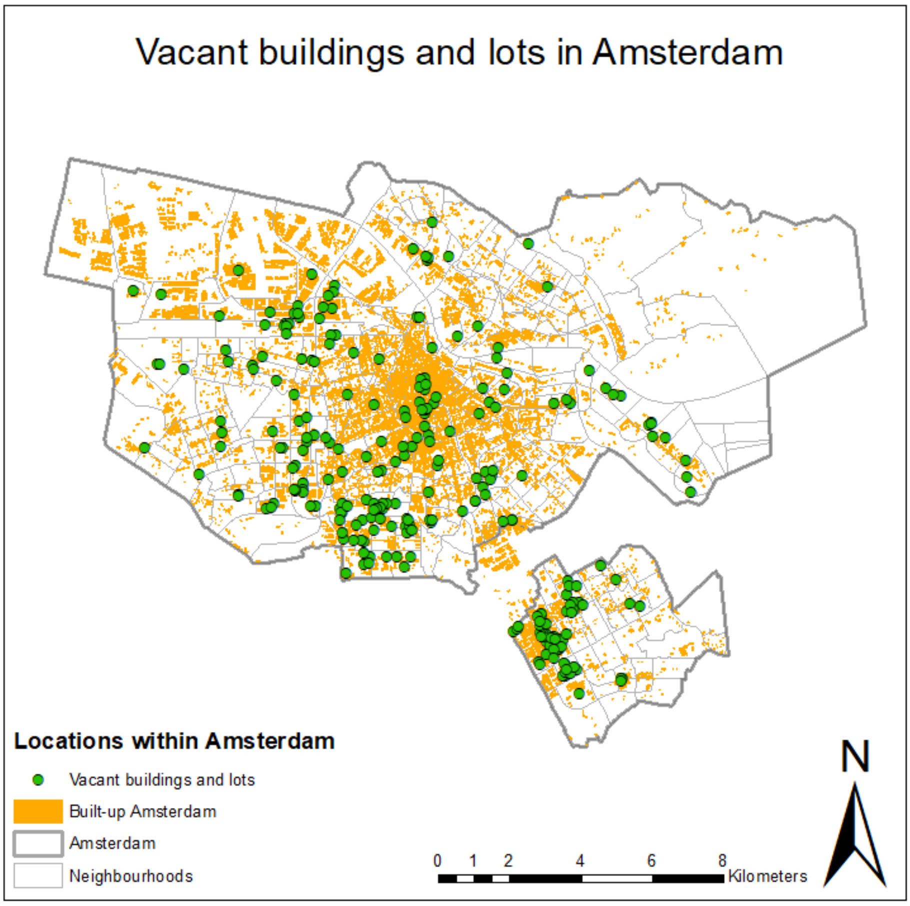
Figure 3.15 All Equal suitability map



3.5.2 Vacant buildings and lots

The descriptions and classification in the available datasets of buildings and lots are somewhat vague. This leads to uncertainty in whether each building or lot is actually available or and to what extent. Here, the buildings are merely used as an example to put the suitability map to practice for the purpose of this research and its applicability. To overcome this issue a more specific selection is made on the allowed future function of the buildings and lots. Eventually, 272 different locations were qualified as input for potential vertical farm locations, distributed over all of (built-up) Amsterdam (figure 3.16).

Figure 3.16 Potential vacant locations



3.5.3 Best locations for a vertical farm

In figure 3.17 all locations with their suitability are shown in the reviewed scenario. In correspondence with the suitability of Amsterdam Locations at the fringes of the city score the best. The three best locations (table 3.4) are located here as well. The reviewed scenario has a strong emphasis on logistics and shows similar patterns to that of market accessibility. However, the best location, 'Admiraal Ruijterweg 408', scores best in almost all scenarios. It has (by an arm's length) the best score in all scenarios except 'Economy of Scale' (Appendix C). It is especially strong in 'the green farming and community empowerment scenarios. It is close to potential renewable energy sources and has the right mix of inhabitants, with a relatively high rate of unemployment. Of all the criteria it only scores low on the number of supermarkets, and hotels and restaurants in the vicinity.

Figure 3.17 Potential scored of location in the reviewed scenario

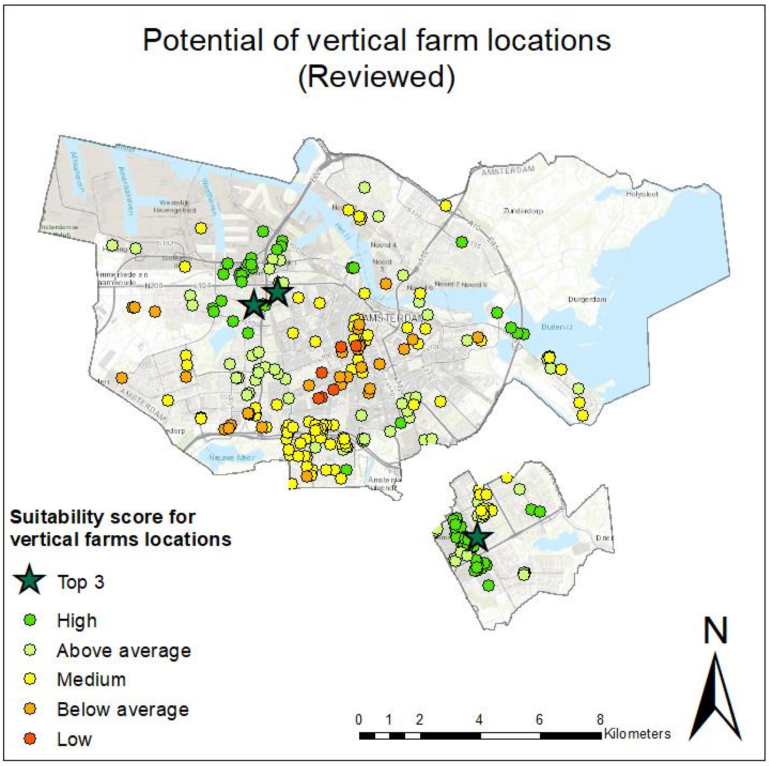


Table 3.4 Top 3 locations 'Reviewed'-scenario

Top 3 Reviewed	*Floor space m^2*	*District*	*Score*
Admiraal Ruijterweg 408	1668	Landlust	85
Karspeldreef 15-19	15100	Bijlmer Centrum	78
Bos en Lommerweg 400	2100	De Kolenkit	77

The least suitable locations are those locations that score badly on the economic criteria of housing prices and average income in combination with the lack of nearby sources of sustainable resources. All scenarios have elements of the four themes in them, affecting the suitability of each location regardless of its relative impact.

3.5.4 How many people can be fed?

Now that there is an idea of the locations that are most suited to vertical farming it is time to look at the specific possibilities of the locations. The floorspace determines the size of production and consequently the number of people that approximately can be fed if a vertical farm is developed in this location. Using the equations explained earlier both are calculated for all locations (table 3.5).

Table 3.5 How many people can be fed per vertical farm

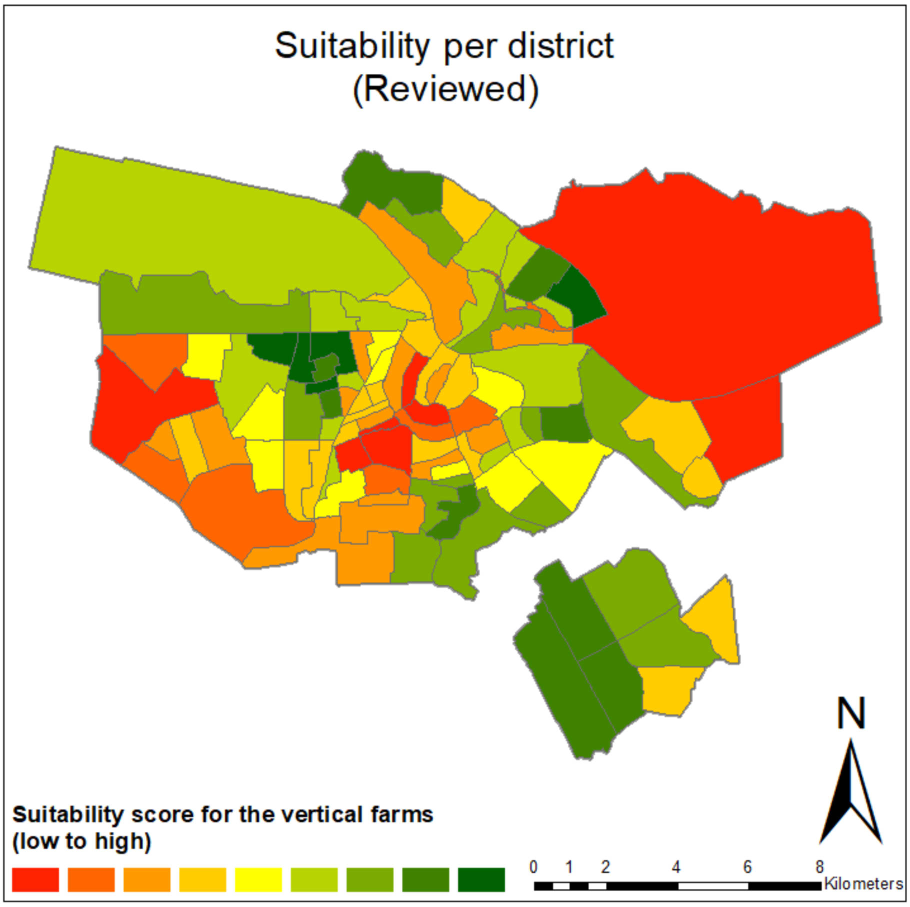
Top 3 Reviewed	*Floor space m^2*	*People fed*	*Production in kg per year*
Admiraal Ruijterweg 408	*1668*	*977*	*52242*
Karspeldreef 15-19	15100	8847	472936
Bos en Lommerweg 400	*2100*	*1230*	*65772*

