Environmental impact of Alternative Food Networks in the Netherlands

Analyzing five different AFN types for fresh produce distribution

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Preface

This Master thesis contains the results of the potential contribution of AFNs to sustainable agriculture in the Netherlands and proposes a new definition for the concept of AFN. This thesis was written in the context of graduating from my Master Sustainable Development at the Utrecht University.

Together with my supervisor Prof. Dr. Ernst Worrell, I came up with the research question for this thesis. I volunteered as a board member of the non-profit organization Groentetas in Utrecht, which is an AFN, which also gave me the motivation for this study and made me realize the relevance of this research. After thoroughly quantitative and qualitative research, I was able to answer the research question.

Besides the academic challenges of writing a thesis, I started my thesis in lockdown because of the Corona virus. Staying at home for months and seeing few people with few distractions made the process more difficult than I had hoped. The death of my dear uncle Jan also made me take a break from writing, hence why I exceeded the planned six months of writing. He would have liked to see the results of this research, but unfortunately that was not possible. Ernst was always there for me during this time and gave me all the space I needed. His gentle approach to this research and motivating attitude towards me to persevere have helped to write this thesis. I am very grateful to him for this. His substantive knowledge of the subject and his experience in conducting research have also been extremely helpful.

I would also like to thank all the people I was allowed to interview to learn more about AFNs in the Netherlands. So, thank you Dinus Herrewijnen, Steven Kempen, Maarten Klop and Sarah Nolan. I also want to thank all my friends for their trust in me and for the kind words of encouragement when I was having a hard time. Thank you, Maria, Mojca and Eva for reading my chapters and providing feedback. I couldn't have done it without you. Dear Laurens, thank you specifically for all your help.

Finally, I would like to thank my mother and give a special shout out to my father, who unfortunately never got to experience this process. Mom, you've always believed in me, and you've always encouraged me to take it one step at a time. As sad as it is that my dad could not experience this, I know that he would be very proud that I am going to get my Master of Science.

I wish you a lot of reading pleasure.

Ilfa Cornelia van Duijvenbode
Utrecht, June 23 2022

Abstract

The conventional, modern food systems in the Netherlands are getting criticized for their large environmental impact and are becoming untenable in the light of new sustainability goals, like the SDGs, the Paris Climate Agreements, and the Dutch Nitrogen policy. There is a need for more sustainable agricultural. In the past two decades a new concept emerged in scientific literature and in practice. This concept is called Alternative Food Networks (AFN) and opposes the modern food system.

The research has been divided into two phases: the identification of AFNs, and an environmental impact assessment of five AFN types compared to the conventional system to determine the potential contribution of AFNs in the transition to sustainable agriculture in the Netherlands. For this, literature and databases have been analyzed and stakeholders of selected AFNs have been interviewed.

In the first phase a general definition has been proposed to stimulate precise communication and research about AFNs by comparing characteristics from existing literature and analyzing the conducted interviews. AFN can be defined as: "*An Alternative Food Network is a food network that opposes the conventional modern food networks. It is a system that operates within short supply chains, in which food is produced and sold locally and fresh. There is an intent to preserve the environment and there is more emphasis on preservation of biodiversity. Transparency within the network is essential and there is active interaction between all parties within the network."*

In the second phase, two crop types - tomato and carrot- have been investigated from the moment the produce is planted, to the moment the produce is bought by the consumer (cradle-to-gate). The environmental impact assessment has been performed, for the impact categories 'Water', 'Land', 'Global warming', 'Eutrophication', and 'Acidification'.

The results show that the AFNs are more sustainable than the conventional systems because they strive for locally produced food that does not need storage since there is no need to conserve it for long periods of time. This reduces the GHG emissions. Furthermore, since there are no pesticides used, the soil quality and the local biodiversity will benefit. However, for the outcomes of these impact categories there is not much difference in values between conventional networks and AFNs. It is strongly recommended to get more insight in the quantitative data of production in AFNs, and that agreements are made about environmental sustainability since those are now lacking. Therefore, it is also recommended that more data is gathered, and that the study is extended with multiple crops to get a better understanding of the AFNs based on different crops.

Keywords: AFN; Environmental impact; LCA; Dutch Food systems; Agriculture; SDGs

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Abbreviations

AFN	Alternative Food Network
C	Carbon
CA	Circular agriculture
CHP	Combined heat and power
CSA	Community-supported
GHG	Greenhouse gas
Kg	Kilogram
Km	Kilometer
L	Liters
L2L	Local2Local
LCA	Life Cycle Assessment
m^2	Square meters
N_2	Nitrogen
OECD	The Organisation for Economic Co-operation and Development
P	Phosphorus
PPP	Plant Protection Products
RIVM	Rijksinstitituut voor volksgezondheid en milieu
RUG	Rijksuniversiteit Groningen
RVO	Rijksdienst voor ondernemend Nederland
SDG	Sustainable Development Goal
SFSC	Short Food Supply Chain
VOKO	Voedselkollectief

1. Introduction

The world population is expected to reach almost 10.9 billion people by 2100. This raises challenges to multiple aspects of society like health care, housing, and food farming (Gerland et al., 2014). This thesis focuses on food farming; with a rising world population, there is also an increasing food demand and food security will need to be actively pursued (Prosekov & Ivanova, 2018). Food security is met when food is available, accessible, utilised, and when there is a stable supply. Food security can be defined as follows: "[..] when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life." (UNCSD, 2011). It is influenced by several aspects, ranging from crop yield and agricultural land to prices and dietary preferences (Popp et al., 2017).

Methods used to ensure food security can lead to negative environmental effects and thus are not sustainable. It is often assumed that food security is only possible with intensive agriculture in which food is produced with relatively low costs, at large quantities and on a relatively small area (Smyth et al., 2015). However, there is no consensus yet as to what kind of agricultural practices secure food supplies and it is likely that the methods that need to be used depend on the region in which the food is produced. Tscharntke et al. (2012) argue that "[..] agriculture practiced under smallholder farmer-dominated landscapes and not large-scale farming, is currently the backbone of global food security in the developing world." (p. 53). Nonetheless, most current food networks operate under the assumption that only intensive agriculture can ensure the food demand. However, intensive agriculture leads to environmental concerns, such as nitrogen and phosphor surpluses, water pollution, greenhouse gas emissions, biodiversity loss, (in)direct land use change, soil degradation and pollutants, due to the use of fertilizers, pesticides, unsustainable water use, and long transport distances (Kopittke et al., 2019; Meena & Mishra, 2020). In the Netherlands, in 2015, the nitrogen surplus was highest of all OECD countries with 189 kg nitrogen per hectare. In comparison, Estonia only had a surplus of 22 kg nitrogen per hectare (CBS, 2018). This is mostly due to livestock farming (Quemada et al., 2020). According to the Global Footprint Network (2019), already in 1970, the available resources were exploited in the world due to the environmental pressure of humanity on the global biocapacity. It is expected that this pressure will increase considering the growing global population and the corresponding aim to ensure food security (Tilman & Clark, 2014). Moreover, with increasing welfare, a further increase in consumption is expected (Global Footprint Network, 2018). This may lead to a larger impact on the environment by the agricultural section.

There are multiple sustainability goals proposed, for example by the IPCC and the UN, that aim to reduce the greenhouse gas (GHG) emissions and secure overall sustainability. An example is the Sustainable Development Goal (SDG) 2 'Zero Hunger'. This goal can only be met via sustainable food supply and when food security is provided (Blesh et al., 2019). Further research is needed into food farming and food networks related to the current and future use of agricultural land to get a better understanding on how to solve these issues. Especially since "[..] the agricultural sector is also one of the most vulnerable to climate change because of its effects on crop yields [..]" (Hansen et al., 2022).

1.1 Food networks in the Netherlands

The Netherlands is one of the largest agricultural producers in the world. It is estimated that the Dutch exported around 94.5 billion Euros worth of vegetables, fruit, flowers, meat, and dairy products in 2019 (CBS, 2020). The Netherlands excels in crop yield and rapid production processes (Viviano, 2017). Most of the Dutch agriculture could be categorized as a modern food system. These are systems in which yield is the starting point, large-scale operations are the standard, and the output is maximized (Hajer et al., 2016). Within these systems, producers export their products and/or sell to wholesalers and consumers buy food originating from all over the world. The conventional method of food systems in the Netherlands is getting criticized more for not being sustainable and is becoming untenable in the light of new sustainability goals, like the SDGs, the Paris Climate Agreements, and the Dutch Nitrogen policy. More concepts are appearing as an alternative for the modern food system; systems that try to produce food in a more sustainable manner. In the past two decades a new concept emerged in scientific literature called Alternative Food Networks (AFNs). AFNs can be described as a "[..] term to cover newly emerging networks of producers, consumers, and other actors that embody alternatives to the more standardized industrial mode of food supply." (Renting et. al., 2003, p. 394). However, this is a broad statement with few specifications. Research into AFNs discuss multiple characterisations, like sustainable farming and relations, and environmentally friendly.

