Urban greenhouse infrastructure

Planning the Rotterdam-The Hague Metropolitan Area

Final version

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Preface

Before you lies my thesis for the Master's programme in Spatial Planning at Utrecht University. Despite previous interests in traffic engineering, the topic of greenhouse infrastructure immediately grabbed my interest. I have always been a person who cares about the natural landscape and the environment. The landscape full of white and transparent boxes amazed me, and my critique of greenhouses was that they took up too much space and ruined the natural landscape. Seeing it with my own eyes, I was still amazed by its immense size. I strongly recommend going to the area and experiencing it for yourself. The entrepreneurs are highly approachable and open people, and various events let you look inside the greenhouses. After a process that began in January 2024, I now understand how society benefits from greenhouse horticulture, especially for a sustainable future. I hope that this thesis also enriches the perspective on the Dutch horticulture greenhouses for the people reading it. Writing this thesis has been quite the journey as a student, broadening my knowledge and academic skills, and personally, opening new insights on food production. Writing this thesis might have influenced me to start a vegetable garden with a small greenhouse.

This journey would not have been possible without several people contributing in different ways. Words cannot express my gratitude for the unwavering support of my dear friends and family, who were always there to support me even though they saw me fluctuating between being deeply stressed or feeling over-excited and euphoric during the writing process. I feel incredibly grateful to Professors Monstadt and Rutherford for the supervision, their valuable feedback, guidance, and the opportunity to intern at LATTS and the Université Gustave Eiffel. I could not have undertaken this journey without all interviewees who were eager to spend some time talking about the exciting and unique topic of Dutch greenhouse developments and allowed me to have a look inside the greenhouses: the driven entrepreneurs who innovatively work towards a more sustainable and liveable future, the ambitious planners of the Municipalities of Westland and Pijnacker-Nootdorp, the planners of the Province of Zuid-Holland, the planner of the metropolitan agency of Rotterdam and The Hague and the lobbyist from Glastuinbouw Nederland for networking and a preliminary interview. Thanks should also go to J. Klein for assisting and giving insight into the bio-engineering tech knowledge as a keystone to the global greenhouse industry and for allowing me to do a preliminary field-visit at Delphy. I have had the pleasure of bumping into L. Wong from the Centraal Bureau voor Statistiek, who kindly provided me with data and statistics.

For all who contributed, if there is a need, I am willing to discuss the topic or provide any other valuable findings that have been left out of the thesis as they were irrelevant to the specific topic. Please feel free to contact me.

With sincere gratitude,

Jelle Wiebenga

Utrecht, July 2024

Abstract

The global urban population is rising and will continue until at least 2050. This increases urban food demand simultaneously. Conventional agricultural practices have a significant environmental footprint, and climate change negatively affects its production. As a result, urban forms of controlled environment agriculture (CEA) are on the rise to combat the demand by optimizing product output and quality. Additionally, urban CEA has the potential to improve food security and increase sustainable food production around metropolitan areas. However, the practices of urban CEA that mainly focused on leafy greens have been the only successors. Or not? What about the large-scale greenhouses in the Rotterdam-The Hague Metropolitan Area (MRDH)? These have been commercially operational for the past decade. Urbanisation and their built-up look caused the greenhouses to become part of the urban area. A recently identified research gap indicates that limited urban studies have looked into integrating CEA into the urban context, specifically on the relationship between urban CEA and urban infrastructure systems.

This paper focusses on examining the infrastructure systems inside and connected to the urban greenhouses in the MRDH. Answering the question: How can urban greenhouse infrastructure be integrated into existing urban infrastructure in a sustainable way? To answer this question, the paper takes a qualitative approach and analyses these findings according to the planning theory regarding sustainable metropolitan development. Data is gathered through a literature review, field visits, and semi-structured interviews with entrepreneurs of urban greenhouses and governmental representatives of planning bodies.

The findings indicate that the infrastructural requirements of the urban greenhouses are mostly similar to CEA's requirements known in the literature. However, two specific networks for CO2 and geothermal energy are found to be crucial for urban greenhouses, and the challenges with infrastructural development are location-bound. The most challenging is …

This paper argues that for urban greenhouses to contribute to sustainable metropolitan development, a more integral and collaborative planning approach on a regional scale is necessary to overcome the transmunicipal challenges.

Keywords:

Controlled Environment Agriculture (CEA), urban food security, sustainable urban planning, Rotterdam-The Hague metropolitan area

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Abbreviations

MRDH: Rotterdam-The Hague metropolitan area. Dutch abbreviation of “Metropoolregio Rotterdam Den Haag”.

CEA: Controlled Environment Agriculture.

LGN: Dutch Land Use. Dutch abbreviation of “Landelijk Grondgebruik Nederland”.

CBS: Central Bureau of Statistics. Dutch abbreviation of “Centraal Bureau voor de Statisitek”

CHPI: Combined Heat and Power Installation. In Dutch called ‘Warmte Kracht Koppeling (WKK)’

1. Introduction

The burden on the agricultural system has grown globally, caused by several complex and multifaced global challenges. The global population is predicted to rise, and 68% of the world population is expected to live in urban areas by 2050 (United Nations, 2018). The rise in urban population leads to increased material consumption and is one of the main drivers of most global environmental challenges (McPhearson et al., 2021). Increased consumption leads to a rising urban food demand, which can be combatted by increasing food production through agricultural intensification and changing the human diet (Davis et al., 2016). Agricultural systems have already been intensifying over the past century, significantly increasing food production, mostly thanks to chemical fertilization and technological advancements (Dalrymple, 1973; Shamshiri et al., 2018). However, environmental issues like climate change show their effects on agricultural production, with an increasing frequency of severe, unpredictable events like flooding, drought, and increasing temperatures (McMichael et al., 2007). Meanwhile, climate change, chemical pollutants from agriculture, and the conversion to intensive agricultural land cause biodiversity loss, seen in a 75% decline in insect biomass in 27 years (Hallmann et al., 2017; Sánchez-Bayo & Wyckhuys, 2019). An issue more perceptible to humans was the COVID-19 pandemic that disrupted global food supply chains, increasing the need for local and secure food production (Despommier, 2010). The rising urban food demand, climate change, and global pandemics urge us to rethink the food system and transition to a more sustainable agricultural alternative.

Controlled environment agriculture (CEA) is becoming a more popular subject in the agricultural world. CEA is enclosed indoor agriculture controlling environmental factors to optimise food production. The method has the potential to transcend various problems like rising urban food demand, food security concerns, climate change and environmental by increasing production in a sustainable matter (Cowan et al., 2022; Marvin et al., 2023; Marvin & Rutherford, 2018; Nicholson et al., 2020). CEA emerges in urban areas, especially metropolises, where demand is highest (Harbick & Albright, 2016; Mougeot, 2000; Pölling et al., 2016). Additionally, recent technocratic and economic literature is positive towards CEA's ability to become economically viable considering historic technological advancement (Al-Kodmany, 2018; Cowan et al., 2022; Despommier, 2010; Kozai & Niu, 2016; Nicholson et al., 2020; Shamshiri et al., 2018; Tyson et al., 2011). Pilots of CEA facilities producing leafy greens have emerged in urban areas using vertical farming methods (Aerofarms, n.d.; Despommier, 2010), but economic viability is not yet certain (Al-Kodmany, 2018; Bidaud, 2019). CEA is also seen in the form of large-scale greenhouses and plant factories in peri-urban areas (Marvin et al., 2023; Nicholson et al., 2020; Shamshiri et al., 2018). Marvin et al. (2023) describe the movement and integration of CEA into urban areas from a spatial planning perspective. Agricultural intensification with urban CEA in metropolitan areas potentially leads to increased production (Dalrymple, 1973; Nicholson et al., 2020), improves food security (Cowan et al., 2022; Despommier, 2010), contributes to urban circularity (Nicholson et al., 2020), lowers the need for chemical fertilization or pesticides (Van Lenteren, 2000), and has the potential for a lower environmental impact (Cowan et al., 2022). Also, metropolises can profit from added economic value (Nicholson et al., 2020; Pölling et al., 2016), labour availability and technological innovation (Shamshiri et al., 2018). On the other hand, urban CEA poses several challenges. Urban CEA might conflict with other land uses (Pölling et al., 2016; Westerink & Aalbers, 2013), is resource intensive (Nicholson et al., 2020), is aesthetically not pleasing (Rogge et al., 2008), and is critiqued on its limited contribution to biodiversity (Messelink et al., 2021). CEA being resource intensive requires the supply of resources through complex and high-capacity infrastructure. Development of new or existing urban CEA might require adapting or constructing infrastructure systems, which is more expensive in urban areas (Nicholson et al., 2020).

Although the urbanisation of CEA poses several challenges, it has great potential to sustainably increase agricultural production near urban areas. The potential of urban CEA to be part of the solution to meet a rising urban food demand with minimal environmental impact indicates this paper's societal relevance. Besides, a limited number of spatial planning studies are known on integrating CEA into the urban context and the spatial requirements this imposes, implicating an empirical gap. Marvin et al. (2023) affirm this, emphasizing the need to conduct more urban studies on urban CEA. Marvin et al. (2023) describe five major directions for subsequent research:

1. Whether CEA in an urban setting is more sustainable.
2. Understanding the complex transmutation into existing infrastructure.
3. The circulation of CEA technology, expertise and finance.
4. The relation between CEA and the wider urban infrastructure systems.
5. The concept of urban nature in relation to CEA (Marvin et al., 2023).

This paper adds knowledge by examining the fourth issue, the relation between CEA and the wider urban infrastructure systems. This is done by specifically looking at urbanising greenhouses in the Rotterdam-The Hague Metropolitan Area (MRDH)(see Figure 1), which are hereafter referred to as the urban greenhouses, as they are either urban or peri-urban (Bidaud, 2019; Westerink & Aalbers, 2013). This case is chosen in particular because the Netherlands is one of the leading countries in agricultural exports (American International Trade Administration, 2024), accounting for 80% of the Dutch total export value (Jukema et al., 2023). Considering the country's size, the amount of agricultural exports produced is considerable compared to larger countries. Equally remarkable, 54% of Dutch land is used for agriculture (Centraal Bureau voor Statistiek, 2020), of which 0.5-0.6% are greenhouses (Berkhout et al., 2023; CBS, 2022). The greenhouses in the MRDH have been operational and commercially viable for over half a century and produce substantially more than the Dutch conventional agriculture (Westerink & Aalbers, 2013). The greenhouses are situated in a peri-urban area between two major urban cores that form the metropolis. The successful development, outstanding production rate and the urbanisation of these greenhouses make this an interesting case to examine. Researching the urban infrastructures of these greenhouses can uncover valuable lessons that will allow other metropolitan areas to better guide the development of new urban CEAs or regulate the urbanisation of greenhouses.

Urbanization causes CEA to become increasingly dependent on urban infrastructure (Marvin et al., 2023), making adequate planning essential for the successful development of these structures.

Three major rationales indicate the scientific relevance of this paper. First, urban CEA is understudied in urban planning studies, and there is insufficient empirical evidence regarding forms of urban CEA. Second, studying the relationship of urban CEA with wider urban infrastructure systems has been found to contribute to solving the empirical gap present. Third, there have been a limited amount of use-case studies in the field of planning about the infrastructures of the greenhouses in the MRDH that have become part of the urban landscape.