The three top scoring locations in the 'Reviewed'-scenario differ in size and floor space. In the model, the size of the locations was not taken as a criterion consciously (apart from excluding locations smaller than 1000 square meters in the local assessment). However, the decision to develop a new farm will most likely to accompanied with a certain scale or size that the stakeholders have in mind. In this stage, the different locations can be examined for their score, their size and the resulting production. The locations of 'Admiraal Ruijterweg 408' scores well in almost all scenario but is relatively small. If a vertical farm were to be developed here an annual production of 52.242 kg providing 977 people their daily vegetable intake can be achieved. Meanwhile, the location of 'Karspeldreef 15-19' has the potential to produce and feed almost ten times more. The impact of such a farm on the district or the whole city is not always significant. District 'Landlust', where 'Admiraal Ruijterweg 408' is situated has 18.652 inhabitants (OIS Amsterdam, 2017), while all of Amsterdam has 844.952 inhabitants (OIS Amsterdam, 2017). Only five per cent of the whole district's population can be fed through a farm here, and only 0,1 per cent of Amsterdam. In 'Bijlmer Centrum' the local impact is much higher with over 35 per cent of the 24.397 people living here, and 1 per cent of the total population of Amsterdam fed potentially. If the focus is on innovation and exploring the possibilities of vertical farming, the choice of a location with the size and score of 'Admiraal Ruijterweg 408' answers for the conditions set. However, if the aim is to feed a significant amount of people with local, large-scale production, locations with the size of 'Karspeldreef 15-19' are much more relevant. This can also be realised by combining a number of multiple smaller locations or with the focus of a whole district on the development of vertical farms in its area. This possibility inspected in the following paragraphs.

3.5.5 Suitability per district

The outcome (figure 3.18) is a weighted suitability per district based on the suitability scores and size of the polygons making up the district. The same areas that were highlighted in the previous analysis as low and high suitable areas are present again. In this map, the impact of the individual criteria is not visible, but the pattern and distribution of the suitability are clear. Using the data in this manner allows a stronger differentiation between the districts of Amsterdam and decision can then be based on the administrative boundaries. The danger is however that certain locations are excluded since the overall district is scoring lower on average than small areas within the district. 'Bedrijventerrein Sloterdijk' for instance scores 23th of the 99 districts in Amsterdam in the 'Reviewed'-scenario's suitability, while 8 of the best 11 vacant locations in Amsterdam using the same parameters are within this district. Based on the suitability score a certain area could be asked to further investigate the possibilities of a vertical farm within its borders. Similarly, districts with a relative high suitability in combination with a large quantity of vacant (floor) space can become more interesting for vertical farming (see next paragraph).

Figure 3.18 Suitability per district



3.5.6 Solitary businesses and clusters

On an individual level, some locations score better than others and are thus more suitable for a single purpose vertical farm. However, there are other ways of interpreting the data that a suitability map provides. Some areas might not score the highest in respect to all criteria but stand out with a large amount of vacant space. If the area is still scoring relatively high, clustering becomes an option. An area that focuses all its vacant buildings on a transition to vertical farming can achieve more by combining forces and splitting the costs. Criteria that the area scores worse in can possibly be compensated by a combined investment of the area and the proposed vertical farm business. This way the size of the farms can be scaled up and more people can be fed. If the city of Amsterdam has the ambition to feed a significant amount of its population by locally produced food these areas have huge potential for vertical farming, perhaps in combination with other forms of urban agriculture.

With the use of the previously constructed suitability per district and the overall suitability map two analyses can be made. The potential vertical farm locations are spatially joined in ArcMap to the suitability map. Now per polygon, a count is given. How many locations are within a specific polygon, generated by the MCA. All polygons are selected with more than five location and a score in the 'Reviewed'-scenario that is higher than 65. The floor space of all location is summed so that the polygon has the floor space of all locations combined as an attribute in the table. Five polygons qualify for these criteria, of which four are located in 'Amstel III Bullewijk' and one in 'Bedrijventerrein Sloterdijk' (dark green polygons, figure 3.19). The number of locations clustered here is high and together with their relatively high score, they form interesting areas for development. Both areas are mainly industrial. Land costs are relatively cheap here, while there are not many residents. Their combined floorspace becomes so high the surrounding districts can be fed, and consequently a significant amount of the total population of Amsterdam (table 3.6).

Figure 3.19 Possible vertical farm cluster locations

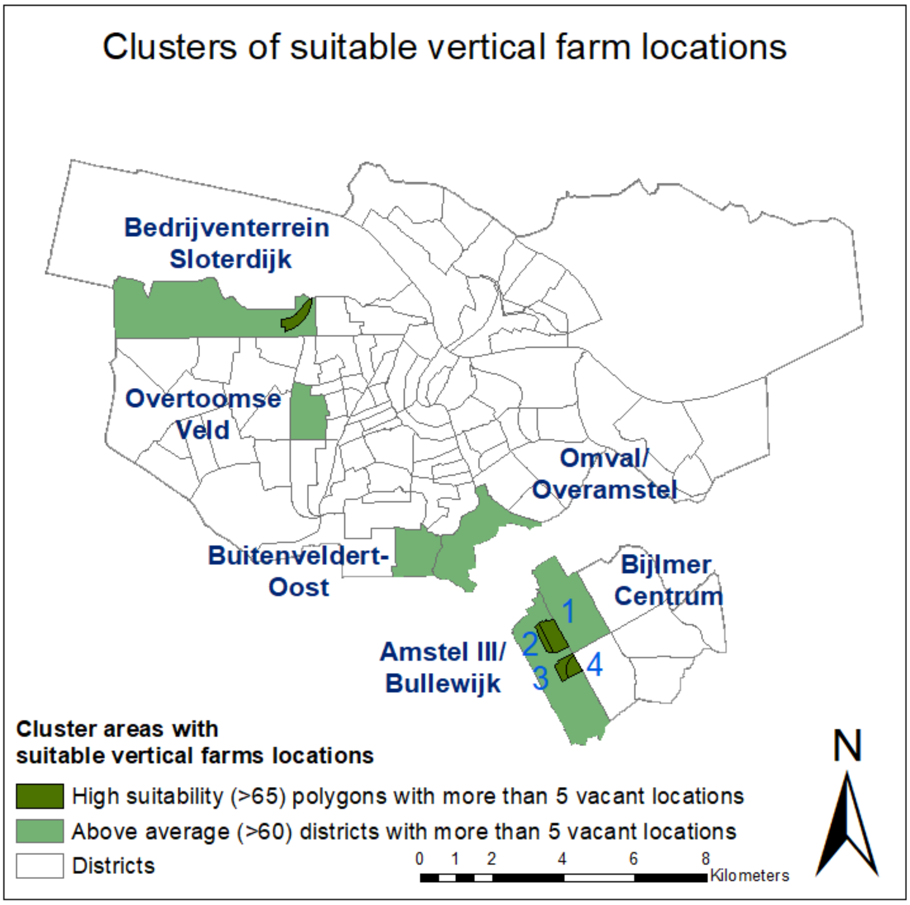


Table 3.6 Polygons with a high suitability score and more than 5 locations

Polygon's District	*Number of locations*	*Reviewed score*	*Floorspace in m²*	*People fed*	*Percentage of Amsterdam*
Amstel III/Bullewijk 1	18	70	125540	73549	8,7
Amstel III/Bullewijk 2	7	70	51500	30172	3,6
Amstel III/Bullewijk 3	6	66	22331	13083	1,5
Amstel III/Bullewijk 4	5	70	73482	43050	5,1
Bedrijventerrein Sloterdijk	6	76	58015	33989	4,0

Since four of the five qualifying polygons are within the same district, the impact can become even higher if the development of vertical farming in and around the city is not focused on single locations but on districts. To examine this the criteria are set again at five vacant locations and the score is set slightly lower at 60. The score of the district is calculated through a weighted average explained earlier. The scores are affected both by the lowest and highest score in the whole district, making the overall scores slightly lower than that of individual polygons. Six districts classify for these criteria (light green districts figure 3.17). Again, the combined floor space of all locations within the area is summed as an attribute in the table, and the potential population fed is calculated (table 3.7).