1.2 Aim of the research

The concept of AFNs is increasingly becoming part of the academic debate and numerous characterisations of AFNs are mentioned in studies. Conversely, since the description is broad there is no unambiguous research about AFNs and the concept of AFNs can be broadly interpreted. One of the aims of this research is therefore to group the characterisations together to propose a general definition for AFNs. This allows a clear distinction to be made between AFNs and non-AFNs and ensures future research to be more precise. Therefore, this study analyses multiple (alternative) food networks and compares those to get more insight in AFNs as a concept. Next to this, a quantitative approach on the impact of AFNs is lacking. Most research focuses on the social and cultural aspects on a qualitative basis, but a more quantitative approach on environmental impacts is not widely researched. Often, it is stated that the impact on the environment is limited but the quantitative proof is lacking - this is also due to the broad interpretation of AFNs. Therefore, this study also aims to determine the environmental impact of AFNs regarding the transition to sustainable agriculture. As a region, consumption in the Netherlands is selected since the country has a lot of agricultural activity. The focus of this research is on arable land and horticulture. Livestock farming has been disregarded since the research gap is mostly within sustainable farming of AFNs in arable land and horticulture. This leads to the following research question: What is the potential contribution of AFNs in the transition to sustainable agriculture in The Netherlands from an environmental aspect?

To answer the main research question, multiple sub-questions are studied:

1. What are the current descriptions/definitions of AFNs?
2. What are the foremost and most likely environmental impacts of AFNs in the Netherlands and how do these compare to current agricultural practices?
3. What is the quantitative environmental evaluation of AFNs in the Netherlands?

By answering these sub-questions, ultimately the main research question is answered.

This research provides new insights for the possibilities of future sustainable farming. While providing a framework at which the AFNs can be identified, and their environmental impact can be quantified. Moreover, this research can possibly fill parts of the knowledge gap concerning sustainability of AFNs, since currently quantitative data is lacking. This may lead to knowledge on the role of AFNs within the sustainability goals of the Netherlands and the EU.

2. Theoretical background

2.1 Sustainable Development

Sustainable development was firstly mentioned in 'Our Common Future' in 1987 also known as the Brundtland report (Brundtland et al.). Here sustainable development is defined as:

> [..] development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts: the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs. (p. 41).

Over the past couple of years this definition has found to not be accurate enough anymore and has been adjusted by considering three pillars: social, economic, and environmental sustainability (Ghisellini et al., 2016; Purvis et al., 2019). The UN proposed a list of sustainable development goals in 2015, which focuses on the three pillars of sustainability. As a result, 17 SDGs have been formulated. Especially SDG 2.4, which is focused on ensuring sustainable food practices and resilient, productive agricultural practices, and SDG 12, which relates to sustainable consumption and production, are of importance for this research. This is because AFNs may have a role in obtaining these goals.

The current study primarily focuses on environmental sustainability, since social and economic aspects are already researched frequently regarding AFNs and the scientific knowledge gap is related to the former (Tregear, 2011; De Bernardi et al., 2019; Stephens 2021).

2.1.1 Environmental impact of agriculture

Any type of food system has impact on the environment, whether that is organic or conventional farming, or a modern or alternative food system. However, for conventional systems (i.e. intensive farming) this impact is mostly negative. Verma (2017) identified the following main environmental impact categories for agricultural practices: land conversion, wasteful water consumption, soil erosion and degradation, pollution, excess nutrients, climate change, and genetic erosion. In the Netherlands, most environmental impact is related to biodiversity decline, GHG emissions and eutrophication (Pluimers et al., 2000). Especially intensive monocultures on agricultural and/or aquacultural areas have large environmental impacts (WWF, 2021). These areas were often habituated by numerous animals and wild plants. However, intensive agriculture and the corresponding monoculture disturb the ecosystems which leads to local and global environmental problems (Verma, 2017). In addition to the problem of monocultures, the focus of most modern farmers lies on crop yields. Which, according to soil expert Andreas Fließbach (2021), should not be the starting point. Fließbach rather speculates that soil quality should be the starting point. The soil quality is strongly influenced by the use of pesticides, artificial fertilizers, heavy machinery and tilting. It is expected that the crop yield increases with the use of the latter. Still, there is no consensus regarding the latter (Gagic et al., 2017). Fließbach argues that farming without those products is proven to be more economical feasible and benefits the soil quality, which has a positive impact for the long-term sustainability and productivity of agriculture. He does state that the yield is on average 20 percent lower than with conventional farming, in which fertilizers and pesticides are used. Conversely, by not investing in the latter, the proceeds are higher.

Water

Water resources in the Netherlands are vulnerable, because of high population density together with intensive water use for both industry and agriculture. Water is used on a large scale for intensive farming practices in the Netherlands. Already, pesticide residues are found in the groundwater. This leads to high costs to purify the groundwater to make the water suitable as drinking water (Schipper et al., 2008). In the study by Sjerps et al. (2019), it was found that in two out of three water abstraction areas pesticides and/or metabolites were detected. Also, half of the time the concentrations exceeded the water quality standards.

The water that is consumed for agricultural practices in the Netherlands is mainly green water. Out of over fifteen countries studied by Ercin et al. (2011), in ratio the Netherlands uses the most green water (rainwater) whereas other countries often use more blue water (surface water and ground water) which is less sustainable. However, during periods of drought, blue water is used in the Netherlands as well. As a result, determining the sustainability of water use for certain crops is challenging.

Land

For land use, the main challenge is about the balance between preserving the environment and the production of high yields (Aznar-Sanchez et al., 2019). Since the Netherlands mostly focuses on intensive agriculture, optimizing yield by applying fertilizers and pesticides is the main goal. However, this leads to exhaustion of the ground and makes the soil unusable for a certain amount of time because of the effect the fertilizers and pesticides have on the microbial properties of the soil (Prashar & Shah, 2016).

Global warming

Global warming is caused by the emission of greenhouse gases. These greenhouse gases results in an increased greenhouse effect, causing the global temperature to rise. The latest IPCC report (2022) state that the temperature increase should be limited to 1.5 degrees Celsius above pre-industrial levels. The report states: "Human-induced global warming has slowed growth of agricultural productivity over the past 50 years in mid- and low latitudes (medium confidence)." (p.14). While at the same time, agricultural practices are also partly responsible for global warming, with the use of machinery, transportation, irrigation process, etcetera. Packaging of the produce is also debated since mostly single-use plastic are used, which causes multiple issues, like micro-plastics, greenhouse gas emissions, litter, and potential biodiversity loss (Schwarz et al., 2019; Schymanski et al., 2018).

Eutrophication

Yang et al. (2008) have defined eutrophication as follows:

> Eutrophication can be defined as the sum of the effects of the excessive growth of phytoplanktons leading to imbalanced primary and secondary productivity and a faster rate of succession from existence to higher serial stage, as caused by nutrient enrichment through runoffs that carry down overused fertilizers from agroecosystems and/or discharged human waste from settlements [..]" (p.198).

Eutrophication is influenced by, among other things, agricultural practices, and the high use of nutrients which runoff into local water bodies. Eutrophication occurs in marine water and in freshwater systems. The indicator for both is rather different, marine eutrophication is indicated as kg N-eq and freshwater eutrophication is indicated as kg PO_4^{3-}-eq.

Biodiversity decline

One of the most damaging aspects to global biodiversity loss is the use of fertilizers and pesticides and the intensification of local agricultural practices (Gonthier et al., 2014). Furthermore, more than 75 percent of food crops are dependent on pollination by insects and other animals (Sustainable Footprint, 2012). With the loss of biodiversity, the functioning of ecosystems is impacted, and food security is at risk (Pilling et al., 2020).

Soil quality

As Prashar and Shah (2016, p.333) state: "Apart from its most widely known role as a medium for plant growth soil performs many other vital functions such as mediating the exchange of gases, flow of energy, nutrients and water, detoxification of pollutants and many other [..]". The soil quality is of great importance since healthy soil can store and process larger quantities of water. Also, the soil quality determines whether revegetation is possible (Lasanta et al., 2020). Soil quality has numerous indicators, such as erosion, compaction, salinization, texture/structure, change in soil organic matter, and pesticide and fertilizer use (Garrigues et al., 2012; Soto et al., 2020).

The soil in greenhouses can be very diverse, e.g. sand, clay, or loamy soil. All have different impacts on the environment and different advantages and disadvantages (Zhou et al., 2021).

2.2 Agriculture in the Netherlands

As stated earlier, agricultural practices and most food networks in the Netherlands are modern/conventional. Within this modern food system multiple sectors can be identified. This is represented in Figure 1. This research focuses on arable land and horticulture. The Dutch agricultural industry holds numerous sectors which all have their own approach regarding innovation and sustainability. Research by Diederen et al. (2002) state that innovation in the agricultural sector is not organized collectively; the individual farmer coordinates their own innovative solutions. Integrated vision on sustainable food systems is needed to stimulate change. Policies, like 'sustainable crop protection', have collectively obligated the farmers to reduce their environmental emissions, use of pesticides, the impact on water quality, and impact on biodiversity (Rijksoverheid, 2013). Nonetheless, these policies are not always combined with subsidies to realize effective alternatives. As a result, there are rising concerns about sustainability and durability of the agricultural land and its practices. Assessing different food systems that could address the impact of agricultural practices in the Netherlands, is of importance to be able to farm sustainably in the future.