1.1 Research questions

The main objective of this thesis is to explore how urban greenhouses infrastructure can be integrated into existing infrastructure in a sustainable way. This objective is achieved by studying the urban infrastructures of the urban greenhouses. The overarching central question to achieve this main objective is:

How can urban greenhouse infrastructure be integrated into existing urban infrastructure in a sustainable way?

Sub-questions:

1. *What are the infrastructural requirements of urban greenhouses?*

2. *What are the main challenges that governments and entrepreneurs face?*

3. *How can urban greenhouses contribute to sustainable metropolitan development?*

The research questions are answered through a preliminary literature study, case-specific interviews, and field visits conducted with governmental planners and entrepreneurs of urban greenhouses in the MRDH.

The second chapter entails a literature study of the theoretical background of CEA and infrastructure. The third chapter elaborates on the use case. The fourth chapter explains the methods used in the research. The fifth chapter presents the results, which are interpreted, and answers the research questions in the discussion in Chapter 6. Chapter 6 ends with conclusions and recommendations for further research.

Figure 1 Landscape of greenhouses in the MRDH

Note. (Swart, 2019) Copyright

2. Theoretical background

Marvin et al. (2023) and Bidaud (2019) describe how CEA is urbanising, especially in metropolitan areas. At the point that CEA is located in an urban area, it is referred to as 'Urban CEA' (Bidaud, 2019; Marvin et al., 2023; Marvin & Rutherford, 2018). Going back to the theory, understanding what is considered urban will help in understanding the definition of urban CEA.

The term urban is described as a characteristic of a place representing a concentration of people organized around non-agricultural activities (Weeks, 2010). On the contrary, Frey and Zimmer (2001) argue that defining an urban area solely based on the absence of agricultural activities is insufficient. This statement states that agriculture can add considerable economic value and that indications of diversity and density of functions should be considered. Additionally, Frey and Zimmer elaborate on urban being defined based on population concentration and whether they consider themselves living in an urban area. Notably, it is stated that population size determining the urban is relative to the population densities in the country, which can vary widely. In short, an urban area is characterized by a high density and diversity of functions with a large concentration of people considering the area urban.

The other part of the term is 'controlled environment agriculture' (CEA), defined as the ability to control the indoor environment to optimize food production (Cowan et al., 2022). With the advantage of enclosure, CEA emerged around the early 20th century, primarily in desolate areas with suboptimal outside growing conditions (Dalrymple, 1973). The enclosure advantage nowadays extends the growing season, even in fertile areas. Dalrymple (1973) writes about how technology has rapidly increased since 1950 and how this trend sustains into the 21st century (Shamshiri et al., 2018). The increase of technological advancements extended growing seasons and enabled greater control over several environmental factors, yield optimisation, and higher production rates than conventional farming methods. CEA eventually developed into a more high-tech CEA, which expanded environmental control to optimise water, electricity, air, temperature, fertilisation, pests, and lighting (Shamshiri et al., 2018). Cowan et al. (2022) explain how CEA protects food production from outside elements, making growing food in any location possible. In this way, CEA transcends the constraints of urban areas, like air pollution and land scarcity. As described by Marin et al. (2023): "Controlled environment agriculture (CEA) utilises digital technologies and artificial environments to produce enclosed indoor farms that seek to transcend the climatic, seasonal and territorial constraints of the city" (p. 1431, derived from Bidaud, 2019). According to Marvin et al. (2023), the following types of urban CEA can be distinguished, sorted top-down based on spatial size:

- Domestic countertop appliances.
- Small and medium-sized enterprises in tents, capsules and cabins.
- Collective or non-profit, in the form of urban agriculture or community gardens.
- Institutional or educational, applied in classrooms, vehicles or containers.
- Commercial using vertical, enclosed, rooftop and container growing methods.
- Agricultural in the form of large-scale greenhouses and plant factories.

Looking critically, these types of urban CEA are all found in urban settings, as defined at the beginning of this chapter. This paper focusses on studying large-scale greenhouses as a type of urban CEA. Shamshiri et al. (2018) describe that the 'modern greenhouses' are essentially CEA and that greenhouses and plant factories are the most common types in urban areas. The difference between a greenhouse and a plant factory is the amount of automation and autonomy. Shamshiri et al. (2018) state that urban CEA can also be distinguished by the extent to which technology is used. The large scale and presence of high-end technologies optimizing food production characterize large-scale greenhouses as urban CEA. Marvin et al. (2023) describe these interlaced technological systems' complexity and presence inside CEA. Marvin et al., therefore, argue that urban CEA can be considered an infrastructure interconnected with other external infrastructural networks. As stated: "CEA is an urban infrastructure that totally reconfigures the (possibilities of) local environment in spatial and temporal terms" (p. 1441). The entanglement of urban CEA with urban infrastructures creates additional resource demand for these facilities (Nicholson et al., 2020). Meeting this demand might require adapting or constructing urban infrastructure to support urban CEA. Successfully integrating urban CEA into urban infrastructures requires adequate planning decisions. To achieve this, it is necessary to examine how urban CEA is becoming an increasingly important part of urban infrastructure. The following paragraph will explore a definition of infrastructures for this paper.

2.1 Infrastructures

With various types of urban infrastructures defined in the literature, it is a multifaced concept, and no universally accepted definition is present. Since its origin at the end of the 18th century, infrastructures were described as the 'sinews' or structure of the city (Tarr, 1984). It included the transit, water, sewer, waste, recreation and power systems, and the park and public buildings. Later, it became clear that urban infrastructures cover more topics. Urban infrastructures became a place for governance and global challenges involving economic growth and combatting climate change (Ferrer et al., 2018). Neuman (2006) describes urban infrastructures as:

> a physical network that channels a flux through conduits … with the purpose of supporting a human population … for the general or common good. It consists of a long-lasting network connecting producers and service providers with a large number of users through standardized (while variable) technologies, pricing, and controls that are planned and managed by coordinating organizations. (p. 6)

Neumann's definition is the most concrete and covers the distribution of resources, including all aspects associated with enabling this distribution. Neumann states that supporting a human population for the general or common good is the purpose of infrastructure. Marvin et al. (2023) consider CEA an infrastructure, which contradicts Neumann's definition as CEA does not directly support a 'human population'. On the other hand, CEA indirectly supports the human population with an essential resource: food. Several articles speak of this 'food infrastructure', which includes the whole food production chain (Allard et al., 2017; Bloom & Hinrichs, 2011; Fagundes et al., 2022; Myers & Caruso, 2016). Because the definition of infrastructure is applied diversely, it is essential to define how the term is used in this paper. To therefore ensure readability, this paper distinguishes between internal and external infrastructures that are interconnected and interdependent.[i]

Internal infrastructure refers to the infrastructure systems that connect and distribute resources to private property to produce agricultural goods successfully. These systems are under the entrepreneur's management, who makes his own planning decisions, dependent on local municipal policies.

External infrastructure refers to the supply of essential resources to the CEA facility, managed by a grid operator and planned by governmental bodies as a public service. The CEA facility is connected to the grid and uses the public services provided. This type of infrastructure is often called urban or public infrastructure, which can be used interchangeably.

In short, defining infrastructure is context-dependent and encompasses the physical structures, governance, and sustainability. In the context of this paper, two types of urban infrastructures are distinguished: the internal infrastructure of urban CEA supporting food production and the external public urban infrastructure supplying the CEA with required resources.

2.2 Internal infrastructure

The presence of the technical infrastructure in CEA and its enclosure from the outside are the main factors leading to higher yields than conventional agriculture (Buurma, 2001). Hence, higher yields have been the main motive for commercial greenhouses to spread globally since the 20th century (Dalrymple, 1973).

The exact systems present in urban greenhouses can differ per greenhouse, but in most cases these systems optimize temperature, air, light, irrigation and fertilization (Shamshiri et al., 2018). The most important factors for plant growth are temperature and light regulation, mainly determined by the building's structure (Shamshiri et al., 2018). The structures are either made from certain types of plastic or glass, with diverse effects on the inside temperature and light conditions, therefore differing in feasibility per crop type (Cabrera et al., 2009; Pollet et al., 2005; Shamshiri et al., 2018).

Most greenhouses use ventilation by either open-air flow or air conditioning systems for total environmental control. In between these ventilation gaps, netting serves as pest protection. These nets and the greenhouse's shape influence air quality, light, and temperature. Shamshiri et al. (2018) describe how there is always a balance between the need for ventilation and protection against weather variables. They find that ventilating with outside air risks pests entering the controlled environment, even when pest netting is applied. More recent literature (Longo & Gasparella, 2015; Syed & Hachem, 2019; Tawegoum et al., 2006) shows that it is possible to optimise the temperature in CEA but that there is a constant search for innovation in improving the system's energy efficiency, in order to reduce costs for the user. For example, observations of experimental CEA with air-conditioning systems using ground heat energy storage for heating and cooling show effective results. However, this requires additional energy from the electricity grid to maintain a constant temperature of 20°C in two of the winter months (Attar et al., 2014). Enrichment of CO2 in the environment occurs when CO2 levels get too low and negatively influence plant growth. Some plant species, like lettuce, increase yield by 25-60% when CO2 levels are optimised (Pérez-López et al., 2015). Heuvelink and Kierkels (2015) show that the general increase in yield lies between 35 and 50%. On the other hand, Shamshiri et al. (2018) explain how ventilation limits CO2 optimisation, thus making CO2 optimisation only beneficial for growing in fully enclosed environments.

Commonly, electricity or natural gas are the energy sources used to heat an enclosed environment, Heated water is then distributed through radiator tubes to warm up the air around the plants as the warm water passes through (Sharmshiri et al., 2018). Shamshiri et al. (2018) and Gómez et al. (2019) describe how electricity is needed to power lighting or small appliances. Shamshiri et al. describe how some facilities use LED lighting to optimise light levels and advanced monitoring systems to gather crucial information on crop conditions.

Traditionally, plants in CEA were soil-grown (Dalrymple, 1973). Nowadays, soilless systems are being explored, which provides certain advantages. According to Shamshiri et al. (2018), hydroponic systems, which distribute nutrients via a solution in water, have various benefits. The wastewater is collected and reused in the system, reducing water consumption considerably (Tyson et al., 2011). Tyson (2011) correlates this reduced resource consumption to lower maintenance costs. Although there are many benefits, hydroponics is only feasible for growing non-fruiting crops, and commercial practices of hydroponics are relatively new (Palm et al., 2018). Shamshiri et al. describe two other soilless methods: growing in rock wool and coconut coir slabs. These methods are more commonly used, especially when growing plants that produce fruiting (Shamshiri et al., 2018). Like hydroponics, both soil-grown and soilless systems can fertilize and water their plants using the irrigation system via nutrient solutions and drip emitters. Drip emitters enable precision irrigation, which optimizes plant growth (Yuan et al., 2004) and reduces water use (Singh et al., 1978; van der Kooij et al., 2013). However, Incrocci et al. (2020) mention that soil-grown and soilless systems commonly have significant nitrate leaching loss.

To summarize, CEA's internal infrastructure consists of a few main systems: material structure, heat, electricity, water and CO2. Temperature control appears to contribute the most to plant growth and, thus, food production. The flow of resources needed for these systems to function is a combination of electricity, natural gas, CO2 and water systems.