Table 3.7 Districts with a high suitability score and more than 5 locations

District	*Number of locations*	*Weighted average score*	*Floorspace in m²*	*People fed*	*Percentage of Amsterdam*
Amstel III/Bullewijk	48	66	381953	223772	26,5
Bedrijventerrein Sloterdijk	14	62	349092	204520	24,2
Bijlmer Centrum (D,F,H)	13	66	262931	154042	18,2
Buitenveldert-Oost	5	63	41003	24022	2,8
Omval/Overamstel	5	61	193580	113411	13,4
Overtoomse Veld	5	63	45367	26579	3,1

If the district of 'Amstel III/Bullewijk' is to transform all their vacancy into vertical farms more than a quarter of the whole population of the city can be provided with fresh vegetables from a local origin. In combination with 'Bedrijventerrein Sloterdijk' a potential of more than half the population can be reached. In that case, there is an area of production at both the east and west side of the city. Of course, all this is a utopian idea. It is not likely that these quantities of space are going to be transformed into vertical farms soon. The development of this type of farming is not mature enough for it yet, and it still has to compete with cheaper forms of agriculture elsewhere. It shows, however, that if municipalities desire to use their own space to feed its population, vacant locations are suitable to provide a large part of their needs. Moreover, using the results from this analysis, approximately 1.450.000 m² (about 1,7 m² per person) is required to feed all of the population through vertical farming. The land surface area of Amsterdam is 16.472 hectares (OIS Amsterdam, 2017). Only less than 1 per cent of this land area needs to be transformed into vertical farms to supply to the city with enough fresh vegetables. In this case, only lettuce is taken, which is efficient in regard to its floor space and height. However, it shows that vertical farming has great potential in terms of space as a form of agriculture, and specifically for dense urban areas.

Both current vertical farms in Amsterdam are located in one of the six districts with a combination of high scores and a large quantity of vacancy (§ 3.2.7, table 3.8). The 'GrowX' facility is in 'Amstel III/Bullewijk', the district with the highest potential of clustering. Collaborating with other initiatives in the area, expanding the business locally and actively positioning vertical farming as an asset to the area, could help to support and grow these own businesses.

3.5.7 Bajes Kwartier a good pilot location?

As a last analysis, the results of this suitability analysis are compared with current and proposed locations of vertical farms in Amsterdam. Other than using the suitability map and data to help to make location decisions, it is also useful for examining and evaluating current locations. Analysing existing locations with the data provides valuable information about the strengths and weaknesses of them, and their score compared to other locations or areas. This information can be used if current farms seek to move their facilities or want to invest in specific areas that are spatially determined. Currently, there is one small-scale vertical farm operational in Amsterdam at this moment: 'GrowX'. It has 250 square meters of growing space. The other location is the proposed vertical farm that is to be built as part of the redesign of the 'Bajes Kwartier'. Both locations were added to the analysis using their coordinates. The locations were added with their suitability using the same method as the vacant locations.

Table 3.8 Score of existing vertical farm locations per scenario

Location	*District*	*Reviewed*	*Market Accessibility*	*Economy of Scale*	*Green Farming*	*Community Empowerment*
GrowX	*Amstel III/Bullewijk*	*66*	*64*	*67*	*72*	*69*
Bajes Kwartier	Omval/Overamstel	63	61	59	67	59

Both locations score better than average compared to all vacant locations but are not part of the best 20 per cent. In all scenarios, the location of GrowX is doing better than 'Bajes Kwartier' (table 3.8). The location of either score worse compared to the 'best' vacant location in Amsterdam on criteria like 'Average Income', 'Education', and most profoundly 'Population density' (table 3.9). Locations on industrial areas are generally cheaper but are further away from population centres. That is a consideration that has to be taken when a final destination is chosen. 'Bajes Kwartier' is currently in an area where few people live. Plans are on the way to develop the whole area into a green and healthy living environment. This will automatically lead to a higher population (density) and an increased consuming market nearby.

Table 3.9 Standardised score of the individual criteria for existing vertical farm locations and the 'best' vacant location

Criteria	*GrowX*	*Bijlmer Kwartier*	*Admiraal Ruijterweg 408*
	standardised score (0-9)		
Heat	3	3	6
CO_2	6	6	9
Wind potential	9	9	9
Food Stores	0	3	3
Restaurants and Hotels	3	3	3
Population density	1	1	9
Roads	9	9	9
Public transport	9	9	9
Property Value	7	5	5
Average Income	5	5	9
Unemployment	9	3	9
Education	3	6	9

The different applications of the MCA and resulting suitability map show that it can be used to a variety of objectives. As a tool, it can show the locations in an area that have a high or low suitability towards the goal, vertical farming. Moreover, it can be used to find a specific location for a vertical farm if potential locations are scored with it. Then again different further uses range from deriving the suitability on a larger scale, showing the clusters of potential locations and evaluating current vertical farming locations.

4 Scenario analysis

4.1 Sensitivity of the model

An important aspect of any (spatial) MCA is a sensitivity analysis (Gómez-Delgado and Tarantola, 2006; Chen et al., 2010; Watson and Hudson, 2015). With a sensitivity analysis, the impact of changing the weights and criteria can be shown. If small changes make large differences in outcomes it means the model is sensitive to interpretation and lacks robustness (Chen et al., 2010). Structuring the sensitivity analysis well allows the identification of parameters that need more attention (Ligmann-Zielinska and Jankowski, 2014). The sensitivity analysis cannot only reveal the factors that determine the variance of the model. It also helps to model simplification (Gómez-Delgado and Tarantola, 2006). If some parameters' influence on the outcome of the model is minor, they can be left out (Saltelli et al. 2000; Saltelli et al., 2004) making the model simpler. It will then require fewer data to collect and thus fewer investments of time and money to execute the model and to apply it to another area. Other than that, it can also reveal those criteria that, if left out, completely alter the outcome of the model. This mainly focuses on the sensitivity of the individual criteria, and not on the effect the decision making can have on the outcome. The sensitivity of the individual criteria is important to delve into further. For this research, the focus is on the decision-making choices rather than finding the criteria that influence a vertical farm's location most or least. The number of criteria distinguished is high and comparing all and their impact is a strenuous task. More valuable to this research on a short-term is what happens to the results when a different set of weights is formulated. The context that influences the spatial conditions and decision makers. Here this represented in scenarios.

4.2 Methodology – Scenario Analysis

4.2.1 The weight distribution in the scenarios

The idea behind the use of scenarios was explained earlier in § 3.4.2. The scenarios are used to examine the effects of different approaches to vertical farming, especially regarding the potential outcome of the suitability. As was shown throughout the criteria analysis (chapter 2) the ideas and purposes of vertical farming differ among experts. One sees it as a new lucrative initiative for business. The sole purpose is then to sell as much against the lowest prices. Others may see vertical farming as a new way to produce sustainably for the masses and will do anything to make their business as circular and/or sustainable as possible. Other than the already discussed 'All Equal' and 'Reviewed' scenarios these are represented by four extra scenarios (table 4.1).

Table 4.1 Weight distribution per theme in each scenario

	All Equal	Reviewed	Market Accessibility	Economy of Scale	Green Farming	Community Empowerment
Circularity	25%	25%	12,5%	12,5%	50%	25%
Logistics	25%	40%	50%	25%	12,5%	12,5%
Economic	25%	25%	25%	50%	12,5%	12,5%
Social	25%	10%	12,5%	12,5%	25%	25%

They all reflect possible ideals that vertical farming could address. 'Market Accessibility' maximises the logistics side of the criteria. 'Economy of Scale', 'Green Farming' and 'Community Empowerment' do the same with economic, circular and social criteria. The most important theme gets 50 per cent of the power, while the second most important gets 25 per cent and the others divide the rest and each get 12,5 per cent. For 'Market Accessibility' and 'Economy of Scale' the importance is with logistics and economic criteria, while for 'Green Farming' and 'Community Empowerment' this is with circular and social criteria.