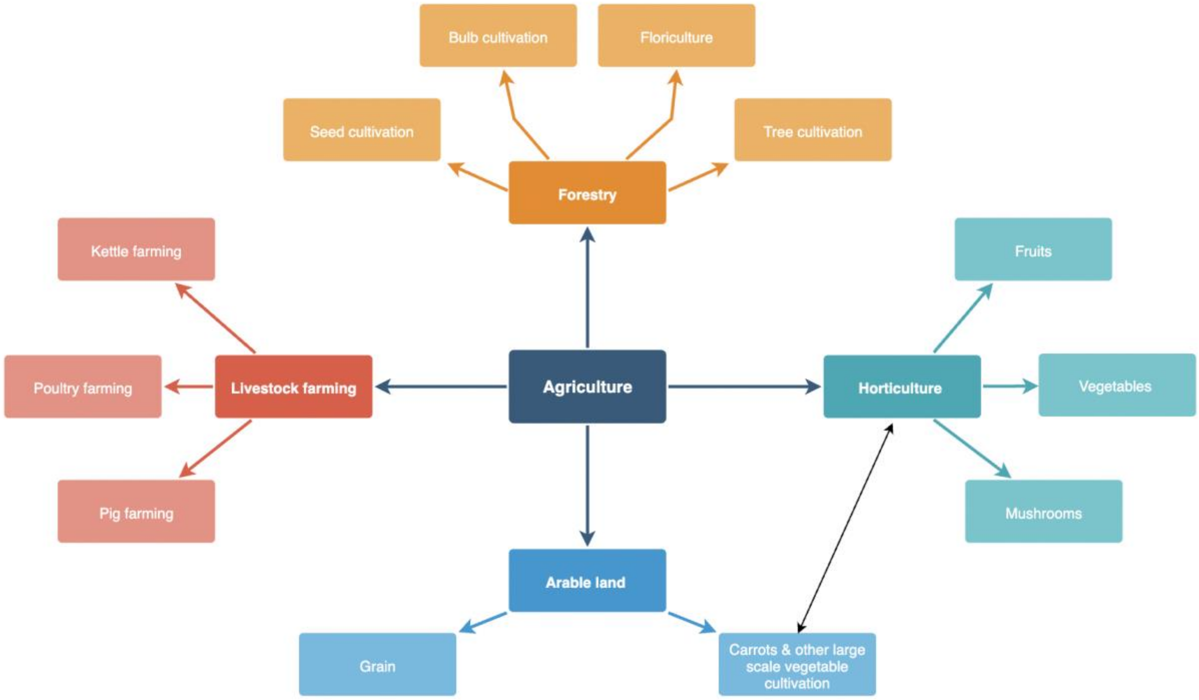

Figure 1. Broad overview of sectors that are part of the Dutch agriculture including forestry, horticulture, arable land, and livestock farming.

2.2.1 AFN definition and types

As discussed in the Introduction, the concept of AFNs is not unambiguous. There are multiple characterisations and descriptions of AFNs circulating in scientific literature and researchers differ in their approaches and motivation for how AFNs can be defined (Chiffoleau et al., 2016). For example, Edwards (2016) found that AFNs are commonly produced locally, and thus make use of short food supply chains (SFSC), that there is a trusting relationship between producers and consumers and that the quality of the products is assured. Therond et al. (2017) state that AFNs can also be on a global scale, as well as local and regional. Conversely, most of the literature state that AFNs make use of SFSC, therefore this will be the starting point of this research. Therond et al. (2017), just as Edwards (2016) stress that food has multiple forms of value, beside the market price. Goodman et al. (2011) and Therond et al. (2017) point out that AFNs address issues like animal welfare and environmental conservation.

In contrast to Goodman et al. (2011), Chiffoleau et al. (2016), Edwards (2016), and Therond et al. (2017), Poças Ribeiro et al. (2021) identified multiple types of AFNs based on their organizational logic and characteristics. They share the same understanding of AFNs as Edwards (2016). They state that AFNs can be 'Consumer-led', 'Producer-led', 'Community-supported', 'Business platform', 'Third-sector-led', and 'Public led'. The different identified types are presented in Table 1 along with their description. According to their research, the types that are most present in the Netherlands are Third-sector-led, Consumer-led and Business platform.

Table 1. Types of AFNs and their corresponding description according to Poças Ribeiro et al. (2021).

Types of AFNs	***Description***
Consumer-led	Informal groups of people who organize themselves to order food directly from farmers.
Producer-led	Farmers who find ways of selling directly to consumers.
Community-supported (CSAs)	Groups of people who have a joint commitment with a farmer, who is paid in advance (for a year or a season), for the produce.
Business platform	Online for-profit web platforms working as marketplaces where consumers can order specific produce from regional farmers, and then get it delivered to their homes or to a pick-up location.
Third-sector-led	Non-profit, formally instituted associations and cooperatives (of consumers or farmers) that organize in various ways an exchange between producers and consumers.
Public-led	Non-profit initiatives organized by public entities that facilitate direct sales from regional farmers, in various ways.

2.2.1.1 Environmentally sustainable practices and circular food systems

According to the Ellen Macarthur Foundation (2019), circular food systems are the only way to go from the 21st century and onwards to combat the negative results of linear food systems that exploits "[..] finite resources, is wasteful and polluting, and harms natural systems."(p. 8). They state that agriculture based on the principles of circular economy, Box 1, results in "healthy and stable soils, improved local biodiversity, and improved air and water quality". It facilitates the combat against food waste, helps build natural capital, and allows nature to thrive. It therefore could stimulate solving problems of biodiversity decline, intensification, and manure problems. In modern food systems, the soil is being exhausted, while circular food systems could preserve the soil and may even improve the environment. This also supports the Dutch (local) government(s) to reach their goal of becoming a circular economy by 2050. LNV (ministry of agriculture, nature, and food) pleads for a circular agriculture (CA) already by 2030 (LNV, 2019). CA is also a concept proposed by the Wageningen University in 2018 that entails a new perspective for the Dutch agriculture. They define the concept as follows:

> Circular agriculture is a collective search by farmers, interested citizens, businesses, scientists and researchers for the optimum combination of ecological principles with modern technology, with new partnerships, new economic models, and credible social services. It not only focuses on good yields and the sparing use of resources and energy, but also stresses the importance of putting as little pressure on the environment, nature and climate as possible. (WUR, 2018, p. 4).

Holster et al. (2014) also state that circular agriculture strives for minimizing negative impact on the environment and nature and has a long-term local vision. Most research focuses on biomass for production of energy, as part of circular agriculture (Barros et al., 2020). Nonetheless, Smits and Linderhof (2015) belief that circular agriculture can be more extensive and innovative. They recognize two types of cycles; internal and external, and they describe multiple examples just as aquaponics (internal), cycle farmers (internal), polydome (internal), permaculture (internal), break down residual flows (external), and not breaking down residual flows (external). Smits and Linderhof (2015) affirm that residential flows can be put directly as input for production without 'breaking it down first', as is the case with, for example, mushroom cultivation or animal feed. They also argue for creating internal cycles, in which Nitrogen (N_2), Phosphorus (P) and Carbon (C) can be reused. Within circular agriculture practices, the soil is vital as it can reduce the need for external input. Circular agriculture aims to be as efficient as possible while handling raw materials. At the same time, it reduces the need for fossil-based energy inputs considering the biomass can be used for energy production on the farm itself as well.

Parts of this can also be identified within AFNs. Therefore, AFNs might even help reach the Netherlands the goal of having a circular economy, since the Dutch food systems are part of the circularity goals of the Dutch government and investing and analysing the potential of AFNs could be a step in the right direction.

Box 1: A Circular economy (CE) is opposing to the linear economic system. For this study, the following definition, based on the frequently cited research, for the circular economy is utilized:

> Circular economy is an economy constructed from societal production-consumption systems that maximizes the service produced from the linear nature-society-nature material and energy throughput flow. This is done by using cyclical materials flows, renewable energy sources and-type energy flows. Successful circular economy contributes to all the three dimensions of sustainable development. Circular economy limits the throughput flow to a level that nature tolerates and utilises ecosystem cycles in economic cycles by respecting their natural reproduction rates. (Korhonen et al., 2018, p.39)

This definition was constructed by considering the three pillars of sustainable development and poses a perspective for circular agriculture. CE can be seen as a mean to end, to reduce the pressure on the environment by closing the loop of material resources and lengthen the product life and minimize waste; the output of a system can be viewed as valuable input in that same system. Therefore, CE can help support the SDGs. The Ellen Macarthur foundation, a private foundation that makes impact investments and grants to support non-profit organisation, makes a distinction between flows of biobased products and materials, as is pointed out in Figure 2. A circular agriculture (CA) can be part of a circular economy, which thus focuses on the left side of the figure.

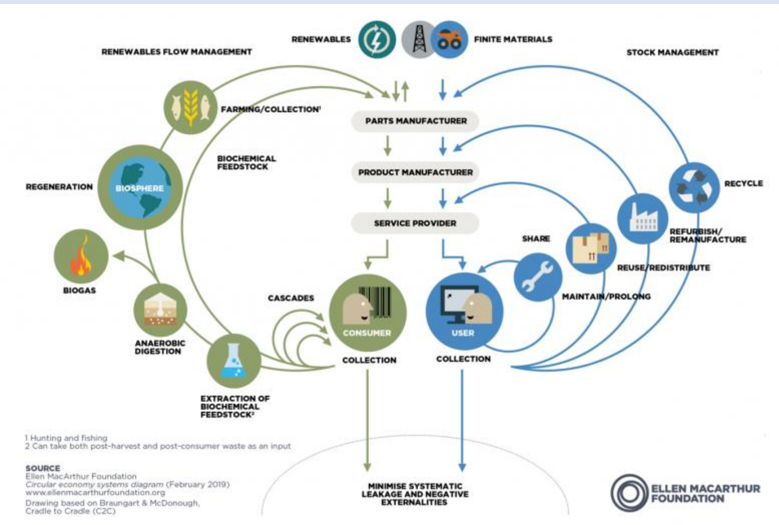

Figure 2. Circular economy systems diagram by Ellen Macarthur Foundation (2017).