Sustainability

CEA has the potential to help address a rising food demand and cope with the effects of climate change on agriculture. However, how best to exploit its potential remains a topic of debate. Compared to conventional agriculture, CEA has a higher yield and can be considered more sustainable with respect to its environmental footprint (Cowan et al., 2022).

Critics of CEA argue that its agricultural intensification has negative effects on the environment, including deforestation and deterioration of the air and water quality (Cowan et al., 2022). Also, Messelink et al. (2021) state that CEA does not contribute to biodiversity. Ecologists have even asked the agricultural sector to lessen its environmental impact by omitting CEA development. Instead, the ecologists suggest focussing on the integration of nature conservation with conventional open-field agriculture to restore lost biodiversity (Altieri & Toledo, 2011; Skinner et al., 1997). However, some of the critiques are about agriculture in general and not specifically about CEA, which is closed off and has control over its output (Cowan et al., 2022; Nicholson et al., 2020). Moreover, as Dalrymple (1973) explained, CEA's impact is place-dependent. Variating temperatures in different climates can cause different results, and the footprint can vary based on where CEA is developed.

Advocates for CEA argue that a more intensive form of agriculture is needed to feed a growing population (Garcia et al., 2023; Wilkinson et al., 2021). CEA's intensiveness makes it more efficient on less land, potentially leaving more land for other uses when used as a substitution for conventional agriculture. With the emergence of the COVID-19 virus, which caused a blockage in supply chains, the necessity of local food security became increasingly important to governments (Clark & Miles, 2021; Despommier, 2010). CEA in urban areas can increase food security (Cowan et al., 2022; Despommier, 2010; Garcia et al., 2023; Neilson & Rickards, 2016) and contribute to resource urban circularity (Nicholson et al., 2020). Urban circularity is designed to minimize waste, maximize resource efficiency, and promote sustainability by applying circular economy principles (Vanhuyse, 2023). Increasing local food production and consumption has been proposed as a more sustainable path than exporting food globally (Bloom & Hinrichs, 2011; Davis et al., 2016). The need for transporting food can also be decreased by the ability to grow non-native crops in CEA instead of importing food from overseas. There are experiments with growing papaya or passion fruit, for example (Benders, 2023). Locally grown non-native crops can be consumed fresh making artificial conservatives unnecessary, which benefits public health (Kim et al., 2017). Finally, integrating agriculture into urban areas fosters a closer relationship between people and their food sources, potentially altering consumption patterns towards more sustainable choices (Neilson & Rickards, 2016).

2.3 External infrastructures

Urban infrastructures

The external 'urban' infrastructures are essential for the internal infrastructure to function. As previously stated, urban infrastructures consist of physical structures forming networks that distribute resources to support a human population, which are planned and managed by coordinating organizations (Neuman, 2006).

In spatial planning, various theories about urban infrastructures explore how they work and should be planned. The following paragraphs highlight the most important considerations and debates in the literature relevant to this paper.

Socio-technical systems

Geels (2002) describes urban infrastructure as a socio-technical system and explains how these systems are affected by long-term transitions propelled by social and technical changes. These transitions can be influenced by the broader landscape that contains global challenges like climate change. Similarly, Graham and Marvin (2001) describe urban infrastructure systems as heterogeneous socio-technical arrangements. This means that the urban infrastructure is made up of complex social and technical components that are modelled by contrasting ideas and norms. In the context of this paper, Marvin and Rutherford (2018) also call CEA: "enclosed and engineered socio-technical spaces . . ." (p. 1144). Due to this, infrastructure systems are constantly influenced by social and technical factors that drive change and development of the systems. Smink et al. (2015) add that changes to socio-technical systems are based on clusters of institutions, actors and interests that create and maintain stability within a system. These changes made during the transitions in urban infrastructures are path-dependent (Geels, 2002). Path dependency essentially means that a set of decisions made in a particular situation is limited by the choices made in the past, even though the previous situation has changed. Once a path has been chosen, the path dependency determines and constrains future options.

Due to CEA urbanizing, it is becoming an increasingly important part of urban infrastructure. Therefore, understanding the concept of urbanization is required, as addressed in the following paragraph.

Climate change and resilience

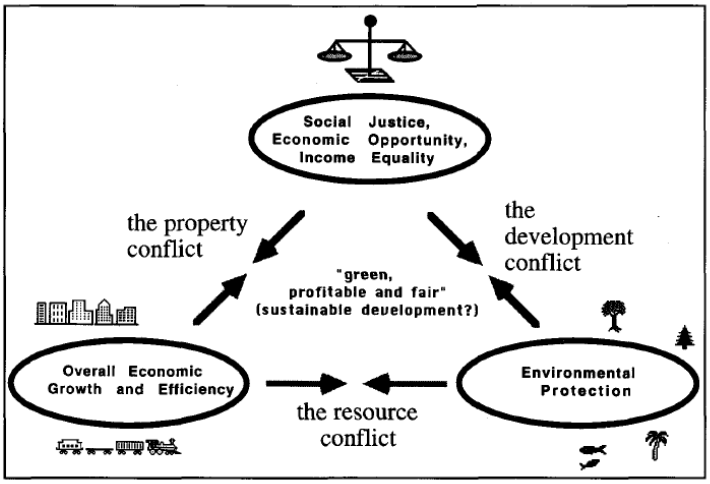
One of the pressing topics within urban infrastructure studies is sustainability. This broad concept encompasses various challenges, with climate change being the most discussed. Resilience, a key aspect of sustainability, involves the capacity to prevent or adapt to unforeseen events, climate change, or socio-economic changes (Zuniga-Teran et al., 2020). In a review, Broto (2022) explains how the resilience of infrastructure networks evolves from splintering urbanism. Urban infrastructures are increasingly stressed by climate change, necessitating investments in both centralized and off-grid systems to ensure their resilience (Broto, 2022). Sustainable urban infrastructure is vital for mitigating greenhouse gas emissions, particularly in rapidly urbanizing regions like China (Broto, 2022). The importance of sustainable infrastructure is further underscored by various studies. According to Lund and Shen (2021) and Monstadt (2009), urban infrastructures are crucial for ecological sustainability, mediating resource flows and shaping environmental practices.

A fitting segue to sustainable development can be made here. Since infrastructure is fundamental to the built environment, it is inherently linked to the concept of sustainable development. The following chapter explores the concept of sustainable development and extends this into a theoretical framework for sustainable metropolitan development.

2.4 Theoretical framework

The idea of sustainable development was first introduced in the Brundtland Report (World Commission on Environment and Development (WCED), 1987), summarized as the practice of “meeting the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987, p. 8). Later, Campbell (1996) laid the foundational link between sustainable development and planning. Campbell’s work explored its implementation in urban planning, emphasizing that sustainable development requires balancing economic growth, environmental protection and social equity, as seen in his ‘planner’s triangle’ (see **Figure 2**).

Figure 2 Sustainable development triangle (Campbell, 1996)



Campbell describes how achieving sustainable development involves solving conflicts between economic, environmental, and social interests which lead to property, the resource, and the development conflicts. The property conflict is the tension between economic growth and striving for equity, fairly distributing wealth. The resource conflict involves the tension between using natural resources needed for economic growth and limiting the use of resources for environmental protection. The development conflict is about protecting the environment while, in terms of social justice, not depriving others in the process. Campbell’s concept of sustainable development and the conflicts that come with it is fundamental for how sustainability can be addressed in planning.

Sustainable metropolitan development

Various municipal governments in close proximity to each other often form metropolises. Future food demand will rise highest in urban areas and thus these metropolises (Davis et al., 2016). As a result, practises of CEA have emerged in these metropolitan areas (Pölling et al., 2016). This makes it relevant to place the emergence of CEA infrastructure in a metropolitan perspective. Wheeler (2000) explains how metropolitan regions emerged through forms of regional government or cooperation of multiple municipal governments. Wheeler also states that metropolitan agencies commonly have the task of making spatial plans regarding regional transportation and not land use plans. Wheeler emphasizes how metropolitan cooperation can improve regional sustainability planning, incorporating this in a framework. The framework describes three main points for regional sustainability planning:

- creation of stronger regional institutions and, if possible, limits to the size and jurisdictional fragmentation of metropolitan regions;

- Intergovernmental incentive frameworks aimed at promoting sustainability, with strong state or provincial support for regional and local action; and
- Participatory planning, consensus building, and long-term processes of public education and social learning (Wheeler, 2000).

Similar to Wheeler's idea on intergovernmental incentive frameworks, combining several perspectives towards an integral planning approach is found essential to achieve urban sustainability (Gleeson et al., 2004; Wheeler, 2000; Yigitcanlar & Teriman, 2015). Davidson and Arman (2014) examined metropolitan strategic planning policies in Australia. The regional strategies assessed acknowledged the concept of sustainability and acted as a fundamental part of the project, but they posed the challenge of lacking a transformative change. Davidson and Arman also emphasize Wheeler's point on the importance of participatory planning and social learning. Making metropolitan planning policies that acknowledge sustainability is the first step. Achieving sustainable development in metropolitan context is mainly done through establishing strong regional institutions, intergovernmental frameworks and close involvement and collaboration with society.

To conclude this chapter, CEA optimises food production in controlled environments, consisting of interconnected internal and external infrastructure systems, which can be physical or digital. There are various cases of CEA becoming increasingly urban. This paper examines the large-scale greenhouses in the MRDH due to urbanization becoming increasingly more connected to urban infrastructure. Therefore, this paper focusses on examining how the infrastructures of the urban greenhouses in the MRDH can be integrated into existing urban infrastructure and how this can contribute to sustainable metropolitan development.

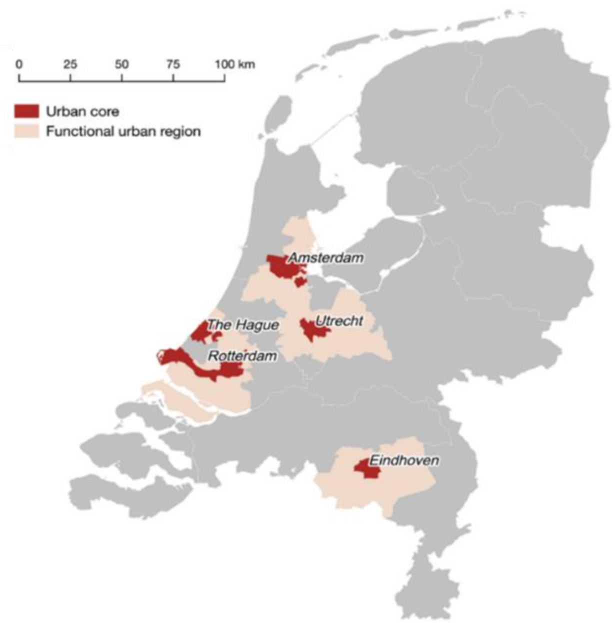
The theoretical background and sustainable development theory serve as a theoretical framework for the continuation of this paper. The next chapter extensively covers the research design and methods applied.