4.2.2 Comparing the number of suitable locations

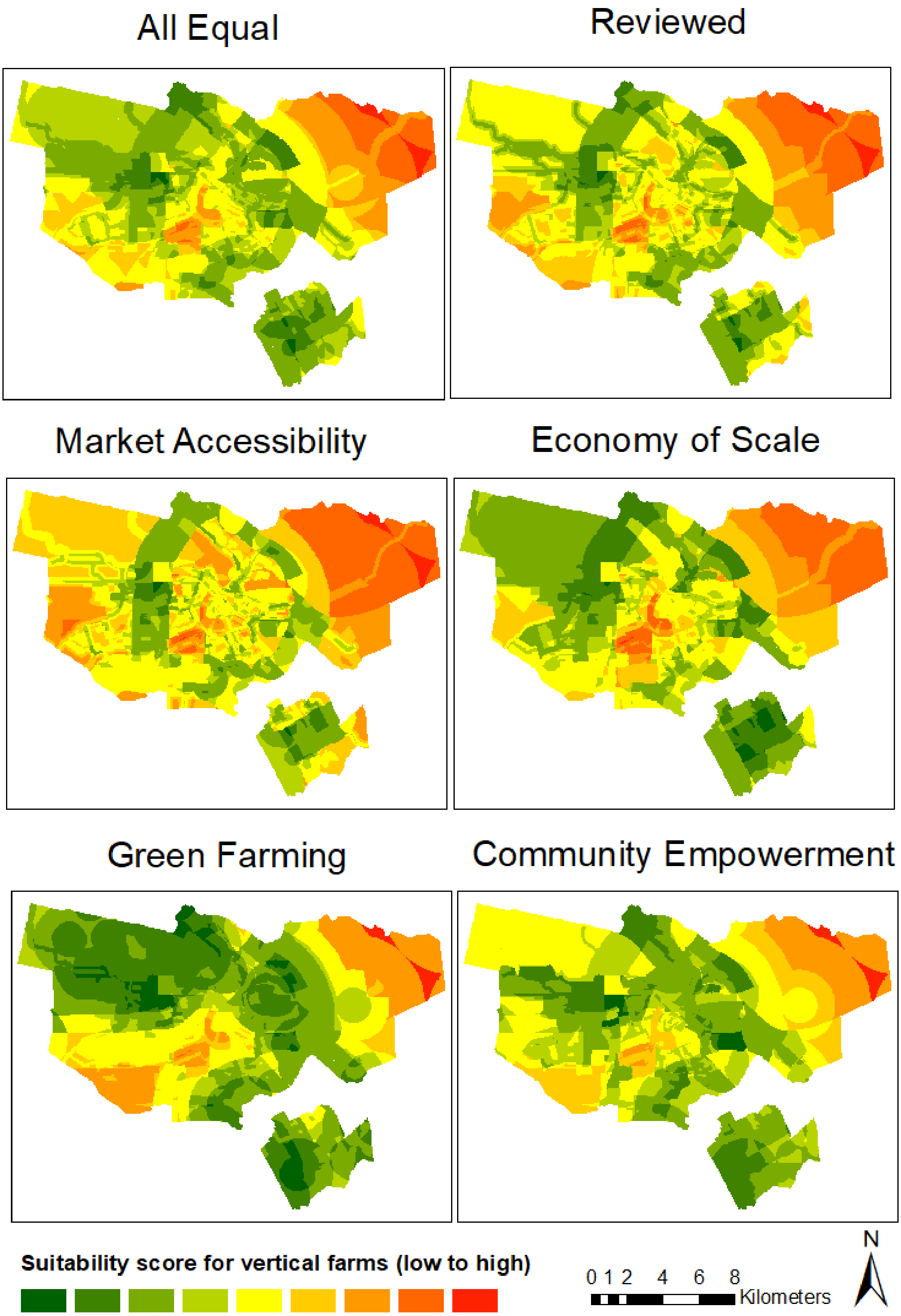
Applying all scenarios will lead to six suitability maps (including the 'All Equal' and the 'Reviewed' scenarios). As mentioned earlier one of the scenarios can be set as a null-scenario to compare the results of the others with. Through this, the differences in outcome can be analysed. All the suitability maps make use of the same combination of criteria and consequently, they all have the same spatial footprint (see § 3.5.1, and figure 3.5.1). In this case, it is a collection of 2431 polygons all having a certain score in combination with a location. Through the same procedure as in the 'scenario application' (§ 3.4.2), all these polygons are given a suitability per scenario. For each scenario, the same classification is used to portray the results. The projection is a direct consequence of the score of the polygon in that scenario. If the scenarios show different patterns the differences can be quantified, and an idea of the influencing criterion can be given. To compare the results, classes of scores are defined for the scenario's suitability. Not suitable are all scores from 0 to 40, average are those between 41 and 60, and suitable are scores above 60. These scores roughly represent the colours red, yellow and green in the suitability maps. Each polygon has a score between one and 100 and has a shape area. For all scenarios, the combined shape area of the three classes are calculated in Excel. The outcomes can then be compared to each other and the changes can be given relative to the null-scenario (All Equal).

4.3 Results

In figure 4.1 all other five scenario's suitability projections are shown. The impact of each of the four themes on the result of the suitability is evident. Roads in and around Amsterdam have a huge impact on the outcome the 'MA', 'EoS' and 'Rev' scenarios. In 'EoS' the most expensive places in Amsterdam, in both rent and income of people are coming forward as areas where vertical farming is not suitable. In the 'EoS' and 'GF' scenarios the 'Westelijk Havengebied' lights up as a potential area due to low land costs and the potential for wind, CO_2 and heat. If the aim of the vertical farm is a combined effort between a cheap location and the maximum potential of circularity this area is interesting. Large parts of 'Amsterdam Zuidoost' scores high on these criteria as well and the area scores well in all scenarios. The area Northeast of Amsterdam is also scoring low on many criteria and thus the overall suitability. This area is mainly rural with some small villages where the housing price is high. As a consequence, it scores low on many of the criteria that have an urban preference.

Assessing the criteria as a whole, the highest scores could have been predicted in the periphery of the city, since this part of Amsterdam is well connected to the highways, renting or buying houses in the periphery is cheaper; more industry is located nearby for circularity options and the right mixture of labour is available. The outcome is not uniform, however, with several areas clearly scoring better than others. The preference of scenario (i.e. different distribution of weights) does impact the outcome of the analysis, but the some patterns remain visible through all scenarios.

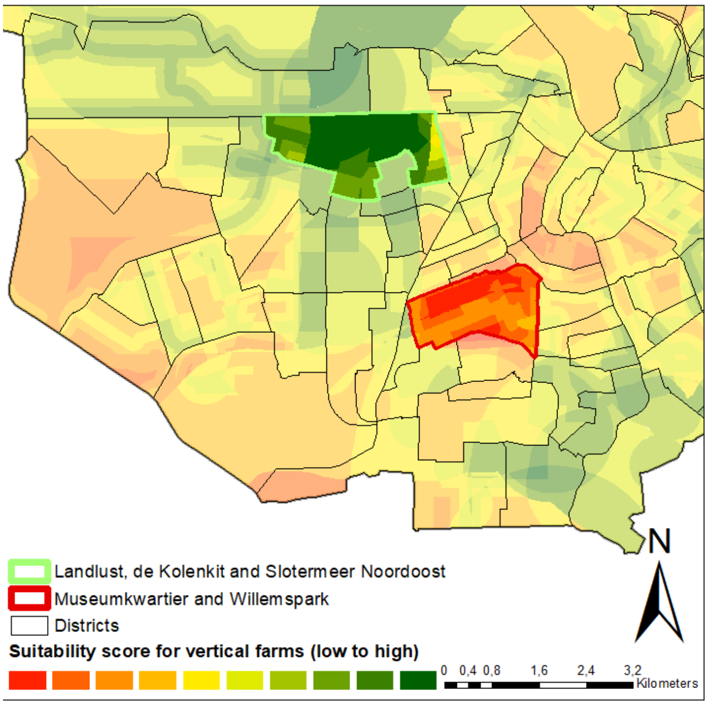
Figure 4.1 Suitability maps in different scenarios



4.3.1 Consistent scoring areas

Interestingly there are two areas at both sides of the spectrum (high and low suitability) that score consistently in each scenario. The area of 'Landlust', 'de Kolenkit' and 'Slotermeer Noordoost' (figure 4.2) is performing well for each scenario. In this figure, it is shown within the 'Reviewed'-scenario. If you compare the area with any of the four other scenarios in figure 4.1, you will find a similar suitability. The attraction of the area can be found in the proximity to industrial areas from which to source CO_2, heat and even wind energy. The position in the vicinity of a highway is vital and it scores well on the social criteria. An area that scores relatively bad in all scenarios is the area around 'Museumkwartier' and 'Willemspark' (figure 4.2). It is an expensive area in Amsterdam with a relatively low population and hospitality density. They score average on education but have relatively low scores for all other criteria.