3. Methodology

This study is subdivided into two phases. The first phase consisted of the identification of AFNs in the Netherlands, and the second phase of an environmental impact assessment of these AFNs. These phases will be elaborated upon in the next paragraphs. Figure 3 visualises the research framework. The output of the first phase was used as input for the next phase of the research.

Figure 3. Research framework showing the different phases of this research. The squares indicate the method of data gathering in each phase. The green figures show the assessment that is performed with the gathered data. The outcomes of the first phase are used as input for the second phase.

3.1 Phase 1 Identification of AFNs in the Netherlands

The first phase consisted of data gathering about AFN characteristics and definitions, and of the identification of AFNs that are present in the Netherlands. This was done by analyzing existing literature and by interviewing stakeholders of selected AFNs.

3.1.1 Data gathering

As described in Figure 3, gathering the data consisted of two methods: extensive literature analysis and semi-structured interviews.

In the **literature analysis**, specific data from (scientific) literature was utilized to identify the different types of AFNs in the Netherlands. This data consists mostly of (international) scientific literature and Dutch government reports. This data was obtained using the keywords as presented in Table 2. The keywords were sometimes combined to have an optimal search result. Moreover, the references from used literature were evaluated and studied. Specific to this phase is that data concerning the characteristics of AFNs was gathered.

Table 2. Keywords, source type and its corresponding search engine used for the literature analysis.

Source content	***Keywords***	***Source Type***	***Search Engine***
AFNs food production in general and the different types of AFN	AFN, Alternative Food Networks, definition of AFN	Articles & Books	Google Scholar & Science Direct, Scopus
General and specific data: Circular economy	Circular economy	Articles & Books	Google, Google Scholar, ScienceDirect
General and specific data: Sustainable development	Sustainable development, Sustainability	Articles & Books	Google, Google Scholar, ScienceDirect, Scopus
General and specific data; Environmental impact	Climate impact, environmental impact	Articles & Books	Google Scholar & ScienceDirect, Scopus
General and specific data; Environmental impact category; Water use	Water, water use, water footprint, water demands, horticulture water use	Articles & Books	Google Scholar & ScienceDirect, Scopus
General and specific data: Environmental impact category; Land use	Land, Land use, (In)direct land use	Articles & Books	Google, Google Scholar, ScienceDirect, Scopus
General and specific data: Environmental impact category; Global warming	Global warming, Climate change, CO2-eq emissions (horticulture)	Articles & Books	UU Library, Google, Google Scholar, & ScienceDirect, Scopus
General and specific data: Environmental impact category; Eutrophication – freshwater & terrestrial	Eutrophication, nitrogen, ammonia, phosphor, water pollution, land pollution	Articles & Books	UU Library, Google, Google Scholar, & ScienceDirect, Scopus
General and specific data: Environmental impact category; Soil quality	Soil quality, fertilizers, pesticides, water storage, revegetation	Articles & Books	UU Library, Google, Google Scholar, & ScienceDirect, Scopus
General and specific data: biodiversity	Biodiversity, PPP	Articles & Books	UU Library, Google, Google Scholar, & ScienceDirect, Scopus

Next to the literature analysis, **semi-structured interviews** were executed with multiple stakeholders to get insight in the different AFNs that are present in the Netherlands. These organisations/companies have been selected based on the six AFN types as identified by Poças Ribeiro et al. (2021). For five AFN types, stakeholders have been selected. Only for public-led AFN, no organization has been found. Furthermore, the selection was made based on the description of the different AFN types and organizations that fulfilled these descriptions. Moreover, organizations were selected that are near the area of the Utrecht because of travel restrictions due to COVID19. By executing these informative semi-structured interviews, the characteristics in which the AFNs were described and other general information about AFNs became apparent. The questionnaire used can be found in Appendix A, as well as the transcripts. The stakeholders are displayed in Table 3. The interviews were held in either Dutch or English, depending on the interviewees' preference. When the interview was held in Dutch, the findings were translated to English.

Table 3. Overview of Interviewees/organizations interviewed for this thesis.

Stakeholder	***Type of AFN***
Local2local	Business platform, third-sector-led
Groentetas	Third-sector-led
VOKO	Consumer-led
Aquaponics farmer	Producer-led
Herenboeren	Community-supported (CSAs)[1]

Local2local (L2L) is an organization located in Houten, that has the ambition to reconnect consumers and farmers. They believe that the current dominant food chain strategy of high volumes at the lowest possible costs is no longer tenable. They want to focus on regional food chains and transparency for their customers. **Groentetas** is an organization run by volunteers, that provides weekly vegetable bags filled with local, seasonal, and biological products. They have a stand in the city centre of Utrecht and one on the campus of the Utrecht University. **VOKO** is a collective, located in the centre of Utrecht, that is run by its consumers/volunteers and that wants to provide customers with local, fresh, seasonal, and environmentally friendly products. The **Aquaponics centre** is an organization that produce their products in an aquaponics system and sell them directly to consumers and restaurants. It is an indoor centre where vegetables, fruit and herbs are produces on water, of which the nutrients come from fish excrement. The produce is grown indoors and therefore the produce is not dependent on the seasonal changes of the Netherlands and can thus grow independent of the season. Lastly, **Herenboeren** is a civil movement that runs cooperative farms, which gives the community shared ownership. They are located throughout the Netherlands. They believe that the production of food can be different and more sustainable.

3.1.2 Identification of AFNs

After the data were obtained, similarities and differences in interpretation of the multiple AFNs were studied. Multiple examples and definitions were analysed, and different (potential) indicators were determined. Per frequently occurring characteristic as found in literature and mentioned by the interviewees, it was shown whether the interviewed

[1] On December 8, 2021, Team Herenboeren Nederland stated they do not have the capacity to hold an interview but affirmed that all their information can be found on their website, therefore statements and information regarding this AFN has been collected from: https://www.herenboeren.nl/

organisation recognizes their AFN with these characteristics. Also, based on the information given by the interviewees, indicators were found to identify whether an organisation/business can be considered an AFN. By combining the characteristics/indicators that most AFNs recognize themselves in, a general definition was proposed to stimulate unambiguous communication about the AFNs. Other AFNs were checked for the same indicators using the information stated on their websites.

3.2 Phase 2 Environmental impact assessment

Phase 2 consisted of quantitative data gathering and an environmental impact assessment of the AFNs as part of the overall sustainability of AFNs. In the Environmental impact assessment, the following indicators were studied: energy use, land use, pesticide use, fertilizer use, GHG emissions, and water use. The following sections explain the assessments in more depth.

3.2.1 Data Gathering

As described in Figure 3, gathering the data consisted of three methods: Literature analysis, semi-structured interviews, and data analysis.

The **literature analysis** was executed by using the search terms as described in Table 2. It was specifically used to gather data that can be used as input for the Environmental impact assessment of AFNs. Search engines like Google scholar, Science Direct and Scopus were used to find the data.

Next to that, **semi-structured interviews** were, again, used to collect data that can be used as input for the Environmental impact assessment. These are the same interviews that were used for input in Phase 1. The outcome of the interviews provided quantitative and qualitative data respecting biodiversity, soil quality, land use, GHG emissions, use of fertilizers, use of pesticides, and water use.

Furthermore, to perform the environmental impact assessment, **data** provided by Blonk Consultants was **analyzed** (RIVM, 2021). Blonk Consultants is a consultancy that advises businesses and the government on environmental and sustainability issues related to the agri-food sector. They provide databases about agricultural footprints based on life cycle inventories that can be used to make calculations about the food networks. These databases are used for the Dutch government, which help substantiate the outcome of this research. The database used in this research contains 250 different foods, for which the environmental impact is calculated via Life Cycle Inventory (RIVM, 2021). Their database was selected because within the limited databases that are available this is the most extensive and complete database.

3.2.2 Environmental impact assessment

To determine the environmental impact of the produce, a Life Cycle Assessment (LCA)-based approach was applied to calculate the impact of 1 kg of produce during its life cycle. Therefore, for the selected AFNs in the Netherlands, their whole networks were analyzed for environmental indicators. The impact categories according to the Nordic Guidelines on LCA were used (Baumann & Tillman, 2004), which include Water, Land, Global warming, Eutrophication, and Acidification. These are displayed along with their units in Table 4. These impact categories were selected based on the findings of multiple peer-reviewed studies as stated in the Theoretical Background (Verma, 2017; Pluimers et al., 2000). Moreover, the impact on biodiversity loss was researched by doing qualitative research. The soil quality was also determined by studying the number of fertilizers and pesticides used, and the interpretation the stakeholders have of the quality of the soil that is used to produce the produce they sell. A reference scenario was used to determine the net environmental impact of the AFNs relative to conventional food systems. This reference scenario is based on the agricultural practices of a conventional farmer. For the impact category Water, a distinction is made between 'green water', and 'blue water'. This was based on the results of the semi-structured interviews; an assumption is made about the distribution of the different types of water.