3 Case context

This paper examines the CEA infrastructure of the greenhouses in the Rotterdam-The Hague Metropolitan Area (MRDH), which spans 451 km2 and is home to 2.39 million inhabitants (Metropoolregio Rotterdam Den Haag, n.d.). As a type of urban CEA, these large-scale greenhouses use technology to optimise yield, monitor crops, and produce most of the Dutch horticultural products (Dutch government, 2023). When driving through the MRDH, a vast landscape of large-scale greenhouses can be seen from your window (Figure 1). The greenhouse area lies between two central urban cores, Rotterdam and the Hague (Figure 4), in the province of Zuid-Holland [South-Holland]. The MRDH is also part of a larger metropolitan area: Randstad, which is commonly used in international studies. Urban researchers classify the Randstad as a polycentric region (Zonneveld & Nadin, 2020) covering Amsterdam, Utrecht, Rotterdam, the Hague and the smaller cities in between the other major metropolitan areas of Amsterdam borders the MRDH to the North (see Figure 3).

The areas between the major cities are increasingly urbanising, creating an ‘urban fabric’ such as Westland, Voorburg, Leidschendam and Rijswijk. Notably, some municipalities became in-between cities due to increased greenhouse development, considering their density and urban appearance (Zonneveld & Nadin, 2020). Greenhouse developments fluctuate rapidly. The major greenhouse influx took place between 1950 and the year 2000. The total surface area of greenhouses increased from 3,300 ha to over 10,000 ha in 1950, of which 5,100 ha was dedicated to horticulture production. Due to an economic backslash in 2010, the greenhouse area declined shortly after by 1.000 ha but rapidly restored itself with an increase of 1.600 between 2019 and 2021 and stayed steady in 2022 (Berkhout et al., 2023). The total area of greenhouses in the Netherlands in 2022 was 10.600 ha (Berkhout et al., 2023), which is equivalent to around 14.000 football fields (Glastuinbouw Nederland, n.d.). The total area of greenhouses in the MRDH is 4.500 (MRDH, n.d.).

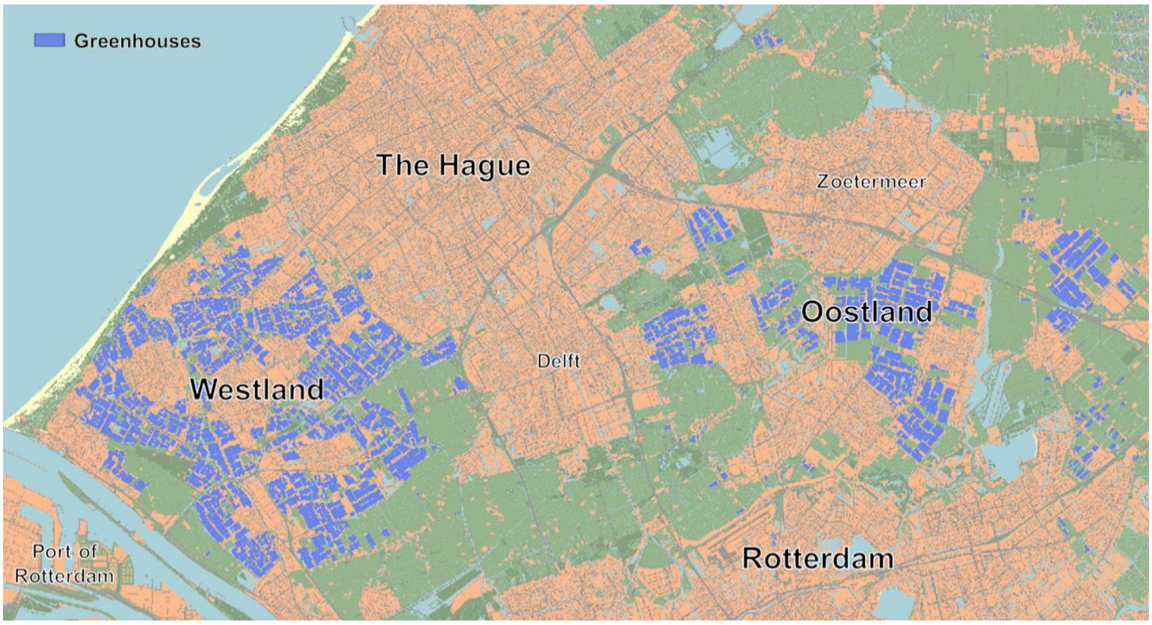
Figure 3 Dutch metropolitan areas and cores



Note. Adapted from Dembski et al. (2021)

Municipalities in the peri-urban areas of Westland and Oostland are making new plans for recreational use in the form of nature at the cost of agricultural land (Pölling et al., 2016). The will to stimulate agricultural production, housing developments, and the need for recreational areas creates conflict between land uses. This discussion seems to be mainly about the interest of developing for economic growth, solving the housing crisis, and the civil need for a high-quality living environment (MRDH, 2023; Westerink & Aalbers, 2013). Westerink and Aalbers (2013) describe how national subsidies stimulate the removal of scattered greenhouses from meadow landscapes. The result is more separation between nature and greenhouses, clustering the natural and greenhouse landscape (Westerink & Aalbers, 2013). Aalbers and Westerink (2013) describe the landscape as one where greenhouses are located between the larger cities and the surrounding towns, described as 'peri-urban'. The Dutch refer to every town as a separate city. However, from an international perspective, most literature considers the entire Randstad, including the in-between areas, as one large urban area or city (Spaans et al., 2020). Moreover, Bonin (2020) states that the terms can be used interchangeably. The Dutch Environmental Assessment Agency has named the greenhouse a 'built-up area' (Planbureau voor de Leefomgeving, 2020), fitting its urban description. The case examined in this paper focusses on the Westland Municipality covering all of Westland and the Municipality of Pijnacker-Nootdorp covering a part of Oostland.

Figure 4 Map of greenhouses in the Rotterdam-The Hague Metropolitan Area



Note. Map made from data provided by Hazeu et al. (2022)

The Netherlands's spatial planning system is divided into several tiers of government, each with a specific function in the implementation and development of spatial policies. The main governments are at national, provincial, and municipal levels. Then, there are the metropolitan agencies. Lastly, unique for the Netherlands is the role of the water boards.

National Government: The national government establishes national policies and the overarching framework for spatial planning through the Ministry of Infrastructure and Water Management (IenW). National spatial strategies offer direction on essential issues like urban development, infrastructure, and climate adaptation. Examples of these are the National Environmental Vision (Nationale omgevingsvisie, NOVI) and the National Environmental and Planning Act (omgevingswet) (Ministry of Infrastructure and Water Management, 2019).

Provincial Governments: Regional spatial planning in the Netherlands is the responsibility of the twelve provinces. In order to align with the national policies and consider regional interests, they create regional plans (structuraurvisies), that coordinate and direct spatial developments within the provincial borders.

Municipal Governments: Municipalities are essential in local spatial planning. The municipalities manage the local land use and private properties by making local land-use plans (bestemmingsplannen), based on local needs and ambitions. These land use plans must align with federal and provincial policies and plans.

Metropolitan agencies:
Metropolitan agencies do not have any legislative planning power and cannot make any spatial policies. Instead, there is a collaboration between municipalities in a region, that collectively invest in projects with similar interests among municipalities to tackle issues that cross municipal borders.

Water Boards: Water boards (waterschappen) are regional authorities responsible for managing water bodies and flood prevention, which is crucial due to the Netherlands' low-lying geography. Their main task along the coast is the maintenance of the dikes. The water board also oversees water quality and groundwater levels, affecting local agriculture. The water boards own some property, but close collaboration with the other governmental levels is needed to integrate water management into spatial planning.

3.1 Regional collaboration

For CEA to move to more urban locations, land costs and availability push it to the cheaper outer lands on the periphery of the MRDH (Zonneveld & Nadin, 2020). Zonneveld and Nadin (2020) describe how commercial viability and adequate planning decisions are decisive for CEA development in the MRDH. This public-private strategy was part of the spatial plan to create several mainports in the polycentric metropolis, the Randstad, attempting to increase international appeal (Notteboom et al., 2013; Zonneveld & Nadin, 2020). The CEA greenhouses collaborate via the so-called 'Greenport' in close relation to the other Mainports, including the port of Rotterdam. These Greenports are areas allocated by the Dutch government dedicated to strengthening the economic value of the Dutch horticulture sector (Randstad 2040, 2008).

3.2 Sustainability footprint of Dutch greenhouses

Data about the energy consumption of the urban greenhouses in the MRDH are available. Sixty per cent of the greenhouses in the Netherlands use a CHPI (Combined heat and power installation) (Blom et al., 2021), which produces around 2.500 MW of power. Blom et al. (2021) describe that using CHPIs is more profitable than using electricity and gas directly from the grid because of the profit made from supplying the grid. TNO and Ecorys (2021) found that in 2019, CHPIs had less carbon emissions than consumption from the grid. Due to the transition to renewable energy sources of grid electricity, this is expected to improve somewhere between 2025 and 2030. The average gas consumption of a greenhouse in the Netherlands was 3,9 billion m3 in 2021 (CBS, 2023a), which is approximately 10% (α=0,05) of the national total gas consumption (CBS, 2023b).

4 Research design and method

This thesis's main objective is to describe the sustainable integration of urban greenhouse infrastructure into the existing urban infrastructure. This objective is achieved by answering the following overarching central question:

How can urban greenhouse infrastructure be integrated into existing urban infrastructure in a sustainable way?

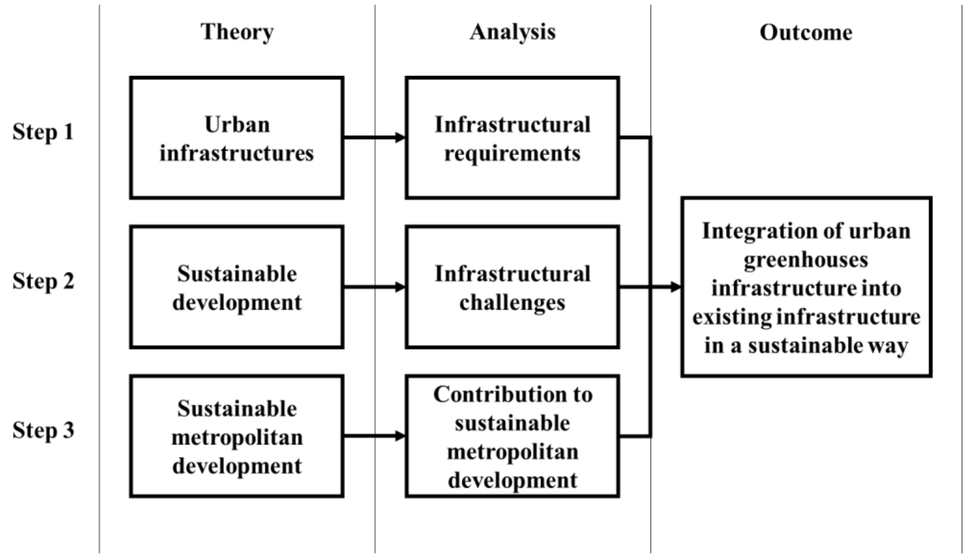
Sub-questions:

1. What are the infrastructural requirements for urbanising greenhouses?
2. What are the main challenges that governments and entrepreneurs face?
3. How can urban greenhouses contribute to sustainable metropolitan development?