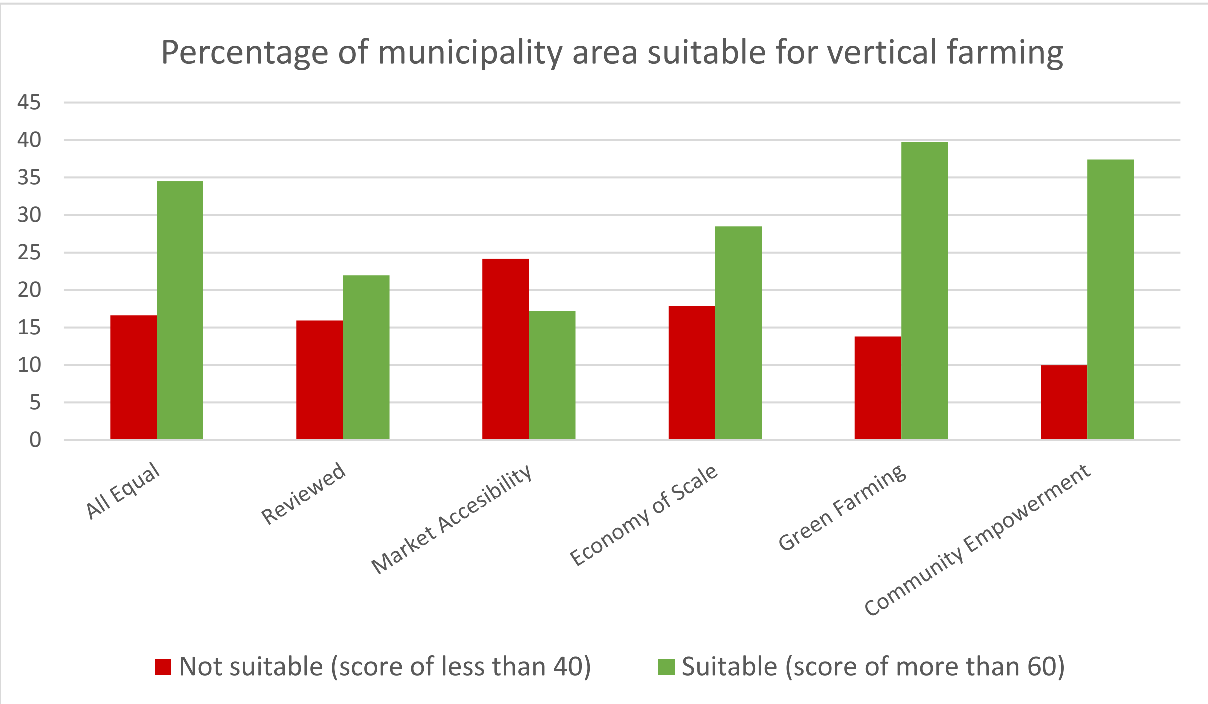
Figure 4.2 Consistent high and low scoring areas in all scenarios



4.3.2 Suitable areas compared

Regardless of the scenario, the distribution of all criteria together stays the same. All scenarios are based on the union of the 12 criteria. For that reason, changes in the outcome are determined by the impact of the individual criteria. In figure 4.3 the percentage of Amsterdam that is suited and not suited

Figure 4.3 Suitability percentage of scenarios



for vertical farming are presented. The scores in between are left out. In both the 'GF' and 'CE' scenarios more than 35 per cent of the total area of Amsterdam is found suitable for vertical farming. While this is up to twenty per cent for 'MA'. At the same time, almost 25 per cent of the total area of Amsterdam is scoring too low to be suitable for vertical farming in the scenario. Community Empowerment sees only 10% of the area as unsuitable. In table 4.2 the suitability areas are compared with the null-scenario ('All Equal'). The relative change per scenario is given, derived from the results in figure 4.3.

Table 4.2 Change in suitability compared to the 'All Equal' scenario

	Reviewed	Market Accessibility	Economy of Scale	Green Farming	Community Empowerment
Change in not suitable	-4,1%	+45,4%	+7,5%	-17,1%	-40,1%
Change in Suitable	-25,7%	-35,3%	-12,4%	+10,8%	+5,9%

'CE' has 40 per cent less area that is unsuitable than the null-scenario while 'MA' has 45 per cent more. Meanwhile, the suitability is highest in 'GF' that has almost 11 per cent more 'greenness' in the municipality. This would suggest that circular vertical farms might be relatively more viable for Amsterdam given its local spatial conditions. 'MA' has 35 per cent less suitable area than the null-scenario. These results can be understood and explained by the criteria and the method of the MCA. If the 'greenness', or suitability, increases or decreases in a scenario this is determined by the score of certain criteria that are relatively easy or hard to achieve. For instance, if almost the whole of Amsterdam is given a high score for CO_2 and the circularity theme is given a high weight (50%) then relatively many parts of Amsterdam will score well in this scenario. This is due to the maths behind the 'weighted sum model'. High values are then more multiplied than low values and have a greater impact on the outcome. In other words, the criteria that are emphasized in the scenario are now strongly satisfied. Similarly, criteria only a few polygons score well on and which are given a relatively high weight in a scenario can lead to less suitable locations (more redness) in the remainder of Amsterdam. This happens for instance in scenarios with an emphasis on logistics. Roads, public transport and also population density are concentrated around specific areas of Amsterdam. Large parts of the municipality have a low score on these criteria. Arguably a correct representation of accessibility of Amsterdam, but also a result of the choices made in the process.

Possible different motives and resulting context of a decision-maker has an influence on the outcome of the suitability map and consequently the choice of potential locations for a vertical farm. In the municipality of Amsterdam, the best and worst location are stable throughout all examined scenarios but the amount of suitable area changes significantly in each of the four scenarios.

5 Conclusion

That a vertical farm can be built anywhere without the need for a certain type of soil or growing environment raises the question whether there are any spatial conditions, or criteria, that influence its success or failure. The analysis of current examples, literature and interviews in this study found spatial conditions that have an effect on the functioning and potential of a vertical farm. Taking those criteria and use them in a Multi-Criteria Analysis (MCA) to come to suitability sites in an area provides decision-makers with insights into the strengths and weaknesses of locations.

The analysis was done using twelve criteria that were attributed to four themes, resulting from the analysis. These were circularity, logistics, economic and social. The themes with their corresponding criteria were applied to the municipality of Amsterdam. The methodology for the MCA was an Analytical Hierarchy Process combined with a 'weighted sum model'. The criteria were standardised and the individual weights of the criteria were specified through the power they have on the overarching theme compared to other criteria in the same theme. A scenario in line with the results of the analysis was elaborated. This 'Reviewed'-scenario puts most power in logistics (40%), a vital contributor to the success of the affiliated horticulture industry in The Netherlands, followed by economic and circularity criteria (25%). Social criteria (10%) do not have a large impact on the location decision of vertical farms. The suitability map that was created using these parameters was used to determine the best locations for vertical farming in Amsterdam.

Of all vacant buildings and lots currently available to the development of a vertical farm the location of 'Admiraal Ruijterweg 408' in the 'Landlust' district scored best. The number of people that can be fed with a converted vertical farm here is less than 1000. Given the floor space used, this is highly effective. However, it is only a small portion of the people in the area, let alone of the whole of Amsterdam (less than 0,1%). If the aim is to feed a substantial part of the urban population with food produced in the urban areas itself, larger or more sites have to be considered. Looking for areas with a lot of vacancy of buildings in combination with a high suitability can be worthwhile. Combining the floorspace of multiple vacant locations and cluster them into an area designated for vertical farming can feed a substantial amount of the municipal population.

Currently assigned locations for vertical farms in Amsterdam, 'GrowX' and 'Bajes Kwartier', can only be partially explained by the resulting suitability. They do score above average. Based on the criteria used in this study there are areas to improve on for both locations. The results of such an analysis can thus also be vital information for current vertical farms. They can assess the (spatial) strengths and weaknesses of their location and see if there is room for improvement at their current location or elsewhere.

Different goals for a vertical farm can motivate a decision maker. This results in different suitability maps and potential location. Four scenarios all with a bias towards one of the four themes show different patterns and locations that suit a vertical farm. Interestingly the areas that score best, 'Landlust', and worst, 'Museumkwartier', and their direct surroundings) score consistently in any of the scenarios. Whatever your motivation 'Landlust' is a good place for vertical farming, and 'Musuemkwartier' is not advised in any situation.

Due to the 'easiness' to obtain a high score for certain criteria in Amsterdam, namely those associated with circularity and social, the scenarios emphasising the weight on these show an increased amount of suitable areas for vertical farming compared to the other scenarios. The scenarios with an emphasis on economic and logistic criteria have relatively more unsuitable areas for vertical farming. Caution is mandatory in interpreting these results. They can either be a correct analysis of the current situation in Amsterdam, for instance with the inaccessibility of which it is notorious for. But might also be a consequence of assumptions and decisions made in the (pre-)processing. More research on the individual criteria and their spatial-temporal relation on a vertical farm's location is needed to further strengthen the model.

The lack of any precedent and insight into the effect of some specific criteria meant that assumptions had to be made. Moreover, the availability and the quality of data determine to what extent, and how secure the MCA can be executed. Some interesting criteria had to be discarded, because there was no, or not the right kind of spatial data available for them.

This research has shown that spatial criteria should influence the decision making of vertical farms. Context-dependent scenarios affect the result of the suitability of areas in Amsterdam and can lead to a decision for a different location. The novelty of vertical farming brings forward many uncertainties for decision-making, that can be mitigated using a spatial MCA to guide the process.

6 Discussion

In this chapter, the results and conclusions are further analysed and discussed. In several stages during the execution of research choices are made that influence the course of the research and possibly the results of the MCA. Furthermore, there were limitations to the available data and the amount of similar research or other forms of scientific data on vertical farm locations. Some of the most essential points are reflected here. The last paragraph discusses the relevance of vertical farming in the Netherlands compared to other countries.

6.1 Data and (pre-)processing

In the data collection and pre-processing phases, a lot of considerations were made based on literature, interviews and my own interpretations of it. A lot can be said about this in relevance to the outcomes of the study. A distinction is made between the effects of the decisions in the model itself (interpretation uncertainties) and external factors that reduced the certainty of choices made.