Table 4. The impact categories 'Water', 'Land', 'Global warming', 'Eutrophication', 'Acidification', their indicators, and corresponding units.

Impact category	***Indicator***	***Unit***
Water	Water demand	L
Land	Land use change	m^2
Global warming	CO_2, CH_4, N_2O	kg CO_2-eq
Eutrophication freshwater	PO_4^{3-}	kg PO_4^{3-}
Acidification	SO_2	kg SO_2

The scope of this research is from the moment the produce is planted, until a consumer buys the produce (cradle-to-gate), this is represented in Figure 4. For each step in the network, the different inputs and outputs were analyzed corresponding to the impact categories. As can be seen in Figure 4, there are different phases that can be identified depending on the AFN type. The inputs and outputs of the production phase and storage/distribution phase were found using the databases and existing literature. The input and output of the transportation phase was calculated based on the findings of the interviews, using equations which are explained at the end of this section. Poças Ribeiro et al. (2019) state that food waste levels in the AFNs is very low in comparison to conventional food systems. Food loss is defined as "a decrease in food quantity or quality in the early stages of the food supply chain, reducing the amount of food suitable for human consumption." (Gustafsson, 2013, p. 3). Food scraps, unconsumed food and food waste are not considered in this research since it is not significant and due to time constraints.

The environmental impact assessment focuses on two vegetables, mainly tomatoes and carrots. This research concentrates on tomatoes grown for direct consumption, disregarding tomatoes grown for processing in the food industry (tomato ketchup, puree, etc.). Both tomatoes and carrots are commonly consumed in the Netherlands (van Stokkom et al., 2016). Furthermore, tomato production was selected because all organizations, except for VOKO, provide tomatoes to their consumers. The tomatoes are produced in greenhouses and therefore, the availability is more flexible instead of strictly seasonal. These greenhouses are heated using fossil energy, thereby emitting a lot of greenhouse gases (Högberg, 2010; Blonk Consultants, 2018). The Netherlands also imports their tomatoes from Spain, so the production of tomatoes in Spain is also analyzed, taking into consideration the transportation and storage of these tomatoes. Moreover, mostly high-tech production systems are used in the Netherlands, for both conventional and organic production. In organic systems, there is limited use of artificial lightning, which can only be used for plant propagation. Both systems make use of heating.

Carrots are produced in the Netherlands and are available throughout the whole year. As with the tomatoes, only carrots grown for direct consumption are studied. Also, carrots are selected because all AFNs, except Aquaponics centre at this moment, can provide these, but they are solely sold when the produce is in season. The conventional food system sells carrots all year. Therefore, for the conventional food systems carrots produced and stored in the Netherlands were analyzed. Table 5 shows the average yield, and the harvest season for the tomatoes and carrots in both the Netherlands (organic and conventional) and Spain (AGF, 2021; Karlsson, 2012; Zhou et al., 2021).

Table 5. Yield and harvesting season of tomatoes and carrots in the Netherlands and in Spain.

	Tomatoes NL – conventional	*Tomatoes NL - organic*	*Tomatoes Spain*	*Carrots NL - conventional*	*Carrots NL - organic*
Yield (kg m^{-2} $year^{-1}$)	90 -100	50	14	61	n/a
Harvest season (weeks)	48	25-33	36	24	20

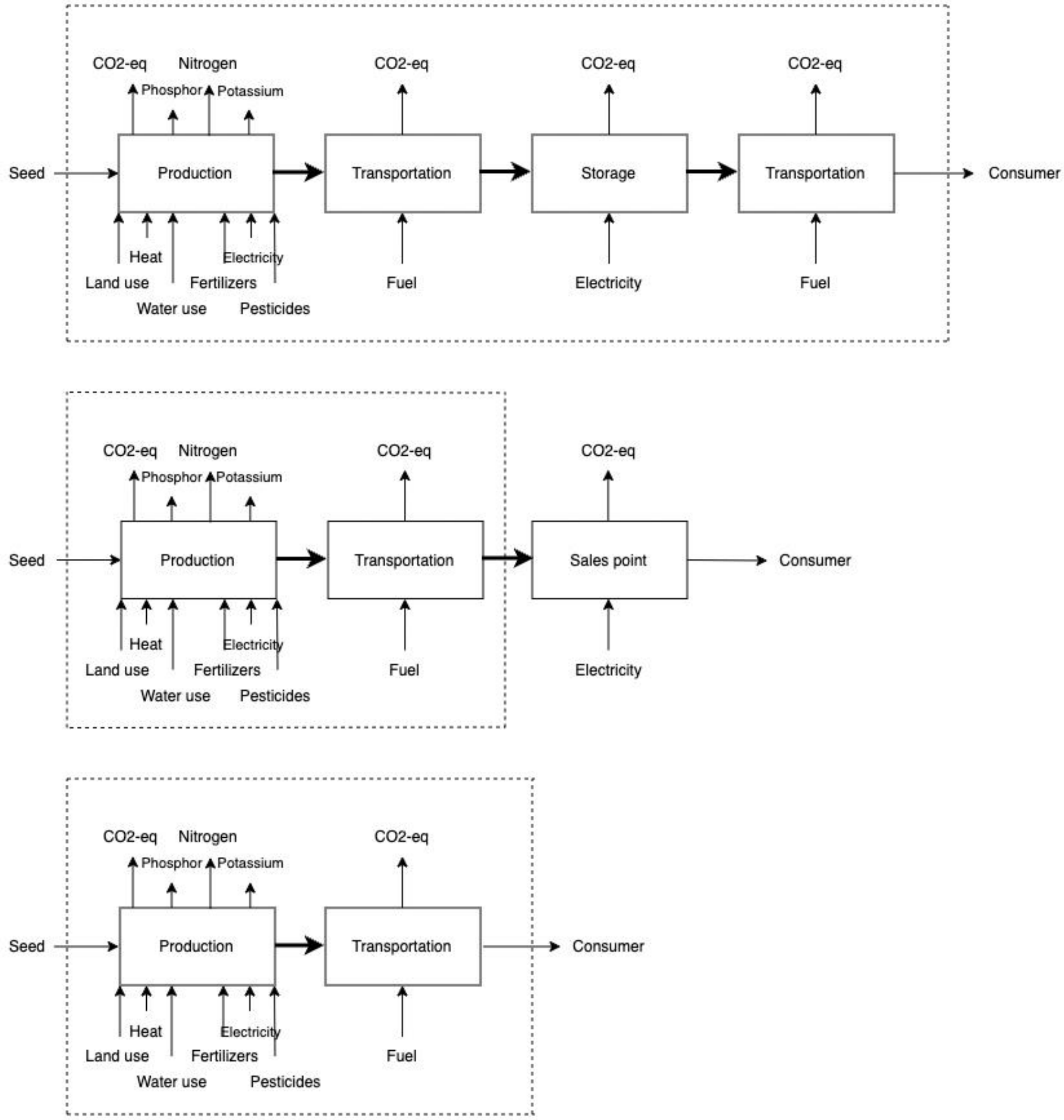

Figure 4. System boundaries for AFNs showing the inputs and outputs for each phase of the network. The top figure shows the boundaries for a conventional system, the figure below represents VOKO, Herenboeren, Aquaponics, and Groentetas. The last figure represents Local2Local.

Equations for CO_2-eq emissions

To calculate the fuel input (F) in liters, Eq. (1) is used.

$$F = V * C * D \qquad (1)$$

In which V stands for the share of 1 kg tomatoes in the vehicle that is used, this is multiplied with the fuel consumption (C) for the total distance in liter/kilometer, and with the distance (D) in kilometers. This is calculated per phase in the network; Groentetas uses small trucks run on Diesel, VOKO uses passenger cars, mostly gasoline, Aquaponics uses bicycles, L2L uses small trucks run on Diesel, and Herenboeren lets their consumers pick up the produce, which is done by car (gasoline) or by bike. The corresponding GHG emissions can be calculated using Eq. (2).

$$CO_2eq = F * E_f \qquad (2)$$

In this equation E_f is the emission factor in kg CO_2-eq/L. The assumed emission factors can be found in Table 6.

Table 6. Emission factors per energy source; Gasoline and Diesel, with their corresponding unit (RVO, 2020).

Energy source	*Emission factor*	*Unit*
Gasoline	2.9	kg CO_2-eq/L
Diesel	3.2	kg CO_2-eq/L

Biodiversity

Besides the impact categories stated in Table 4, biodiversity loss is one of the largest issues of the Dutch agriculture (Dudley & Alexander, 2017). Since biodiversity cannot be assessed by performing LCA-based research, the semi-structured interviews and scientific literature were used to provide insight on the impact a certain network has on biodiversity preservation. Biodiversity was a qualitative aspect of this research.

Soil quality

The soil quality was also qualitatively approached because of its difficulty to represent its impacts in an LCA framework. It remains an unresolved problem in LCA "[..] because of soil's spatial and temporal variability and the complex interactions among soil properties." (Garrigues et al., 2012, p. 343). The latter has proposed a method to integrate the soil quality, however, this is not widely assessed and time consuming. Accordingly, most of the AFNs make use of biological/organic farming in which no or little pesticides are used. Therefore, the outcomes of the interviewees also determined the soil quality.

3.2.3 Assumptions

Table 7 presents the key assumptions used in this research. It also states for which part of the research the assumption had influence on.