To answer the research questions, this research adopts qualitative methods to answer these questions, covering a preliminary literature review, semi-structured interviews and observational field-visits. Qualitative research is chosen for its strength in uncovering complex phenomena within specific contexts (Hay, 2021), especially feasible for interviewing. The continuation of this methodology chapter is based on Hay (2021).

The thesis research is divided into three steps, each with an objective and a research question to be answered (see **Figure 5**). Using available data, step one establishes definitions and explores urban infrastructures underpinning the infrastructural requirements of urban greenhouses. In step two, theories about sustainable development are used to describe the challenges interviewees face. In step three, the implications for metropolitan planning are discussed using current theories on sustainable metropolitan development.

Figure 5 Research design



Each step is guided by its own sub-question, building towards an answer to the main research question. Following this, recommendations for future research are given.

4.1 Data collection

For this research, the primary focus is on the urban greenhouses in the MRDH. Two feasible groups for interviewing have been identified from the actors in this area. Interviews were held with entrepreneurs of urban greenhouses and planners working for local or regional governments. The governmental actors have the legislative planning power to adjust the spatial layout, thus making them relevant in the case. These interact and collaborate with the entrepreneurs in the CEA industry, who make their own planning decisions within their company. Data collection is done through semi-structured interviews. These interviews consisted of open questions asked in an iterative manner based on an interview guide (Appendix A). Iterative in this context entails the interviewer's back-and-forth focus attention to observations and analysis, thereby stimulating new questions. After each interview, the questions in the interview guide were revised based on new insights. The entrepreneurs have specifically been invited for an in-person on-site interview. This enabled additional non-participant observations, allowing for a better understanding of the context and the environment in which the entrepreneurs operate. Pictures were taken of certain aspects to complement the observational data. The governmental representatives have had the option of an online or in-person interview.

Participant selection

Informants were found by attending and scouting local networking events, via personal contacts in the industry, and through social media searches. Several other interviewees were discovered utilizing the snowball effect (Hay, 2021). To ensure adequate selection, an external and independent informant has validated the selection of participants. Klein is a bio-engineering expert at Delphy and specializes in developing monitoring systems inside CEA. This research and consultancy company tests the latest technological infrastructure on CEA, as they work closely with universities and international governments like the EU. Klein can confirm that the selection of participants includes companies with the latest technological infrastructure, ensuring a valid overview of the infrastructural requirements of the greenhouses in the MRDH.

Table 1 Overview of interview respondents

Reference	**Role**	**Interview date**
Entrepreneur A	Flower greenhouse entrepreneur	07-05-2024
Entrepreneur B	Bell pepper greenhouse entrepreneur	22-04-2024
Entrepreneur C	Flower greenhouse entrepreneur	19-04-2024
Entrepreneur D	Tomato greenhouse entrepreneur	03-05-2024
Westland planners	Two planners of the municipality of Westland. One respondent is a greenhouse spatial planner.	18-04-2024
Pijnacker-Nootdorp (P-N) planners	Two planner at the municipality of Pijnacker-Nootdorp (P-N). One of the respondents is a greenhouse spatial planner.	22-04-2024
Province of Zuid-Holland (PZH) planner A	Province of Zuid-Holland (PZH)	18-04-2024
Province of Zuid-Holland (PZH) planner B	Province of Zuid-Holland (PZH)	
MRDH planner	Rotterdam-The Hague Metropolitan Area agency (MRDH)	29-05-2024
Glastuinbouw Nederland (GTBNL) Lobbyist	European lobbyist at Glastuinbouw Nederland (GTBNL) [Dutch Greenhouse organisation]	09-04-2024
Delphy consultant	Bio-engineer at Deplhy Consultancy	03-05-2024

Preventing biases

Conducting semi-structured interviews with an interview guide gives respondents enough room to tell their stories but simultaneously provides guidance to the interviewer, preventing common biases. The guide helps avoid these biases by using neutral and open-ended questions that avoid assumptions. Reflective listening ensures the interviewer's correct understanding of the response.

4.2 Analysis and operationalization

A combination of closed and open coding methods was applied. This entails that predefined codes were determined as a starting base before analysis, focussing on elements depicted from the research questions. These predefined themes are social, technical, socio-technical arrangements, challenges, opportunities, planning, and planning instruments. The first three codes are based on sub-question 1. The codes 'challenges' and 'opportunities' were chosen based on sub-question 2. The remaining codes were based on the focus of sub-question 3 on the contribution to planning, specifically sustainable metropolitan planning. The coding process was undertaken with these themes in mind to ensure the adequate answering of the research questions while still having the freedom to code openly and add new codes if needed. The codes were used in NVivo software (version 14) to identify themes in the interview transcription, which later became convenient when writing the results and discussion section of the paper. After all transcripts were coded, the semi-open coding method resulted in a large number of codes. Four main themes were identified to ease the writing process: roles, social, spatial planning and technical. The main themes consist of subcodes, as seen in Table 2.

Table 2 Coding scheme with codes per theme

Roles	Social	Spatial Planning	Technical
• Grid operator • Investors • Knowledge institutions • Lobby and groups • Metropolitan • Municipality • National • Politics • Provincial • Tech companies • Water board	• Collaboration and participation • Education • Employment • Faith and culture • Housing • Public support Recreation	• CEA definition • Challenges • Dependencies • Ecological sustainability • Economic and price • Food security • Globalization • Infrastructure definition • Land use • Liveability • Opportunities • Planning instruments • Urban sustainability	• Automation and digitalization • Electricity • Logistics and trade • Pest protection • Structure • Heating • Lighting • Water • CO2

4.3 Project process

The thesis project started in February 2024 and ended on the 31st of August 2024. The project was split into three phases to successfully plan a long-lasting project (see Figure 6).

Figure 6 Project process

Research phase

- Gathering literature
- Contact participants
- Make interview guide
- Conducting interviews and field visits

Analysis phase

- Transcribing
- Coding data
- Write results
- Write discussion
- Write conclusion

Paper preparation phase

- Write remaining chapters
- Concept version
- Revise and finalize
- Final hand-in

4.4 Validity and reliability

The MRDH area of CEA-type greenhouses consists of two main clusters: Westland and Oostland (West-side and East-side). Interviews have been conducted in both areas to ensure reliable findings. Furthermore, employees of all governmental levels involved have been questioned. Gathering data using interviews enables understanding the context with all the complexity it entails, making sure that conclusions are drawn based not only on numerical data or societal speculations but also on lived experiences.

4.5 Limitations and risks

Analysis with Nvivo was limited due to Dutch interviewing and transcriptions. The software was not able to run functions like thematic auto-coding and word count analysis in Dutch with adequate and reliable results. Therefore, manual coding and analysis have been adopted. Hence, a preference because this results in more accurate results.

One of the most high-impact risks could have been encountering non-responsive interviewees. Applying the snowball effect reduced the risk of non-responsiveness because interview invitations were done by an already familiar face and plenty of respondents were reached. Some other high-impact risks were considered possible beforehand. External risks like pandemics or illness of the intern or supervisors could have occurred. This would have limited the ability to travel and conduct field visits. A possible way out of this would have been conducting online interviews on platforms like Microsoft Teams, which has certain limitations that must be kept in mind. Fortunately, none of this happened. Regular backups of data and documents were made in an external cloud-based storage to combat data loss due to potential software or hardware malfunctioning.

5. Results

5.1 Urban greenhouse infrastructure

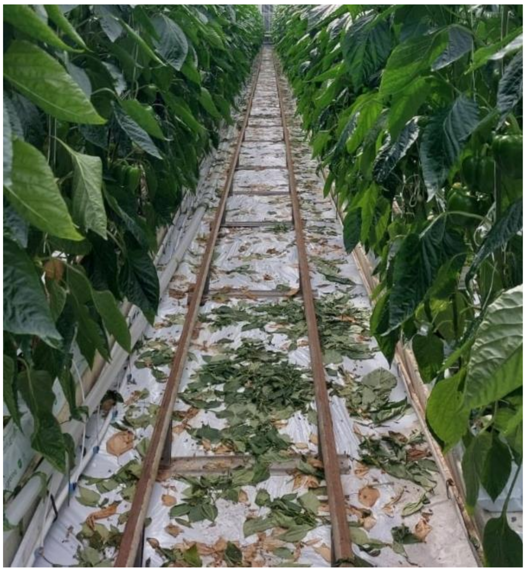
In alignment with the theoretical background, the urban greenhouses in the MRDH consist of several internal infrastructure systems. All interviewed entrepreneurs indicate that they use a heating system in the greenhouse. Entrepreneur B: “So, we have one [combined heat and power installation] CHPI for nine hectares of greenhouses”; “and there we still use four to five thousand cubic metres of natural gas” (Entrepreneur B). “We have geothermal energy input. And we have had combined heat and power for 14 years” (Entrepreneur D). Combined heat and power installations (CHPIs) are small-scale power plants built on-site that use natural gas to generate electricity, heat and CO_2 (see Figure 7). All interviewees reported that they use the generated electricity of CHPIs and that any excess electricity or warmth is sold to the main electricity grid’s operator. Entrepreneur C reported using solar power for electricity generation. However, Entrepreneur B opposed and clearly stated that solar power is not feasible for powering greenhouses. Entrepreneur B: “But solar panels, you need most of your electricity in October, November, December, January, and February. But that's when the solar panels produce the least” (Entrepreneur B, 2024). Maintaining an optimal temperature in the greenhouse is essential for plant growth. The warmth generated on-site or from the grid is used to warm up water distributed through radiation tubes around the greenhouse, heating up the inside air (see Figure 8). The heating systems present in the urban greenhouses require the consumption of electricity, gas or geothermal energy.

Figure 7 Combined Heat and Power Installation (CHPI)

Note. Westland 22-04-2024

Plants are grown in soil slabs, with drip emitters connected to the soil for irrigation. Internal water infrastructure precisely water plants using drip emitters, making use of every drop (Figure 9). A nutrient solution is used to feed the plants.

Figure 8 and Figure 9 Greenhouse with radiation tube system (left) and drip emitters (right)




Note. During a field visit at KomInDeKas on 06-04-2024

Besides gas, the entrepreneurs reported the requirement of using electricity to power small appliances, robotics and lighting (Figure 10). The electricity is used from the grid or generated on-site. Entrepreneur A stated to store electricity when prices are beneficial in lithium batteries and use the electricity stored when prices rise. Entrepreneur B explained another way of storing energy: large water basins to store warmth as a buffer for the radiator tube network.

Figure 10 Large-scale greenhouse with artificial LED-lighting

Note. During a field visit to the event KomInDeKas on 06-04-2024

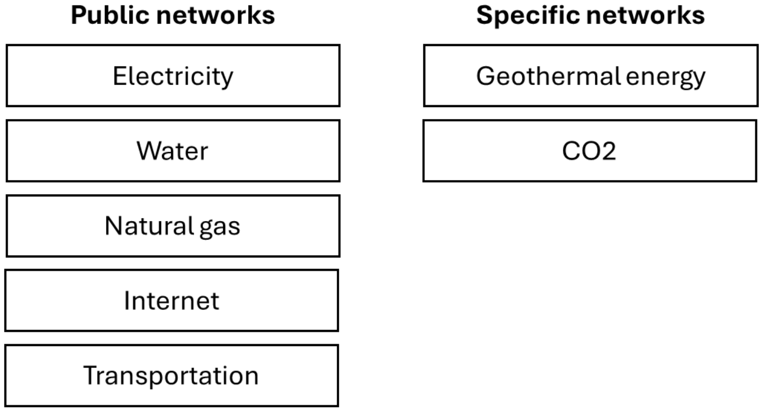
Entrepreneurs A and D stated to use CO2 to optimize plant growth. Entrepreneur A explains how the use of CO2 in the greenhouses started with a project where an old pipeline was re-used to transport CO2 residue from industries at the port of Rotterdam to the greenhouses. The pipeline was formally constructed for fuel transportation from the port of Rotterdam to Amsterdam Schiphol Airport. Entrepreneur B: “It is […] not yet there. And then they still have to come two or three kilometres this way". Indicating that not every greenhouse has access to CO2. In contrast, entrepreneur B ventilates or cools down the greenhouse with outside air by opening rood windows.