6.1.1 Interpretation uncertainties

The pre-processing or spatial-temporal decisions made in the model are purposely kept simple. Per criterion, only a few classes are added for normalisation. This way it was possible to create and execute the model efficiently using 12 distinct criteria. However, this means you are dealing with discretion issues where two classes meet. This is most evident for the 'roads'-criteria. Here locations just outside the 1000-meter buffer around the highway, and not near another road, are given a score of 0 instead of 9. If a location is 999 meters from the highway it gets a score of 9 and 1001 meters gets a score of 0. In practice, this slight difference in distance does not make this impact difference. Another approach to these criteria is desired. It would be more accurate to use a network analysis that shows how many customers can be reached in a given timeframe for example. Then the road itself is of less importance. Then the importance is the people you can reach from your location.

This discretion issue is most evident to this criterion but exists in almost all criteria to some extent. This is a sensitivity of the individual criterion that is not further investigated here. That can be the effect of a different amount of classes, but also the effect of different class boundaries. Some areas might score significantly better or worse by a slight variation in the size of buffers or the classification of values. In any case, standardisation based on a continuum can lead to better results (Yousefi and Carranza, 2017), but is also more time-consuming. Similarly, the decision made on the classes was done based on interpretation and for some backed up by literature or the interviews. An approach using standard deviations to define the classes might lead to different classes and thus differences in the impact of the criteria.

The choices made in the data pre-processing thus have an impact on the outcome of the MCA and the suitability map. In this study, no analysis is done of the changes that occur when different spatial or temporal classes are defined in the pre-processing part. As an example, CO_2 perhaps fluctuates in supply throughout the year while the demand is constant. Similarly, the demand for heat is likely to be higher in winter compared to summer, whilst the available supply is highest in summer.

Similarly, one year the supply can be different due to weather or other conditions than other years. The data that is based on yearly-averages and does not account for these fluctuations.

The sensitivity of the model is in this study only determined from the a decision makers, or external, viewpoint. It shows what happens to the suitability if another weight distribution is given to the themes and subsequently the assigned criteria weights. The impact of changing the weights of the individual criteria is not assessed. The weight they have towards their overarching theme are based on interpretations and are the same in each of the scenarios. An analysis into the sensitivity of the model to internal changes like these can provide with more understanding of the effect the individual criteria have on the outcome (Chen et al., 2010) and provide understanding of the most impacting criteria on the vertical farm's location. Those that have almost no impact can be left out, leading to a simpler model.

A completely different approach could have been taken as well. The analysis was done form an Amsterdam point of view. This meant all data was fitted and processed to the extent of Amsterdam and consequently the locations were identified to the overall result. Another approach would be to use the location as input and derive the values of the criteria from there. The result would be less fixed by administrative boundaries, but the result would only say something about the individual locations and not for the whole of Amsterdam. This is a method that may be considered when there is an idea of a specific location already.

Data that is based on the statistics of administrative areas is spread over the whole of Amsterdam and every polygon is filled with a score accordingly. Data that is determined using spatial proximity like roads and wind potential are more likely to have areas with a low score due to areas being too far away from them when they are not represented in the all of Amsterdam. All data from the economic and social themes are based on statistics and have a more uniform scoring pattern over Amsterdam. Each district has data, and gets a score. Due to the decision to not exclude areas like water in the analysis also these areas are scored for each criterion. If the water body is big enough this means roads are less likely to score here, while statistics data reaches here because the body of water is part of an administrative area. This impurity can be an explanation of a relatively large area of unsuitability in the 'MA'-scenario.

To calculate the production of a vertical farm a method based on that of Kozai and Niu (2015a) is used. This method assumes that lettuce is grown and that certain ratios are held to facilitate the growth of the plants. If another type of crop is taken, or a combination of crops the amount of total production changes and in most cases it drops. However, vertical farming is then still an effective method for production in terms of space. The calculations are done using the maximum kilograms of production per m^2 in a greenhouse for each tier. Theoretically, it is possible to produce much more than that in a vertical farm per m^2 (interview B), regardless of the number of tiers. However, this would affect the resource efficiency of the farm and increase the cost price of the product (interview B). The of product a farmer wants to grow and at what density he places them determines the possible production capacity and the cost price of the products.

6.1.2 External factors

Other than the choices made during the execution of the study, the results are also affected by external factors. The quality of data of the vacant buildings and lots is poor. It contains a lot of different attributes that should make the data richer and better qualified for selection. However, the amount of attributes and the vagueness of the distinction makes the selection of potential locations hard. Here the locations are merely an instrument to show the applicability of the suitability and the model. In real cases the potential of locations needs further examination. This can happen before these locations are matched with the suitability of Amsterdam, or when the best scoring locations according to the suitability are found and then these can be further analysed. The size of the building, the construction specification, the floor height amongst others are important characteristics that determine its actual potential. If the method used in this research is chosen the result is still only a selection of locations that show potential according to their spatial conditions, and not because the structure itself is best suited for vertical farming. Also developing a vertical farm somewhere will impact its surroundings, an issue that is not taken as a criterion here. Noise pollution, waste streams etc. all have to be accounted for by the building and it has to be within the norms of the law. Some locations might thus not actually be suited to vertical farming because they do not conform to these laws.

In the literature and interviews, no major criteria were found, criteria that make or break a vertical farm's location. In any way, an MCA becomes unnecessary if this is the case, but at the same time, the MCA is now based on people's opinions and assumptions rather than hard facts. It was hard to find expertise in vertical farming's location decision-making. The persons interviewed were all connected with the subject but none has been part of the choice of any vertical farm's location. The opinions they have are based on other closely related businesses like the horticulture industry. Current vertical farms in The Netherlands were addressed to have an interview with but declined or showed no interest. This together with the absence of some data made the model less solid.

There are little opinions or standpoints available from staff members of (local) government and political parties. It is shown by other unconventional farming practices in the city that the social acceptance of a novel idea is crucial for it to work (interview A). At this moment, however, the level of acceptance for a vertical farm is hard to capture with any existing data set. Research specifically on the image of and the openness towards the development of large-scale (vertical) farming of urban citizens are needed to clarify this. At the same time the political colour of a city at the time of the decision-making can determine the importance of certain criteria. A leftish, green government that is currently in power is likely to put more emphasis on criteria associated with circularity and unemployment.

More research and expertise is needed to improve the understanding of spatial and temporal conditions of vertical farming. And even then, the decision-making is likely to happen with other considerations in mind or targets that have to be met. After all, as shown by the outcome of the different scenarios, these kinds of tools can only guide the decision-making process, but not determine it or predict its outcome. The actual decisions are made by people and through that many other forces come into play.

6.2 Review considerations

The criteria analysis was done using the input of seven interviews and the literature that was available at the time. During the course of the thesis work, many new articles were becoming available on a variety of subjects within the domain of vertical farming, meaning that there is already more information available now than at the start of the research. This shows the topic is hot and that more and more is known about the development of vertical farming. An effort is made to incorporate all recent work. However, the pace of new research being published means it is hard to do this constantly. Not all are in favour of vertical farming and the discussions around the high energy use of vertical farms and its impact on the environment are likely to continue for a while.

In my interviews, I stuck to an interview guide that I set up before the first interview. As I had done a few interviews I gained more knowledge myself and would use things that I gathered from other interviews in my questioning. This was helpful to guide the interview into certain directions and clarify and verify certain things I heard earlier. However, this also meant I was unconsciously guiding the talks into directions that I had already explored in other interviews, and not allowing to let the interview take its own route. Perhaps some interesting thoughts and ideas of interviewees were missed out on, and certain topics or opinions forced onto them.

6.3 Why is spatial context important?

The study focused on the spatial conditions at a relatively small scale, the municipality. How does the direct surrounding of a vertical farm influence its success rate and how can decision-making be guided by it. Early in the research, it became evident that a large part of the success might not be determined at a micro-scale like this but rather on a macro scale. The differences in culture and geography of countries.

Amsterdam or the Netherlands as a whole is perhaps not the most suitable location to catalyse the development of vertical farming. Ideally, the model will be reproducible and applicable to any city. If this is pursued it is important to acknowledge the context in which the research was executed, and keep in mind which conclusions are case specific and what would apply anywhere. In the case of Amsterdam, a few things have to be addressed. The horticulture sector in The Netherlands is arguably the most advanced in the world currently and is based on growing under glass (interview B; E). The production and supply of fresh vegetables in The Netherlands is more than sufficient for the domestic market and only uses a small percentage of the total land area of the country (Vermeulen, 2016). Any vertical farm will have to compete with this supply and can do so only in terms of a closer proximity to the consumer or the exclusivity of the product itself. At the moment of writing the cost for the average crop from a vertical farm is 2-3 times higher than that of products grown in greenhouses in The Netherlands (Spruijt et al., 2015; interview B). In other countries, the efficiency of the current agricultural system may be far less, or the environment is less suitable for traditional farming or horticulture (Graamans, 2018; VPRO tegenlicht, 2017). This could mean the difference between the cost price of a crop for a vertical farm and the current produce is lower. Think of places with extreme climates less suitable for crop growing; in the far north (Iceland, Siberia etc.) and in the desert (Dubai, Nevada). Deserts also have the advantage of having a high solar power potential and thus more possibilities to supply the energy for the farm sustainably (Despommier, 2010). Countries like Iceland and Norway have a large amount of sustainable energy potential in the form of water power or geothermal and can use this as a source to supply locally grown food that is impossible to grow under the normal outdoor conditions there.