Table 7. Key assumptions used in this research with their description and, if applicable, a source to back up the assumption.

Key assumptions	*Type of assumption*	*Description*	*Source*
Distance to supplier	EIA: global warming	The distance from supplier to consumer is taken as an average of the minimum and maximum distance.	N/A
Transportation VOKO	EIA: global warming	Consumers from VOKO get their produce by bike since it is in the city centre.	S. van Kempen (Personal communication, December 13, 2021)
Oversea distance	EIA: global warming	One production location in Spain is considered, and the distance from Spain to the Netherlands is therefore constant.	RUG (2021); Karlsson (2012)
Packaging	EIA: global warming	Packaging is either reusable plastic crates or fully plastic, LDPE, packaging.	RUG (2021); Abbate et al. (2022); Del Borghi et al. (2021)
Indicator selection for EIA	General	Water, land, global warming, eutrophication, soil quality and biodiversity are the most important ones when determining the environmental impact in agricultural practices.	Verma (2017)
Organic vs not organic	General	Some AFNs do not have an official organic trademark, however in practice they are organic and therefore they are approached as organic.	N/A
Greenhouse system	General	Greenhouses have either low-tech systems or high-tech systems. This thesis focuses on high-tech greenhouses since most farms in the Netherlands are high-tech.	Zhou et al. (2021)
Consumption type	General	A distinction can be made between direct consumption or processing function. This thesis focuses on direct consumption.	Zhou et al. (2021)
Research boundaries	General	The cultivation phase is not taken into account, solely	N/A

		from the moments the plants are growing until the vegetables are bought/consumed.	
Vegetable consumption	EIA: global warming	An average family of four eats around 7 kg of vegetables and fruit per week. Of which 1 kg is tomatoes.	N/A
Herenboeren transport	EIA: global warming	The co-owners/consumers from the Herenboeren farms come get their produce with passenger cars.	N/A
Type of tomato and carrot	EIA	There is no distinction made between different types of tomatoes and different types of carrot.	N/A
Energy requirement	EIA: global warming	Energy requirement is including transportation of electricity, thus primary energy & Dutch efficiencies.	N/A

4. Results

4.1 Identification of AFNs

Table 8. Characteristics/indicators for the AFNs L2L, Groentetas, VOKO, Herenboeren and the Aquaponics centre, derived from literature and as stated in the semi-structured interviews.

	L2L	Groentetas	VOKO	Herenboeren	Aquaponics centre
Conserving environment/ environmentally friendly	✓	✓	✓	✓	✓
Focus on preserving biodiversity	✓	X	✓	✓	N/A
Circularity	~	~	N/A	✓	✓
Transparency	✓	✓	✓	✓	✓
Short food supply chains	X	✓	✓	✓	✓
Fresh products	✓	✓	✓	✓	✓
Contact with consumers	✓	✓	✓	✓	X

Alternative food systems as a concept have been established somewhere in the end of the 1990s and the beginning of the 2000s. Since then, no general definition of AFNs has been proposed. When the concept appeared in scientific literature, it mostly stated there is a need for alternative food systems as opposed to conventional food systems. The concept has recently gained more attention because more research is conducted.

The concept has different characterizations in various studies. Therefore, multiple studies were analysed for their characterizations, which can signify as indicators. The characterizations that were mostly reoccurring in literature were 'transparency' (Brinkley, 2018), 'short food supply chains' (Fourat et al., 2020; Ribeiro et al., 2019), 'contact with consumers' (Brinkley, 2018; Fourat et al., 2020), and 'fresh products' (Ribeiro et al., 2019; Kajzer Mitchell et al., 2017). Since there is no general definition for AFNs, for this study the characteristics/indicators mostly mentioned in literature and by the interviewees are presented in Table 8. Per interviewee it is shown whether that AFN recognizes itself fully, partly, or not with that characterization/indicator (tick, tilde, cross); the transcripts of the interviews can be found in Appendix A. Circularity, biodiversity and preservation of the environment are added to the indicator list since those are becoming more important in the food systems in the Netherlands as explained in Chapter 2.

All interviewees describe that they are working towards a more **environmentally friendly network** and focus on preserving local **biodiversity**. However, since most organisations are non-profit and managed by volunteers, they all state that it is sometimes hard to secure this ambition. Also, methods to quantify whether farmers make use of environmentally friendly farming methods are lacking. Not one of these AFNs have binding agreements with the farmers regarding environmental sustainability. For example, Local2local stated that right now, they have a gentleman's agreement when a farmer joins their community, that the farmer will put effort to preserve biodiversity and maintain or improve the quality of the soil.

Herenboeren state that their organisation is focused on 'working together with nature' and having lots of diversity in their products - simultaneous cultivation - and farming methods. The Aquaponics centre also prioritizes biodiversity, but since it is a closed system, the production of crops does not cause concern for the local biodiversity. VOKO also state that they do not have 'hard agreements' regarding biodiversity and preservation of the environment.

Circularity as indicator has various outcomes; the Aquaponics centre and Herenboeren strive to be as circular as they can be. Aquaponics is structurally circular by reusing the water and nutrients and having a system that is balanced out with the needs for the fish and the crops. Herenboeren makes use of perennial crops and state that, at least one of their farmers is fully circular. However, it is not explained what this entails exactly. On their website they do explain that the farm is diverse (livestock, fruit, vegetables) and that everything is "cooperative with each other". This is different than how Groentetas approaches the circularity aspect. They do not focus on circularity during the production phase, but rather while selling the produce to the consumers by using crates as only type of packaging, and letting the consumers bring their own bags. Furthermore, all interviewees stated that circularity is an important issue to them, and that they try to adjust their networks in such a way that it is as circular as possible.

All interviewees affirm that all their products are **fresh**, that **transparency** within the network is important, and that they make use of **short food supply chains**. The spokesperson of L2L affirmed that transparency and connection between all parties is the most important aspect of an AFN. That way, farmers can respond to consumer wishes and the environmental impact can be reduced (M. Klop, personal communication, November 9, 2021). Also, **interaction and contact** between consumers, organisation and producers is stated to be important. VOKO, as well as L2L, claims they think this interaction is one of the most important aspects for their organisation. The interviewee of the Aquaponics centre has not particularly spoken about interaction with their consumers but has spoken about their desire to teach people about aquaponics and the benefits of this system (D. Herrewijnen, personal communication, October 20, 2021).

Besides the information provided by the interviewees, other examples of AFN types have been analysed as well. A carbon farm in the Netherlands, which is a new way of farming to sequestrate carbon in the soil that would have otherwise ended up in the atmosphere (European Union, n.d.), which can be identified as producer-led AFN, also indicates that a different approach to producing food is necessary and concentrates mostly on alternative farming. Next to that, Voedselcoop, an example of a consumer-led AFN, mostly focuses on gathering data, being transparent and maintaining short food supply chains.

By combining the information given by the interviewees and studies, a new definition can be proposed, extended from the existing characterizations and descriptions:

An Alternative Food Network is a food network that opposes the conventional modern food networks. It is a system that operates within short supply chains, in which food is produced and sold locally and fresh. There is an intent to preserve the environment and there is more emphasis on preservation of biodiversity. Transparency within the network is essential and there is active interaction between all parties within the network

4.2 Environmental impact assessment

The environmental impact of each AFN type is calculated for 1 kg of tomatoes and 1 kg of carrots. The results are presented per type of AFN and per vegetable.

4.2.1 Tomato – AFN

Table 9 and 10, show the results of the environmental impact assessment for the producer-led AFN, represented by Aquaponics training centre, the Business platform AFN, represented by Local2local, the Third-sector-led AFN, represented by Groentetas, Consumer-led AFN, represented by VOKO, and the Community-supported AFN, represented by Herenboeren, for 1 kg of tomato in the Netherlands.

Table 9. Impact categories per kg of tomato for the AFNs Aquaponics centre, L2L, Groentetas and Herenboeren.

Impact categories	***Quantification***			
	Aquaponics	L2L	Groentetas	Herenboeren
Nitrogen emissions (kg N/kg/y)	n/a	1.01E-03	1.01E-03	1.01E-03
Global warming (kg CO_2-eq)	1.65	1.32	1.30	1.28 - 1.54
Acidification (kg SO_2-eq)	n/a	0.0356	0.0356	0.0356
Freshwater eutrophication (kg PO_4^{3-} -eq)	n/a	5.00E-04	5.00E-04	5.00E-04
Land (m^2)	0.02	0.02	0.02	0.02
Water (L)	60	22	22	22

Table 10. Input for production of tomatoes for organic greenhouse production of tomatoes.

Input for production		***Quantification***
	Aquaponics	Organic greenhouse
Energy (MJ)	21.1	~16.4
Pesticide (kg/ha)	0	0

Water

For this **Aquaponics** system approximately 5000 L of water is used for the whole aquaponics cycle. The water used can be categorized as green water, as it comes from precipitation. When rainwater is not sufficient, blue water is used from nearby water reservoirs. There is approximately 8 m^2 of containers where produce is grown, this leads to ~625 L of water per m^2. The exact amount of water needed to produce 1 kg of tomatoes is difficult to calculate, since the water in the system is constantly used in a circular process and thus multiple harvest periods take place using the same water. However, Greenfeld et al (2022) state that in an aquaponics system, approximately 60.0 L of water is used to grow the tomatoes. This includes the water that evaporates and that the plant takes up. When comparing this number to the water use in a high-tech organic greenhouse system, as is the case in the **remaining AFNs**, this is relatively high. Zhou et al. (2021) state that in high-tech greenhouse systems the water use is 22.0 L/kg tomato, of which zero percent is recycled water.