During the interviews and field-visit, trucks full of paprika's or tomatoes drove by and got loaded up. Entrepreneurs A, C and D have their own truck loading docks. The number of goods delivered and picked up was also expressed: "from 1st October to early November we receive around 60,000 to 65,000 plants at home every day" (Entrepreneur B). "We have 3 million peppers per year". This made clear that the urban greenhouses generate heavy truck traffic. Entrepreneurs and governmental planners often mention the value of the quality logistics present in the MRDH. Entrepreneur D stated that "export is very important … for logistics in this region" (Entrepreneur D), which is mainly thanks to a multitude of "logistics companies" (Entrepreneur D) that emerged because "everything that is grown here needs to be transported somewhere" (MRDH planner). According to the MRDH planner, high-quality logistics is directly linked to high-quality road infrastructure. The Westland planners emphasise the importance of road infrastructure and public transport that contribute to the accessibility of urban greenhouses. The Westland planners assess public transportation around the urban greenhouses as "bad".

The entrepreneurs describe several monitoring systems and appliances that need an internet connection to work. The internal infrastructure systems also use the internet to exchange data with tech companies, enabling outsourcing distanced infrastructure management of energy flows. As an example: "They also manage our CHPI. […] that is automated […] and they monitor it 24/7". The requirement for reliable internet is made clear: "Because we simply had too little internet here" (Entrepreneur C).

Infrastructural requirements
The results indicate that the main resources the urban greenhouses require are electricity, water, natural gas, geothermal energy, CO2, internet and transportation (Figure 11). The urban greenhouses acquire these resources from the external infrastructure, which is either public or consists of specific networks. In the Netherlands, the public infrastructure provides these resources nationwide through electricity, water, natural gas, internet and transportation networks. CO2 and geothermal energy are supplied through specific networks for the urban greenhouses.

Figure 11 Infrastructural requirements of urban greenhouses



5.2 Main challenges

Changing energy sources

To ensure economic viability and built-up capital, entrepreneurs constantly search for ways to reduce costs and maximize profit. For the entrepreneurs buying natural gas for CHPIs to produce electricity, warmth, and CO2 is the cheapest option. Mainly due to the opportunity to sell or store excess electricity for the main grid. The current challenge with these CHPIs is that the local grid operator, in this case, Stedin, does not allow new CHPIs to be built due to the grid reaching capacity, limiting the expansion of CEA greenhouses. This creates misunderstanding among entrepreneurs because they think the CHPIs are part of the solution to stabilize electricity imbalances on the grid by switching on to produce electricity when electricity demand is high and by switching off to consume from the grid when demand is low. The following quote clearly shows this:

> . . . essentially, boiler gas is out of the question. We pay much more energy tax on it. . . .With a new CHPI, we are told by Stedin that we can no longer supply to the grid. . . . I find that a bit strange. Because horticulture supplies when electricity prices are high. . . .. And once the sun is out, and the wind is there, the electricity prices go down, and then you turn the CHPs off. (Entrepreneur B, 2024).

Meanwhile, entrepreneurs A and B both emphasise the increased tax on natural gas. "The government . . . they are imposing heavy taxes on gas so that it will soon be unaffordable." (Entrepreneur A, 2024). "The boiler gas is out of the question. We pay much more energy tax on it." (Entrepreneur B, 2024).

Searching for energy alternatives

Entrepreneur B indicates that due to the construction restrictions on new CHPIs, entrepreneurs start searching for other alternatives, asking for advice from consultancy companies:

> But coincidentally, I asked INNOVA just yesterday to partially look into that for us. . . . then you end up with e-boilers or heat pumps. . . . and then we store the heat in the buffer. A buffer is comparable to a battery. We have about 1000 cubic meters of water in those storage tanks. . . . You can store electricity in batteries, but suppose we request a large battery pack, just lithium, then we partly store the water (heat) in those tanks, and partly you can store the electricity in a battery pack, . . . But still, new CHPI's are being blocked by Stedin, and a CHPI is a revenue model and even a condition for horticulture to be able to operate. (Entrepreneur B, 2024)

Both entrepreneurs A and B explain that local public support appears to be low for the realisation of new geothermal energy stations.

> And we hope now with geothermal energy to take a step forward within a few years, because look, the neighbourhood, the council, everyone is in favour, and the neighbourhood can't stop it, but they can delay it. Because there are residents, we see each other at the Council of State. (Entrepreneur B)

The entrepreneurs mention that they try to improve the public opinion by teaching them how food is produced. This is done by organising events, involving educational organisations, and opening the greenhouse to the public.

Entrepreneurs A and D in Westland mentioned that they already (partially) run on geothermal energy, which points out that it is possible. Geothermal energy is reported to be expensive but a viable alternative if gas prices become higher than geothermal energy prices:

> The annoying thing about geothermal energy is that it is actually far too expensive . . . But if they make gas expensive enough, then eventually it will become interesting to try it. Geothermal energy is important, but what we are particularly focusing on are heat pumps. (Entrepreneur A)

Both expensive geothermal and gas sources lead entrepreneurs to explore heat pumps with relatively low electricity consumption.

Employment and housing

As factually mentioned by entrepreneur B the greenhouse enterprises are primarily dependent on the availability of migrant workers: “But in the sector, we are primarily dependent on migrants because the wages are [. . .] [low]”. Entrepreneur B also expressed that they support fair loans for their employees and that this could be quickly done if the supermarket’s prices were slightly increased:

> If you want to pay your own people a bit more, then a retail company should also show its support . . . . We . . . are talking about 2 eurocents per bell pepper . . . Well, there is no one in the shop who would mind paying 2 eurocents more for a bell pepper” (Entrepreneur B, 2024)

Additionally, better loans could increase job attractiveness and a shortage of employees in the sector is mentioned: “We see that there is simply a huge shortage of labour, and one of the solutions for that is to ensure that you need fewer workers” (MRDH planner, 2024). The planner (MRDH) insinuates that using fewer employees is the solution. The PZH planner B (regional economic advisor) mentioned that a top-down price increase to improve the loans is not achievable because of the market's competitiveness between distributors and supermarkets. The distributor might go to a different, cheaper entrepreneur, or the supermarket might lose sales, which they would not be willing to risk. PZH planner B: “Yes, that doesn’t work, because then I’ll go to ALDI instead of LIDL. . . . for the grower, they also want to keep their costs as low as possible”. This again insinuates that the entrepreneur must keep maintenance costs low.

The Entrepreneur indirectly mentions this as the problem that limits a product price increase: “But the retail companies do check each other's shelves to see what is being asked” (Entrepreneur B). Motivated by their own values to improve working conditions for employees, entrepreneurs (A and B) show initiatives to convert or build residences for employees on their private land, close to their working space:

> Housing working migrants in the neighbourhood of the enterprise poses possible disturbance with local residents, which is looked after by the entrepreneur: “If we have migrants living in that house, then you depend on the neighbourhood accepting it. So, we normally ask the neighbourhood: ‘Do you experience any nuisance?’. . . Because if the support is gone, you will be working against your own neighbourhood, so in that respect, you also try to seek a compromise with the neighbourhood. (Entrepreneur A, 2024)

Robotics and Automation

This causes entrepreneurs to always look for ways to limit their energy or labour costs. Robotics and automation in the production process aid entrepreneurs in limiting labour costs. Entrepreneur A proudly describes the sorting process that has been automated by sorting robots, whereas previously, sorting was done by hand (Figure 12 and 13). Entrepreneur A reports that automation improves efficiency and reliability. Because fewer employees are required, labour costs decrease, and employee health is improved.

> And then you can see what we do with automation. . . . Where in the past we needed 5-6 people to sort, we can now do it with just three . . . It does break down sometimes, but I've never experienced it getting sick. (entrepreneur A, 2024)

Entrepreneur C made a similar statement, reporting increased efficiency because of automation. Additionally, entrepreneur C mentioned that introducing automation increases the need for “higher quality personnel” to operate machines. The planners of Pijnacker-Nootdorp and PZH (A) stated that automation and robotics become increasingly important in the industry.

Figure 12 and Figure 13 Sorting robot (left) and unsorted harvest (right)

Note. During a field visit on 22-04-2024

Besides automation as *a* result advancing technology, digitalization is increasingly useful in urban greenhouses. Entrepreneur A reported that an advisor is used to share knowledge between growing entrepreneurs. The entrepreneur also stated that they are considering improving this crop analysis and optimisation process by implementing sensors to analyse plants.

> An advisor is hired to visit and inspect all the gardens. They provide analysis reports and compare variables to explain problems. The advantage is that they visit everywhere and share knowledge among the growers […] Due to competition, there's often secrecy between neighbours or within closed groups. Differences in opinions arise. (Entrepreneur A, 2024)

This identifies another challenge regarding emerging secrecy between entrepreneurs, caused by competitiveness. The essence of an independent advisor sharing knowledge without limitations is emphasized.

Social spaces

Entrepreneur A reported that the state of his greenhouses can be described as medium-tech greenhouses. The urban greenhouse still depends on sunlight, but the entrepreneur spoke about his ambition to move towards complete independence of outside weather by implementing LED lights in periods of insufficient sunlight. Entrepreneur A reported that the decision on whether this investment is profitable depends on the distributor’s (buyer of the entrepreneur’s product) ability to pay more for the product. The entrepreneur emphasises the importance of the product’s characteristics to justify a higher selling price. Therefore, the entrepreneur conducts a trial in a small greenhouse on the property. Entrepreneur A: “We don't have a [*sic*] lamps hanging. Coincidentally, we have, well, the test chamber, of 40 square meters [. . .] Then, with [the new] lighting, we will see if it's possible to get through the winter with lamps”. The entrepreneur explains how such an infrastructural investment increases the product’s selling price, making concurrence more attractive for buyers. Entrepreneur A: “where you now get 1.45, you might need 2 euros”. The higher-priced products are made more attractive with the argument that it is “clean, [and] almost organically grown”. Successful on-site experimentation is shared within the local entrepreneurial community.

> they discuss it at the football match and come up with ideas on a coaster, and they start tinkering at home and suddenly they have a drone to combat moths because the pesticide doesn’t [*sic*] work […] And that all starts in such a small niche greenhouse. (Westland planners)

Van Kessel et al. (2005) found that the social networks around the urban greenhouses served as a base for preserving the various quality-of-life services in the area.