Secondly, location is not only important for its potential but also for its purpose. In Amsterdam, the reason to invest in vertical farming could be to have an ultra-fresh source of food for restaurants. However, the reason of interest in vertical farming in China could be much more focused on the concerns of food safety (King et al., 2017) and the potential of producing in an enclosed environment. Providing longer shelf life and the disease-free food is then the primary purpose (interview G). Japan, consequently, is due to its geography a country that is highly dependent on imports for many of their food supply. On islands, the food logistics chain is much different from that of mainland countries. The country has little flat farmland and vertical farms can be ideal solutions to produce large quantities of food on limited space. For that reason, it is argued that it is not about city or rural where you want to do vertical or indoor farming but rather in which geographical environment or position. Weather, density and terrain are here much more important than the rural vs. urban argument. How the logistics are organised, due to the geography of a country determine the potential (interview G). Similarly, Areas where there is a high density of living, and not a lot of space left to build or to produce food will have more benefits of farming vertically (interview B). Thirdly there is the dependence on other countries for food provisioning (interview E). That is of no issue in peace times, with good trade relations but can become hazardous for a country's integrity in times of hardship. Countries that now rely on imports for food are generally not able to produce the domestic demand for food in their own country due to geographical reasons. Examples are nation-states or islands. Singapore is heavily reliant on Malaysia and other neighbouring countries for its food supply and is investing in vertical farming. This is way to farm on a large scale in this small and highly urbanised country (Interview E). Qatar was meeting up with Dutch horticulture industries just days after the recent Arabian lockdown, to invest in new ways to produce food in their own territory (interview E). To overcome this problem, they want to invest in food sovereignty and have a constant domestic supply of food without having to deal with a foreign nation.

Cultural aspects of places are also important. In Amsterdam, the idea of keeping pigs in the city was hard to sell to the inhabitants, according to the decision makers in government (interview A). In the city, there are multiple initiatives of urban agriculture, but they only account for a minimum amount of the total food supplied to the city. In reality, food production is still seen as a concern of the rural population. The farms are multi-million companies grown throughout the years by scaling up. A strict boundary between the rural and the urban still exists today in The Netherlands. In other countries, this divide is less visible but other concerns arise. Most of the time food policy has long been neglected by urban citizens (Wiskerke, 2015). In many Asian countries for example, farming is seen as an occupation of the poor. Being a farmer is looked down upon. The introduction of vertical farming could be a tool to encourage the urban inhabitants to be involved in food provisioning once again (interview B). In a vertical farm, the farming is seen more as a technology, and a higher-level job than on the rural lands (interview E). A vertical farm resembles a lab more than the open fields. To perform the job well, education is essential. Combining these elements might make the job of a farmer, be it a high-tech indoor farmer, in these regions more attractive. In contrast, the image around urban farming and local food in the Netherlands are not that of food produced in lab-like environments but rather that of organic, your hands and feet in the dirt, farming (interview E).

The biggest current advantages of vertical farming are arguably fresh (local) produce and food security (Japan). Both of these advantages are not an issue in the Netherlands. The horticulture business in the Netherlands is able to supply vast amounts of fresh products during the year and consequently also provides food security for the country. It can even be argued that this a form of urban agriculture (interview A; E). Island countries are more inclined to have issues with either. Japan is showing that vertical farming is an interesting new technology that can help tackle its internal problems with food supply. Thus, there is arguably more to gain for a country like Japan in the development of vertical farming than for the Netherlands.

7 Recommendation

Since this research's intention was an exploration the idea of determining a vertical farm's location with spatial conditions, still a lot is unclear. It is shown that it is possible to provide guidance for decision-making and do this on the basis of different scenarios. However, this results in many more questions and possibilities. A few are discussed here.

First of all, and most importantly, a much more detailed look has to be given to all the (spatial) criteria that influence a vertical farm's location. More criteria can likely be added and others might not be as relevant as this study suggest. In order to do that, research with a focus on the criteria itself is advised. For instance, an assessment of all the current vertical farm locations could be made in combination with interviewing the companies behind them and how they have come to their choice of location. Also, examining the locations of well-functioning and underperforming vertical farms to see if there is a relation in spatial conditions with a successful or failing business. This can provide a better insight into the most vital criteria.

With the same goal in mind, tests can be run on the MCA performed in this study to find out the internal sensitivity of the model and the impact of the individual criteria. Both by changing their weights or by changing the classes or standardisation of them. Extending the model so that discretion issues are less impacting the outcome is needed to polish the model and have a stronger result. A use of continuous instead of discrete values in standardisation could be a way of dealing with this. A proper sensitivity analysis can not only reveal the essential criteria but this also help to simplify the model (Gómez-Delgado and Tarantola, 2006). Now twelve criteria are used to determine the suitability, making the model complex. Perhaps some can be left out because they are already covered by other criteria or are not of enough importance on the results itself.

Then again, some criteria were left out in this study because the right data could not be found or was not of decent quality. The make a proper assessment this data needs to be available. Solar power can be a strong criterion for those vertical farms that want to use its benefits for a more sustainable method of growing food. It is then essential that more data becomes available of the possibilities of solar power. A vertical farm is not likely to be able to source all energy it requires from solar panels on its own terrain. For that it requires too much energy. After all its growing multiple layers of food, where outside only one layer can benefit from the sun. It then needs access to other places that produce an excess of solar power. This can be solar farms or a collection of households. In any case, usable data that shows these places were not found yet for Amsterdam. Creating these maps can not only benefit the search for vertical farms' locations but can also help more projects that look for ways to source (excessive) solar power.

The way the results of the suitability map can help current vertical farms by showing their strengths and weaknesses raises the opportunity for many more applications of this data. If the model is further solidified and has proven its worth, the suitability map can be used for decision-making according to the preference of the stakeholders. A group of stakeholders, together in control of a new location decision can be asked to score the four themes individually for a combined score of 100 per cent. They determine for themselves which theme is most important to them for, in this case, a vertical farm. The results of all stakeholders can also be combined into an average score for each of the four themes. These average scores can then be set as parameters for the MCA and this will result in a suitability map according to the combined (averaged) preference of the stakeholders. The top ten can then be considered as possible locations that need to be further analysed and decided upon, based on other non-spatial criteria. This is not only possible for the considered vertical-farm case but for any spatial decision-making problem that can be brought back to manageable parts, here called themes, on which decisions can be based.

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Appendices

Appendix A: Interview guide

The interview guide is set up in such a way that the interviewee's role in the Vertical Farming can be anything from researcher to farmer itself. When conducting the interview the background of the interviewee should be kept in mind.

Things I want to know:

- Location criteria for a vertical farm;
- What typifies a vertical farm to the interviewee;
- What is the current relevance of a vertical farm (profit, research, educational, social awareness etc.);
- What are the techniques used, and what amount of production is possible with them
- Is there any spatial data associated with the criteria available? (if the interviewee is aware of this).

The interviews will be done semi-structured, keeping the information that is wanted in mind, and using the following questions as a guide through the interview and as a backup when the conversation draws to a conclusion.

The interview today is about the emergence of vertical farms in urban areas. More specifically I'd like to talk about the location of these farms within cities. To do this we first have to look at the concept of the vertical farm itself. In my research, I have come across a number of different types of vertical farms, that all share the 'vertical' nature of the term, but vary in the actual design of the farm itself.

1. What is for you the definition of a 'Vertical Farm', or how do you see it? What is it, and perhaps also what is it not according to you?
2. When you look at a new location for a vertical farm are there any specific criteria that (would) influence your choice?
    a. What criteria are that and why do you find them important? Or: Why not?
3. What is for you the most essential contributor to the success of a vertical farm? (does not have to be spatial)
4. What techniques are essential for any vertical farm currently?
5. What purpose do current vertical farms have according to you?
    a. And do you think this will change in the future?
6. Do you think the location of a vertical farm in a city has a large influence on its success?
    a. If *yes*, why do you think that and in what way?
    b. If *no*, why do you think it does not matter?

When looking for locations space is an important factor. Therefor any indication of the space that is needed for a farm, or what can be produced per unit of measure is powerful when doing your calculations. The sizes of current farms differ largely.

7. Is there an indication of space you can give? This can be the yield per m^2 or an economically viable size of a farm?
8. Are you familiar with spatial data, and do you have access to specific spatial data that is interesting for a vertical farm (location)?

Interviewed persons

Interview A:

Dr Peter Smeets researcher at Wageningen Research and Metropolitan Food Clusters. Specialised in Agroparks and Metropolitan Food Clusters.