Land

The land use for this **Aquaponics** system is not unambiguous, considering that this aquaponics system has approximately 12 m^2 of containers used for the whole system while located in a larger facility where workshops are given, and meetings are held. For 1 kg of tomato, ~1 m^2 is used (D. Herrewijnen, personal communication, October 20, 2021). However, since the plant grows vertically, it can sometimes produce over 5 kg of tomatoes on 1 m^2, meaning the land use is assumed to be 0.02 m^2/kg tomato.

The land use to produce 1 kg of tomato in the **remaining AFNs,** thus in a high-tech greenhouse system, is approximately also 0.02 m^2 (Zhou et al., 2021). As with water use, there is hardly any data available.

Global warming

Production

In **organic, high-tech greenhouses**, the energy use is between 15.0 and 17.8 MJ per kg tomato (Zhou et al., 2021; van der Lans et al., 2013). This leads to greenhouse gas emissions between 0.800 - 1.15 kg CO_2-eq per kg tomato on farmsite (Zhou et al., 2021; van der Lans et al., 2013). The primary energy use for the cultivation of tomatoes in an **aquaponics** system is ~20.0 MJ/kg tomato (Greenfeld et al., 2022; D. Herrewijnen, personal communication, October 20, 2021; Blok & Nieuwlaar, 2017), with an emission factor of 64.2 kg CO_2/GJ for natural gas (Blok & Nieuwlaar, 2017), this translates to ~1.35 kg CO_2-eq/kg tomato.

Transport

The greenhouse gas emissions during transportation for the **Aquaponics** AFN are neglectable. The farm shop where the produce is sold is located one km from the Aquaponics center. The produce is brought to the farm shop by bike by one of the students (D. Herrewijnen, personal communication, October 20, 2021). However, for each **remaining AFN** the emissions related to transport are calculated using Eq. (1) and Eq. (2). All distances are based on the average distance consumers can drive (Herenboeren), or that the organization of the AFNs must drive to pick up the vegetables and bring them to their consumers house or sales point.

Local2local – The assumed average distance Local2local drives is 150.5 km. The organization makes use of Diesel delivery vans from the farmers to the assembly point, and from the assembly point to the consumer zero-emission vehicles are used to distribute the produce. Based on the interview with Local2Local, it is assumed that the transportation distance by zero-emissions vehicles is short in comparison to the transportation distance by the Diesel delivery vans. Therefore, only transportation by Diesel delivery vans is considered. Those have a content of 1,300 kg of produce, a fuel consumption of 0.11 L/km (Bridgestone Mobility Solutions B.V., 2020), and an emission factor of 3.2 kg CO_2-eq/L (RVO, 2020). This gives 0.041 kg CO_2-eq/kg tomato.

Groentetas – With an assumed average distance of 91 km, and the use of a Diesel delivery van, that can take approximately 1,300 kg of produce, and has a fuel consumption of 0.11 L/km, the fuel needed can be calculated using Eq. (1). Multiplying the outcome with the emission factor for Diesel of 3.2 kg CO_2-eq/L, this gives 0.025 kg CO_2-eq/kg tomato.

Herenboeren – Herenboeren advice their consumers to join a farm that is not farther than 15 km away. Therefore, the distance is somewhere between 15 and 1 km, which gives an assumed average distance of 8 km. When the produce is picked up by car, and per transport an average of 7 kg is carried, the fuel consumption is 0.08 L/km (Li et al., 2018), and the emission factor is 2.88 CO_2-eq/L, this gives 0.263 kg CO_2-eq/kg tomato. However, when the produce is picked up by bicycle, the emissions are zero.

Packaging

Aquaponics, Local2local, and **Groentetas** do not package their products individually during transportation and storage. Rather, they are transported in multi-use plastic crates. These crates are assumed to be reused at least 50 times, which results in an overall process result of 0.30 kg CO_2-eq/kg tomato (Del Borghi et al., 2021). Furthermore, the consumers must pick up their produce with their own bag, and no other form of packaging is used during the lifecycle of the tomatoes. For **Herenboeren**, no additional packaging is needed during transportation since the produce can be collected at the farms. Only packaging used by the consumers themselves is assumed to be used. However, to store the produce, again it is assumed that the multi-use plastic crates are used, which are reused at least 50 times. This again, gives 0.30 kg CO_2-eq/kg tomato.

Eutrophication freshwater

Aquaponics operates in a closed system, so in theory no nutrients can leak into outdoor water or soil. Therefore, nitrogen surplus is not present. The feed that the fish get, are packed with nutrients, and converted by bacteria from ammonia into nitrite, and then into nitrate which can be used by the plants. The plants, however, remove the nitrate from the water and the water is returned filtered to the fish. Since this is a closed system, the eutrophication is seen as 0 g PO_4^{3-}-eq.

According to Voogt el al. (2010) and Zhou et al. (2021), the N-application in high-tech organic greenhouses (**remaining AFNs**) was 'double the crop demand', which resulted in 709 kg of N/ha/year. Van der Lans et al. (2013) affirm that the freshwater eutrophication is 5.0E-04 kg PO_4^{3-}—eq/kg tomato.

Acidification

The acidification because of the organic tomato production is 3.56E-02 kg SO_2-eq/kg tomato in organic high-tech greenhouse systems. Most of the acidification is a result of the energy use, namely 3.09E-02 kg SO_2-eq (van der Lans et el., 2013).

Biodiversity

For the **Aquaponics** AFN, there is no impact on the local biodiversity since the produce are grown indoors. D. Herrewijnen (Personal communication, October 20, 2021) stated that biodiversity is an important factor for their center, and that the location of the containers of water are in an area where multiple (native flower) gardens are planted. Furthermore, multiple crops are produced at the same time, which can help regulate the nitrogen supply and release.

Furthermore, in organic high-tech greenhouse systems**, the remaining AFNs,** the impact on the local biodiversity is mostly negative and "[..] associated with the introduction of alien species by biological pest control strategies." (Ibarrola-Rivas et al., 2020, p.7). The introduction of alien species can cause competition for food or space, transmit diseases and the indigenous biodiversity can be predated on (Ibarrola-Rivas et al., 2020; Oerlemans et al., 2015). However, it is also stated that the effects have been limited, since the last few centuries the regions have already been under horticultural cultivation. Furthermore, in organic cultivation the use of synthetic PPPs is nearly zero, which thus leads to less impact on the biodiversity (Zhou et al., 2021). M. Klop describes that biodiversity is crucial for agriculture considering the future resilience of the soil (Personal communication, November 9, 2021).

Soil quality

Soil quality in organic systems is actively advocated for. With nearly zero pesticide use, soil quality thrives. All analyzed AFNs also state that they have agreements with their farmers that the soil quality is looked after. However, no specific agreements or data are available. Herenboeren experiments with polycultures, which increases the soil quality and makes the crops more resistant to diseases. L2L also has agreements with farmers who make use of food forests, and polycultures. They state the better the soil, the more nutritious the food is. Also.

diversification is crucial to make the ecological systems more resilient (M. Klop, personal communication, November 9, 2021). That is why local production is important, because the system can be organized per location and becomes more resilient.

4.2.2 Tomato – conventional

Table 11 and 12, show the results of the environmental impact assessment for the conventional food system in the Netherlands (NL) and in Spain (ES), represented by a high-tech conventional greenhouse (Netherlands) and a low-tech conventional greenhouse (Spain), for 1 kg of tomato.

Table 11. Impact categories of the conventional food system per 1 kg of tomato for high-tech conventional greenhouse systems in the Netherlands (NL) and low-tech conventional greenhouse systems in Spain (ES).

Impact categories	***Quantification***	
	Conventional NL	Conventional ES
Nitrogen emissions (kg N/kg/y)	2.00E-04	4.10E-03
Global warming (kg CO_2-eq)	0.810 – 1.53*	0.232 – 1.37*
Acidification (kg SO_2-eq)	3.26E-03 – 3.71E-02	4.83E-04 – 2.68E-03
Freshwater eutrophication (kg PO_4^{3-} -eq)	3.40E-05 – 5.65E-04*	~4.57E-04
Land (m^2)	~0.0289	0.165
Water (L)	5.7 – 77*	~26

** Range of values*

Table 12. Input, energy and pesticides, for production of tomatoes in conventional greenhouse system in the Netherlands and in Spain.

Input for production	***Quantification***	
	Conventional NL	Conventional ES
Energy (MJ)	~16.1	~2.99
Pesticide (kg/ha)	10.0	~29.0

Water

In the **Netherlands**, the water use depends on the recirculation of nutrient solution; when recirculation is applied, significantly less water is needed for production. Zhou et al. (2021), states that the water use is respectively 14 to 16 L/kg tomato. However, RIVM (2016) articulate that the water demand to produce tomatoes is 5.7 L/kg tomato, which is half of what Zhou et al. state. Blonk Consultants (2018) claim the water use is 77 L/kg tomato.