Strict investment requirements

The Westland planners explained how investment actors like banks set sustainability requirements to be able to apply for new private equity. The Westland planners report that Rabobank, [a large Dutch bank], indicated that “[they] only invest in areas that are future-proof”. Rabobank has defined future-proof as climate-adaptive, meaning that the area is adapting to climate change while also ensuring guaranteed sustainable energy supplies. Rabobank will “no longer invest in horticultural companies with a gas installation”. They will continue to finance horticultural companies with a CHPI but ultimately aim to invest in horticultural companies that “run entirely on geothermal energy or CO2-neutral installations, such as hydrogen” (Westland Planners, 2024).

Adding to this, Entrepreneur B spoke about the investors and banks basing their investment choice on operational costs like labour and energy costs, putting pressure on entrepreneurs to limit these costs as a requirement to acquire the capital needed to expand or develop their infrastructure. Entrepreneur B: “If we want to expand . . . that bank then says, show us your administration from the last few years, and the key points are energy and the cost of your personnel” (Entrepreneur B).

5.1.8 Difference in development ambition

There is a consensus among respondents that there are two types of entrepreneurs: progressive and conservative. The MRDH planner stated that this conservative group limits development, which harms the region's overall production value.

> There are a few major players with highly efficient production who are also technologically advanced, engaging in innovative projects. However, there's also a large group that doesn't have this. . . . This causes a delay in the entire production chain because if the suppliers in that chain are not efficient, it limits what you can achieve [as a whole] since your suppliers or the recipients of your products are less advanced.”

On the other hand, all interviewed entrepreneurs (A, B, C and D) find themselves progressive entrepreneurs, eager to share knowledge and embrace technological and infrastructural development. Entrepreneur C: “A leading company that stays ahead with developments.” The MRDH planner and the PZH planner (A) explain attempting to overcome this challenge by encouraging knowledge sharing between conservative and progressive entrepreneurs. PZH planner A: “By establishing contact between the companies that are very innovative and capable, and their suppliers or partners who are not yet at that level”.

Another difference can be seen between entrepreneurs and governments. Entrepreneurs tend to dare to look beyond governments' planning terms for their spatial plans. Entrepreneur D: "But you have to look beyond that period. Much of spatial planning is for 2030, 2040, 2050. We dare to look as far ahead as 2120."

5.3 Sustainable metropolitan development

Regional collaboration

The current metropolitan agency, MRDH, reports that it is not involved with the planning of greenhouse infrastructure (Interview with MRDH planner). The MRDH rather focuses on establishing a healthy economic climate, with which they take into account the economic value of the greenhouses in the MRDH. However, the Greenport West-Holland is often mentioned as a regional collaboration, and its value to the greenhouse industry is emphasised. Entrepreneur D on regional collaboration: "Well, we do that, of course, through the Greenports. It is much more at the regional level". The MRDH planner described the Greenport as a "fantastic collaboration". Besides Greenport West-Holland, five other Greenports are present. Greenport West-Holland calls themselves a triple-helix organisation. The triple helix concept is a collaboration between three main parties: government, industry and knowledge institutions. Greenport West-Holland works on building a "sustainable and vital future for the regional horticulture greenhouse cluster" (*Greenport West-Holland*, n.d.). Besides the Greenport, some other collaborative initiatives from entrepreneurial groups are described. Entrepreneur C explained how they collaboratively improved internet infrastructure because of a low-quality network. Entrepreneur C: "Where we have a business association, of which I am the chairman, we started an initiative to improve the internet. Because we simply had insufficient internet here".

Besides collaborations between entrepreneurs, the collaboration between entrepreneurs and the municipality is critiqued as slow due to bureaucracy, and that the relationship can be improved. Entrepreneur A states that there is a need for clear goals and communication from the government. Entrepreneur A: "There must be light at the end of the tunnel. And if you see the light and know that you are being supported, then everything will be fine."

Regional and Municipal Plans

The Westland planners explain how regional plans have been made, in line with national plans, to introduce more greenery and space for natural waterways in the areas with greenhouses. The goals of this are to improve biodiversity, natural value, and recreation. Westland planners: "That also fits in with the NPLG (National Programme for Rural Areas). The provincial implementation of it and the required 10% green-blue areas" (Westland planners, 2024). The Westland municipality aligns its visions with these national policies but has not yet implemented the same goals in its local policies. "Well, no, it is not yet in policy. It is, of course, described that we aim to work towards connecting green elements," the Westland planners noted. Controversially, the P-N planners have not reported such policies. The entrepreneurs experience the implemented policies as "too extreme", possibly limiting development and innovative creativity: "The rules being devised in the Netherlands are becoming too extreme. I understand it is not simple, but it is very irritating." (Entrepreneur A).

Allocation of National Investment Capital

The Westland planners discussed that the national investment capital available for the sustainability transition of agricultural lands is divided evenly among the provinces. They believe much more money would be needed for developing the Westland area due to its greenhouse density:

> The government has allocated 24 billion for this, . . . The province needs 9-10 billion from that fund, but it has to be divided among twelve provinces. Densely populated provinces should receive a higher percentage than others, one could argue. With our current land value, it would cost Westland 3 billion to achieve that 10% [green-blue zone]. If you look at the area of Westland compared to the whole of the Netherlands and the entire fund, we

> would be entitled to about 24 million. These are, of course, figures that make you think it is completely unfeasible. But then you would have an established green-blue zone. (Westland Planners, 2024)

They attribute this to the lack of an integral national spatial planning approach, previously managed by the former Ministry of Spatial Planning. The need for a more regional or even national integral approach is clearly expressed: "The problems are cross-border, so they must be viewed from a cross-border perspective. . . . but also at an interest level and an economic level. At all those levels." (Westland planners, 2024).

Investment in Future-proof Areas

The Westland planners reported that the Municipal plans aim to only invest in future-proof areas: "In the horticulture cluster, we will soon only invest in those areas that are future-proof" and "that run entirely on geothermal energy or have CO2-neutral installations, such as hydrogen" (Westland Planners). Several planners (Westland, P-N, MRDH, and PZH A) stated that it is not necessary to stimulate technological innovation and the development of greenhouses, as this task is fit for entrepreneurs. The Westland planners said, "We don't need to stimulate the development itself; the sector will take care of that on its own." The P-N planners echoed this sentiment: "Look, our position is that the greenhouse horticulture area should handle it on its own."

6. Discussion and conclusion

This chapter discusses the findings guided by the sub-questions and the conclusion that answers the main question: "How can urban greenhouse infrastructures be integrated into existing urban infrastructure in a sustainable way?". At the end of the chapter, future research recommendations are given.

6.1 Infrastructural requirements

The literature provides a baseline description of the systems found in urban CEA: heating, electricity, water and CO2. These were all found to be infrastructural requirements for urban greenhouses. The systems inside the urban greenhouses are mostly similar to what the literature described. The urban greenhouses optimise the inside temperature with heating systems that run on electricity or gas. Irrigation and fertilization are optimized by using drop emitters. Small appliances, lighting and robotics require electricity and a reliable internet connection. The road infrastructure ensures access for both freight transport and personal vehicles. Unlike the literature, the urban greenhouses have two additional infrastructural requirements that are dependent on resource availability in the area. All infrastructural requirements of the urban greenhouses can be split into publicly available networks and specific networks directly supplying the urban greenhouses (see Figure 11).

Geothermal energy is only available in lands suitable for geothermal extraction and CO2 is a rest product of heavy industries located in certain locations. The MRDH's location appears optimal for extraction, making the location suitable for transitioning to clean energy sources. Westland already runs lots of the urban greenhouses on geothermal energy. The municipality of Pijnacker Nootdorp does not but is working on it. Although the transition towards geothermal energy is widely supported by governments and popular among entrepreneurs, there are some challenges.

6.2 Main challenges

Geothermal energy can be expensive, and only lucrative in combination with other cost-lowering measures. Additionally, geothermal extraction installations are not popular among the surrounding residents. Innovative integral combinations of infrastructure systems, like selling excess energy from CHPIs can help suppress costs. Alternatively, if the government wants to transition, it can choose to subsidise geothermal energy. The government now steers from the other side, taxing heavily on gas, putting pressure on entrepreneurs to develop their own solutions.

Changing the public opinion on infrastructure projects is easier said than done, as infrastructures "tend to remain invisible" and therefore "taken for granted" by the public (Graham, 2001). Also, public opinion is influenced by, for the industry, uncontrollable factors like the media and political statements. Introducing the overarching sustainability benefits of urban greenhouses to the public might positively influence the public's opinion on the necessary infrastructural project. This involves close participation and increasing engagement with the public, hence one of Wheeler's (2000) key points in achieving urban sustainability. Public events and tours The public events and tours in greenhouses are the right platforms to spread the overarching interest. Active and engaging participation increases equality and ensures forms of good governance, but can be a lengthy process, while with sustainability, time is of the essence.

Investors, banks and governments steer entrepreneurs with financial instruments towards more sustainable alternatives. Examples include gas taxation or investing in areas considered 'future-proof'. This creates an economic climate where entrepreneurs are required to constantly limit their labour and energy costs as much as possible. Improving plant growth by optimizing CO_2 increases profits that can be used to balance out other increasing costs. Like geothermal energy, CO_2 is constrained to its extraction location, which is in this case the industrial areas of the Port of Rotterdam. The CO_2 project is not as far as the geothermal project in Pijnacker-Nootdorp and is still in the plan-forming stage. Therefore, similar challenges have not been reported.

Besides minimizing energy costs, automation and robotics can offer a solution for entrepreneurs to limit their labour costs by substituting tasks and increasing efficiency. Additionally, automation can improve working conditions, create new jobs that attract a younger workforce (The Economist Group & SGInnovate, 2021). The results indicate that the entrepreneurs care about the well-being of employees and are eager to improve these working conditions. The downside of applying automation is that it requires a large initial investment. Entrepreneurs having to limit their labour costs has caused the urban greenhouses to rely mostly on lower-income migrant workers. Low-quality public transport and the housing crisis in the Netherlands negatively affect the workers' livelihood security (Giuliano et al., 2001) and food security (Baek, 2016). As a result, entrepreneurs build employee housing on private property. Creating these mixed-use environments is limited by the availability of old residences and the allocation for new residential use between the urban greenhouses. Entrepreneurs are finding their own solutions, but it could also be beneficial to incorporate housing for employees in spatial plans for urban greenhouses, as previously done in England (Raco, 2008).

Another spatial element in the findings is the social cohesion and the meeting places, such as sports clubs or bars, crucial for knowledge distribution among entrepreneurs. These social meeting places are fuelling overall infrastructural change within the industry. Incorporating the value of these places in policy plans is crucial for sustaining the greenhouse industry. This emphasizes the social components that model urban infrastructure (Graham & Marvin, 2001). Another social component from the findings is the engagement of entrepreneurs in education. Goméz et al. (2019) describe how incorporating these educational elements into business plans creates access to alternative funding from schools, research institutions, communities, and the government.