Interview B:

Prof.dr.ir. LFM (Leo) Marcelis; Head of chair group Horticulture and Product Physiology. Specialises in the physiology of plants. Much of his research is on vertical farming and other forms of indoor agriculture.

Interview C:

Dewi Hartkamp: Programme manager of SIGN. The innovation monitor of Glaskracht which is part of the Land-en Tuinbouw Organisation (LTO) (agri-and horticulture organisation).

Interview D:

Patrick Zwaan and Tom van dan Dool from Rabobank. Patrick is the horticulture specialist for the bank and Tom did an internship for Rabobank concentrating on business models for vertical farming.

Interview E:

Jan Westra of Priva. He is responsible for to the overview of business opportunities and developments in the horticulture sector. He has met several of the key writers on vertical farming and is responsible for finding new partners to work with for the company.

Interview F:

Rosanne Wielemaker. She has done extensive research on the reuse of nutrients from human waster flows in urban agriculture and is currently doing her PhD on this subject. We talked about the possibilities of this for vertical farming.

Interview G:

Céline Nicole. She does research for Philips Lighting in the Horticulture group. She specialises in the growth of different plants and cultivars under LED lights in controlled environments. I was able to visit their facility in Eindhoven and was shown around the test modules.

Appendix B: Weight distribution per scenario

Table B1 All equal

Goal	Themes	% of goal	Relative weight	Sub-themes	% of themes	Relative weight	Criteria	% of sub-themes	Relative weight
VF suitability	Circularity	25%	0,25	CO2	25%	0,063	Waste CO2 streams	100%	0,063
(all equal)				Energy	75%	0,188	Wind potential	75%	0,141
							Heat sources	25%	0,047
	Logistics	25%	0,25	Transport	50%	0,125	Roads	75%	0,094
							Public transport	25%	0,031
				Consuming markets	50%	0,125	Population density	50%	0,063
							Hotels and restaurants	20%	0,025
							Supermarkets	30%	0,038
	Economic	25%	0,25	Rental prices	60%	0,150	Property value	100%	0,150
				Labour (cost)	40%	0,100	Average income	100%	0,100
	Social	25%	0,25	Labour (availability)	50%	0,125	Skilled labour	100%	0,125
				Labour (inclusion)	50%	0,125	Unemployment rate	100%	0,125
total			1,000			1,000			1,000

Table B2 Reviewed

Goal	Themes	% of goal	Relative weight	Sub-themes	% of themes	Relative weight	Criteria	% of sub-themes	Relative weight
VF suitability	Circularity	25%	0,25	CO2	25%	0,063	Waste CO2 streams	100%	0,063
(reviewed)				Energy	75%	0,188	Wind potential	75%	0,141
							Heat sources	25%	0,047
	Logistics	40%	0,40	Transport	50%	0,200	Roads	75%	0,150
							Public Transport	25%	0,050
				Consuming markets	50%	0,200	Population density	50%	0,100
							Hotels and restaurants	20%	0,040
							Supermarkets	30%	0,060
	Economic	25%	0,25	Rental prices	60%	0,150	Property value	100%	0,150
				Labour	40%	0,100	Average income	100%	0,100
	Social	10%	0,10	Labour (availability)	50%	0,050	Skilled labour	100%	0,050
				Labour (inclusion)	50%	0,050	Unemployment rate	100%	0,050
total			1,000			1,000			1,000

Table B3 Market Accessibility

Goal	Themes	% of goal	Relative weight	Sub-themes	% of themes	Relative weight	Criteria	% of sub-themes	Relative weight
VF suitability (market Accessibility)	Circularity	12,5%	0,125	CO2	25%	0,031	Waste CO2 streams	100%	0,031
				Energy	75%	0,094	Wind potential	75%	0,070
							Heat sources	25%	0,023
	Logistics	50,0%	0,500	Transport	50%	0,250	Roads	75%	0,188
							Public Transport	25%	0,063
				Consuming markets	50%	0,250	Population density	50%	0,125
							Hotels and restaurants	20%	0,050
							Supermarkets	30%	0,075
	Economic	25,0%	0,250	Rental prices	60%	0,150	Property value	100%	0,150
				Labour	40%	0,100	Average income	100%	0,100
	Social	12,5%	0,125	Labour (availability)	50%	0,063	Skilled labour	100%	0,063
				Labour (inclusion)	50%	0,063	Unemployment rate	100%	0,063
total			1,000			1,000			1,000

Table B4 Economy of Scale

Goal	Themes	% of goal	Relative weight	Sub-themes	% of themes	Relative weight	Criteria	% of sub-themes	Relative weight
VF suitability (Economy of scale)	Circularity	12,5%	0,125	CO2	25%	0,031	Waste CO2 streams	100%	0,031
				Energy	75%	0,094	Wind potential	75%	0,070
							Heat sources	25%	0,023
	Logistics	25,0%	0,250	Transport	50%	0,125	Roads	75%	0,094
							Public Transport	25%	0,031
				Consuming markets	50%	0,125	Population density	50%	0,063
							Hotels and restaurants	20%	0,025
							Supermarkets	30%	0,038
	Economic	50,0%	0,500	Rental prices	60%	0,300	Property value	100%	0,300
				Labour	40%	0,200	Average income	100%	0,200
	Social	12,5%	0,125	Labour (availability)	50%	0,063	Skilled labour	100%	0,063
				Labour (inclusion)	50%	0,063	Unemployment rate	100%	0,063
total			1,000			1,000			1,000

Table B5 Green farming

Goal	Themes	% of goal	Relative weight	Sub-themes	% of themes	Relative weight	Criteria	% of sub-themes	Relative weight
VF suitability (green farming)	Circularity	50,0%	0,500	CO2	25%	0,125	Waste CO2 streams	100%	0,125
				Energy	75%	0,375	Wind potential	75%	0,281
							Heat sources	25%	0,094
	Logistics	12,5%	0,125	Transport	50%	0,063	Roads	75%	0,047
							Public Transport	25%	0,016
				Consuming markets	50%	0,063	Population density	50%	0,031
							Hotels and restaurants	20%	0,013
							Supermarkets	30%	0,019
	Economic	12,5%	0,125	rental prices	60%	0,075	Property value	100%	0,075
				Labour	40%	0,050	Average income	100%	0,050
	Social	25,0%	0,250	Labour (availability)	50%	0,125	Skilled labour	100%	0,125
				Labour (inclusion)	50%	0,125	Unemployment rate	100%	0,125
total			1,000			1,000			1,000

Table B6 Community Empowerment

Goal	Themes	% of goal	Relative weight	Sub-themes	% of themes	Relative weight	Criteria	% of sub-themes	Relative weight
VF suitability (Community Empowerment)	Circularity	25,0%	0,250	CO2	25%	0,063	Waste CO2 streams	100%	0,063
				Energy	75%	0,188	Wind potential	75%	0,141
							Heat sources	25%	0,047
	Logistics	12,5%	0,125	Transport	50%	0,063	Roads	75%	0,047
							Public Transport	25%	0,016
				Consuming markets	50%	0,063	Population density	50%	0,031
							Hotels and restaurants	20%	0,013
							Supermarkets	30%	0,019
	Economic	12,5%	0,125	Rental prices	60%	0,075	Property value	100%	0,075
				Labour	40%	0,050	Average income	100%	0,050
	Social	50,0%	0,500	Labour (availability)	50%	0,250	Skilled labour	100%	0,250
				Labour (inclusion)	50%	0,250	Unemployment rate	100%	0,250
total			1,000			1,000			1,000

Appendix C: Top 3 scoring locations per scenario

Table C1 Best scoring locations per scenario

Scenario's best Vertical farm locations	Score (0-100)	District
Top 3 Reviewed		
Admiraal Ruijterweg 408	85	Landlust
Karspeldreef 15-19	78	Bijlmer Centrum (D,F,H)
Bos en Lommerweg 400	77	De Kolenkit
Top 3 Market Accessibility		
Admiraal Ruijterweg 408	84	Landlust
Karspeldreef 15-19	75	Bijlmer Centrum (D,F,H)
Kempering 100B	75	Bijlmer Oost (E,G,K)
Top 3 Economy of Scale		
Kempering 100B	83	Bijlmer Oost (E,G,K)
Admiraal Ruijterweg 408	82	Landlust
K-buurt: Karspelhof fase 2 laagbouw	82	Bijlmer Oost (E,G,K)
Top 3 Green Farming		
Admiraal Ruijterweg 408	91	Landlust
Naritaweg 12	84	Bedrijventerrein Sloterdijk
Naritaweg 223-233	84	Bedrijventerrein Sloterdijk
Top 3 Community Empowerment		
Admiraal Ruijterweg 408	93	Landlust
Amsteldijk 194	77	Rijnbuurt
President Kennedylaan 1	77	Rijnbuurt

Appendix D: Table of contents of accompanied files

- Report (Word, PDF)
- Final presentation (PPTX)
- Datasets used and created
- Figures/Maps/Tables (in case of)
- Scripts
- Interview (summaries and recordings)
- Literature