The national electricity grid has reached capacity, and upgrading it is slower due to a lack of certified electricians (NOS, 2024), creating constraints for entrepreneurs on new infrastructure developments. CHPI's cannot be newly constructed until the electricity grid's capacity is upgraded. This causes entrepreneurs to search for alternative ways to generate electricity, which is not necessarily bad. Entrepreneurs search for ways to generate their own electricity and use or store it locally, making the greenhouses less dependent on supply from the main grid. Creating such a buffer also creates opportunities for the grid operator to use the greenhouses as giant batteries and increase supply and demand flexibility. Electricity can be consumed or stored if an abundance of electricity is generated, and the greenhouses can generate electricity in times of shortage. However, urban greenhouses still require high-capacity infrastructure to and from the facility, especially if they are increasingly used as giant batteries. This comes with the need for significant costs. The preferred and sustainable approach is to connect all greenhouses to the same infrastructural system and minimize the costs. Fortunately, municipalities already have this insight and are actively working towards clustering greenhouses together. However, the results indicate that the clustering of greenhouses is solely implemented at a municipal level. The province does provide a general overview of the land uses in the region, but the legislative planning power for allocating land uses is delegated to the municipalities.

To sum up, the findings indicate that planners face transmunicipal challenges, like climate change and the energy transition. These are to be solved by initiating large-scale infrastructural projects, that also require a transmunicipal and integral approach. Paragraph 6.3 addresses the role of the metropole and how these transmunicipal challenges could be managed through sustainable metropolitan planning.

6.3 Sustainable metropolitan planning

The regional collaboration Greenport West-Holland seems to be the backbone of greenhouse development in the MRDH. The initiative deliberately ensures continuous knowledge sharing and joint interests among governments, industry and knowledge institutions. Even with such a strong collaboration initiative, infrastructural planning still lacks integrality among governmental levels to solve transmunicipal issues. Planners indicated that the national government does not distinguish between conventional agriculture and urban greenhouses regarding funding. In contrast, urban greenhouses are, in fact, a more industrial and intensive form of agriculture with different characteristics. Because of this, the sustainability transition costs more than the funding allocated to the urban greenhouses, while they are crucial for feeding our growing urban population (Davis et al., 2016). Meanwhile, entrepreneurs are put under pressure by various factors. Governments impose heavy taxes on fossil energy sources, and private equity is only available to those who are 'future-proof'.

An agency such as the metropole (MRDH) seems a suitable candidate to take on the role of coordinating regional planning for the urban greenhouses. Even if this is only an advisory role, like the MRDH already does for transportation and economic plans and policies, it would still fulfil the need for an overarching and integral view on the transmunicipal issues, which is utterly needed to achieve sustainable infrastructure plans. As Wheeler (2000) suggests, creating stronger regional institutions can limit jurisdictional fragmentation among municipalities, provinces and the metropolitan agency.

The results indicate that entrepreneurs appear to think more ahead with their plans than the spatial plans of governments. Long-term planning is needed for the creation of integral sustainability plans (Hajer & Versteeg, 2019) and is found crucial for agriculture focussing on high-value crops and organic farming (Pölling et al., 2016). Long-term planning and imagining alternate futures is known as the concept of 'futuring' (Neuhoff et al., 2023). Futuring is a relatively new concept that is an effective form for achieving urban sustainability. Futuring has the ability to "open up alternative pathways by using consciously designed visioning and backcasting processes" (Neuhoff et al., 2023, p. 10). However, Neuhoff found that researchers highlight the need for additional research to determine how futuring could be consistently implemented into urban policymaking. An initiative from Wageningen University is a prime example of taking an integral approach to futuring (Baptist et al., 2019).

6.4 Conclusion

In the end, urbanisation causes the greenhouses in the MRDH to become increasingly more urban. The infrastructure urban greenhouses require is similar to what urban infrastructures already provide. Still, the integration of greenhouses demands more capacity and specific networks for geothermal energy and the supply of CO2. The findings of this paper indicate that integrating urban greenhouse infrastructure into existing urban infrastructures, to use urban greenhouses as a solution for growing urban food demand and exploiting its sustainability benefits requires the following steps:

- Allocating planning power to an overarching authority that can focus on taking an integral and transmunicipal planning approach, strengthening regional institutions;
- Allocating a feasible amount of national funding that reflects the value urban greenhouses create for society and to support transitioning the energy infrastructure;
- Clustering greenhouses to create integral infrastructure combinations;
- Sustain and develop local amenities that create social meeting places, host events and offer educational services.

6.5 Research recommendations

This paper examined the large-scale (urban) greenhouses in the Rotterdam-The Hague Metropolitan Area. Therefore, it is advised that future research studies urban greenhouses in other metropolitan areas as it is plausible that these areas pose other yet unknown challenges. Additionally, this paper might inspire planners to create or adapt similar structures in a metropolitan context. This would require area-specific, in-depth case studies.

As the literature suggests, urban CEA has the potential to create a more resilient food system and contribute to meeting local food demand. However, most of the food produced in the MRDH is exported. Therefore, future research is suggested to study creating more circular and local food systems while keeping food affordable and equally available to all.

This study argues for changing the planning approach but does not specifically focus on spatial policies affecting the urban greenhouses in the MRDH. This paper recommends conducting in-depth research specifically designed to analyze spatial policies affecting the urban greenhouses in the MRDH.

Finally, the last recommendation for future research is to study whether combining urban greenhouse intensification in metropolitan areas and the simultaneous transition of conventional agriculture to nature-inclusive agriculture is sufficiently sustainable to overcome global environmental challenges.

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Appendices

Appendix A - Interview guide

This appendix includes the last known version of the interview guide.
Changes migth have been applied in-between interviews.

General information
Participant: …
Role/job function: …
Online/Real-time: …
Consent for recording and transcription: YES/PARTIALLY, namely…

NOTE: 'Controlled Environment Agriculture (CEA) and 'Greenhouse' or 'the (CEA) facility' terms can be used interchangeably, depending on the context.

Private sector

Opening

- How would you describe your (your organisation's) role in the CEA sector?
- How do you define CEA / greenhouses?
  - Would you define it as an infrastructure?
  - What do you consider an infrastructure?
- What is your view on the development of CEA?

Technical

- Can you explain to me the process of how you grow your crops?
  - What technical systems do you use to optimise their growth/production? (After answering: Interviewer verifies answer with a list of CEA variables and infrastructures from literature)
  - Which digital systems does that include? (Show list)
  - How do you monitor your crops? (show list)
  - What dependencies do these systems have? (Answer for technical, digital and monitoring systems.)
- What connections exist between the tech infrastructure in the facility and other infrastructures outside of the facility?
  - How are they connected
  - And what parties are involved?
- How has the CEA infrastructure (and technology) changed over the past 10 years?

Social

- How do you describe your role in society?
- How do you act to maintain this active role?
- From a broader perspective: How does CEA add social value to the region/MRDH?
- What interactions does the facility have with the surrounding area (peri-urban neighbourhood)?
- How does CEA add employment value?
  - How many employees work at your facility?
  - How do you expect this number will develop over the next 10 years?

- What informal social initiatives (explain definition) are present and how have they been established?
    - What is your view on these initiatives?
      E.g. if unanswered: educational programs, voluntary work, social farming (special needs people), and local road selling.
    - How do you experience these initiatives?
    - How important are they?
    - How do they relate to CEA development?
- How has the relation from society to CEA changed over the last 10 years?

Challenges

- What challenges do you face and how do/will you deal with them? (<u>Sensitive question</u>)
      E.g. if unanswered: lack of resources, collaboration, social support/subsidies, inflation?
- How do these factors hold back technical development of your CEA facility?
- How do these factors hold back social development of your CEA facility?
- Have the challenges of CEA been different the past 10 years and how has this changed?

Opportunities

- How are opportunities created for the development of the CEA facility?
  <u>Politically laden question</u>
- What opportunities do you see for the CEA sector?
- What opportunities do you see for you?
- How have the opportunities for CEA changed over the last 10 years?

Promotion

- How would you stimulate the development of CEA?
- How does the government support CEA development?
    - At what governmental level(s)?
    - How have you experienced this?
    - How important are they for CEA development?
- How has the way in which CEA development is promoted changed over the last 10 years?
- What do you think of CEA in terms of sustainability?
    - Do you think CEA is sustainable?

Space for questions informal talks

- Based on our conversation, are there any things you still want to discuss or have become curious about?
- Do you have any further questions?

Ending of interview

<u>Public sector</u>

General information is the same as at the top of the document.
Give the participant an introduction to the research topic.

Opening

- How would you describe your (your organisation's) role in the CEA sector?
    - And how is the organisation related to CEA development?
- How do you define CEA / greenhouses?
    - Would you define it as an infrastructure?
    - What do you consider an infrastructure?
- How does the process of CEA development take place?

Technical

- How does your organisation relate to the technical infrastructure in CEA?
    - What technical infrastructures are present in CEA or connected to CEA? (After answering: Interviewer verifies answer with a list of CEA variables and infrastructures from literature)
        - How are they connected?
        - What parties are involved?
    - Which digital systems does that include? (Show list again, if needed)
        - How are they connected?
        - What parties are involved?
    - What monitoring systems are used?
        - How are they connected?
        - What parties are involved?
    - What dependencies do these systems have? (e.g. spatial overview of CEA) (Answer for technical, digital and monitoring systems.)
    - How would you explain the process of the implementation of such infrastructures?
- How has the CEA infrastructure (and technology) changed over the past 10 years?

Social

- How does CEA add social value to the region/MRDH?
    - How are other spatial functions related to CEA?
- What social interactions does the facility have with the surrounding area on a (peri-urban) neighbourhood level?
- How does CEA add employment value?
    - How do you expect this number will develop over the next 10 years?
- What informal social initiatives (explain definition; bottom-up) are present and how have they been established?
    - What is your view on these initiatives? E.g. if unanswered, educational programs, voluntary work, social farming (special needs people), and local road selling.
    - How do you experience these initiatives?
    - How important are they for CEA development?
- How has the relation from society to CEA changed over the last 10 years?

Challenges

- What challenges do you face regarding the development of CEA and how do/will you deal with them?
  (Potentially sensitive question)
    E.g. of unanswered: lack of resources, collaboration, social support/subsidies, inflation?
- How do these factors hold back technical development of CEA?
- How do these factors hold back social development of CEA?
- How have challenges of CEA been changing the past 10 years and how has this changed?

Opportunities

- How are opportunities created for the development of the CEA?
  (politically laden question)
- What opportunities do you see in CEA development for the region?
- How have the opportunities for CEA changed over the last 10 years?

Promotion

- What is the best way to stimulate the development of CEA?
- How do you stimulate the development of CEA?
    - What policies influence CEA the most?
    - Which other governmental bodies do you collaborate with for CEA development?
      E.g. if unanswered: municipal/provincial/metropolitan/state government
- How has the way in which CEA development is promoted changed over the last 10 years?
- What do you think of CEA in terms of sustainability?
    - Do you think CEA is sustainable?

Space for questions, informal talks

- Based on our conversation, are there any things you still want to discuss or have become curious about?
- Do you have any further questions?

Ending of interview

Appendix B - Interview transcriptions

Transcriptions of the interviews are available with the author upon request in original Dutch or translated into British English.

Endnotes

[i] The external resource supply is determined by the needs created by the internal resource need. The internal infrastructure can be lighting. The electricity needed for this is supplied from the external infrastructure to the internal infrastructure to meet the electricity demand. The amount of electricity supply is dependent on how much the internal infrastructure needs or allows. Conversely, the internal infrastructure depends on how much the external infrastructure allows or can allow. The internal and external infrastructures can be the supplier and the consumer, showing the interconnectedness.