In **Spain,** water is used for irrigation and as solvent for fertilizers and pesticides. The water used is mostly blue water from nearby wells. Research by Muñoz et al. (2007) stated that the water consumption for 1 kg of tomatoes produced in a greenhouse in Spain, is 24.24 L/kg tomato. Research by Hueso-Kortekaas et al. (2021) state that the water consumption for production is 28.58 L/kg tomato, which is 90 percent of the total water consumption. The use of blue water is cause for concern, considering the freshwater scarcity in the south of Spain (Muñoz et al., 2010; Zhou et al., 2021). Zhou et al. (2021) state the water use is 179 L/kg tomato, this however, is such an outlier that it is not considered.

Land
Land use in the **Netherlands** is relatively low, because of intensive cultivation and it is mostly dependent on the crop yield per hectare. For land use, the cultivation phase is not considered because of lack of data. Land use is approximately 0.01 - 0.02 m^2 per kg tomato (Zhou et al., 2021; Blonk Consultants, 2018). The highest number is mentioned by RUG (2021), which is 0.06 m^2. These numbers are relatively low when compared to other countries. For example, **Spain** needs 0.2 m^2 to produce 1 kg of tomatoes (RUG, 2021).

Global warming
Production
In the **Netherlands**, the emissions of GHG are dependent on heating of the greenhouses, electricity use, the production of fertilizers, packaging, and transport. No data could be found about the distribution of impact each aspect has during the production of tomatoes, however the energy use to produce fertilizers, heating and electricity use is 13.0 - 19.1 MJ per kg tomato (Zhou et al., 2021; van der Lans et al., 2013).

The CO_2-eq emissions ranges in literature from 0.65 kg CO_2-eq (Blonk Consultants, 2018) to 1.6 kg CO_2-eq /kg tomato (RUG, 2021). The quantification of the research by Blonk Consultants is relatively low because they did not take the electricity consumption into account. Zhou et al. (2021), also has a relatively low number because they considered that most conventional greenhouses in the Netherlands make use of CHP, which leads to "[..] deducting the CO_2 emissions of the excessive electricity transferred to national electricity grid." (p.5), namely 0.7 kg CO_2-eq/kg tomato. Van der Lans et al. (2013) state 1.3 kg CO_2-eq/kg tomato, and RIVM (2016) state 1.5 kg CO_2-eq/kg tomato.

In **Spain**, the results for greenhouse gas emissions at farmgate differ a lot. Numbers differ from 1.2 kg CO_2-eq (RUG, 2021), to 0.057 kg CO_2-eq (Hueso-Kortekaas et al., 2021) per kg of tomatoes. Research from Irabien and Darton (2016) and Zhou et al. (2021), come closest in results namely 0.25 and 0.30 kg CO_2-eq per kg of tomatoes. Romero-Gámez et al. (2017) and Muñoz et al. (2007), stated that the greenhouse gas emissions from 1 kg of tomato production was 0.62 kg CO_2-eq/kg of tomatoes and 0.074 kg CO_2-eq/kg of tomatoes.

Transport
In the **Netherlands**, transportation of produce is mostly done using trucks that run on Diesel, which has an emission factor of 3.2 kg CO_2/L (RVO, 2020). The distances supermarkets must travel from their farms to their selling points, is assumed to be an average distance of 152.5 km. The consumption of fuel is assumed to be 0.35 L/km (Li et al., 2018). Next to that, the average truck can hold 25,000 kg of produce (Webfleet solutions, 2020). Using eq (1). and (2), this translates to CO_2-eq emissions of 0.0069 kg/kg tomato.

For **Spain**, the assumption is made that all tomatoes come from Almería, a city in the Southeast of Spain. From there, the produce needs to be transported for 2250 km across land by a cooled truck (RUG, 2021). Trucks mostly run on Diesel, which have an emission factor of 3.2 kg CO_2/L (RVO, 2020). The fuel consumption is assumed to be 0.35 L/km (Li et al., 2018), using Eq. (1) and (2), this gives 0.10 kg of CO_2/kg tomatoes.

Storage
No data could be found considering tomato storage in the Netherlands and this is therefore not considered in the calculations.

Packaging
In the Netherlands, most conventionally produced tomatoes are packaged in fossil based single-use plastic, like LDPE. To package 1 kg of tomatoes, approximately 13.3 g of LDPE is

needed (RUG, 2021). Based on the research by Abbate et al. (2022) and Turner et al. (2015), between 4.23 and 5.57 kg CO_2-eq per kg LDPE is emitted. Taking the average of 4.90 kg CO_2-eq per kg LDPE, for 1 kg of tomatoes, 0.0615 kg CO_2-eq is emitted.

However, the remaining packaging during transportation by truck (e.g from Spain to the Netherlands) is not considered due to lack of data.

Eutrophication freshwater

The use of fertilizers can lead to N-surplus and P-surplus resulting in freshwater eutrophication. In the **Netherlands**, the outcomes for freshwater eutrophication range from 3.8E-05 (RIVM, 2016) to 5.7E-04 kg PO_4^{3-}-eq/kg tomato (van der Lans et al., 2013). No explanation has been found for this difference since the database of RIVM (2021) does not clarify their numbers. RIVM (2016) affirm that 3.0E-05 kg PO_4^{3-}-eq/kg tomato is emitted, while Zhou et al. (2021) affirm this is 6.3E-04 kg PO_4^{3-}-eq/kg tomato.

The European Commission stated in 2021 that local water bodies in **Spain** are heavily polluted by nitrates. Zhou et al. (2021) claim that the value for eutrophication is 0.79 g PO_4^{3-}-eq/kg tomato, while Muñoz et al. (2007) state that the eutrophication because of 1 kg of tomato production is 0.12 g PO_4^{3-}-eq.

Acidification

Acidification is mostly related to the use of energy during the production phase, and to the use of fertilizers and pesticides (NO_x, SO_2, NH_x). This relates to the yield per m^2, and thus the energy use and acidifying substances per m^2. In the **Netherlands,** conventional agriculture has high yield per m^2 (70 kg/m^2), and therefore the impact of acidification is relatively low, namely between 3.26E-03 and 3.71E-02 kg SO_2-eq/kg tomato (van der Lans et al., 2013; RIVM, 2016).

In **Spain**, acidification is mostly caused by greenhouse gas emissions and the use of acidifying substances like NH_x and NO_x found in fertilizers. Muñoz et al. (2007) affirm that acidification has a value of 2.68E-03 kg SO_2-eq/kg tomato, however this is much higher than what Romero-Gámez et al. (2017) state, with a value of 4.80E-04 kg SO_2-eq/kg tomato. The latter does make a distinction for specific cherry-tomatoes, while other research analyze 'tomatoes' in general.

Biodiversity

The impact of conventional agricultural practices on biodiversity preservation is negative, which is associated with the use of pesticides and fertilizers, such as nitrogen. The emission of PPPs affects the loss of biodiversity. The emission of PPPs in the **Netherlands** is approximately 10 kg active ingredients/ha/year (Zhou et al., 2021), while the emission of PPPs in **Spain** lies between 26 (Karlsson, 2011) and 32 (Zhou et al., 2021) kg active ingredients/ha/year. This is approximately three times higher than with high-tech greenhouse systems. The production of tomatoes in the South of Spain can be assumed to have negative effects on the preservation of biodiversity.

Soil quality

Soil quality is determined by multiple factors, as stated in section 2.1.1. Partly it is determined by P emissions. However, due to a lack of data, P emissions were not considered. However, as Zhou et al. (2021) state, is "P fertilization an important factor in the sustainable management of greenhouse production systems and should be actively managed and monitored." (p.4). Moreover, in the **Netherlands**, the use of Plant Protection Products (PPP) in conventional high- tech systems is approximately 10 kg active ingredients/hectare/year, in comparison to nearly zero for organic systems. This leads to emissions to the soil, water, and atmosphere, and can directly or indirectly influence human health. However, legislations have been set for a stepwise reduction of PPPs and nutrients to zero.

Furthermore, Zhou et al. (2021) claim that the water use, and land use are not efficient in **Spain**, and that water is not properly stored in the environment, which leads to desertification. Since the biodiversity can be assumed to be affected negatively, soil quality will also not be sufficient considering biodiversity is needed for proper soil quality.

4.2.3 Carrot

In literature it is explained that organic carrot production is barely researched since it is already known "[..] to substantially increase GHG emissions." (Röös & Karlsson, 2013, p.66). Nevertheless, some research has been done which is presented in Table 13 for the producer-led AFN, represented by Aquaponics training centre, the Business platform AFN, represented by Local2local, the Third-sector-led AFN, represented by Groentetas, Consumer-led AFN, represented by VOKO, and the Community-supported AFN, represented by Herenboeren, for 1 kg of carrot in the Netherlands.

Table 13. Impact categories per kg of carrot for the AFNs L2L, Groentetas, VOKO and Herenboeren. As well as for the conventional production of 1 kg of carrot.

Impact categories	***Quantification***				
	L2L	Groentetas	VOKO	Herenboeren	Conventional
Global warming (kg CO_2-eq)	0.395	0.363	0.367	0.338 – 0.601	0.522 – 0.880
Acidification (kg SO_2-eq)	2.97E-04	2.97E-04	2.97E-04	2.97E-04	3.62E-03
Freshwater eutrophication (kg PO_4^{3-} -eq)	4.80E-06	4.80E-06	4.80E-06	4.80E-06	6.50E-05
Land (m^2)	~0.402	~0.402	~0.402	~0.402	0.270
Water (L)	8.63 – 69.0*	8.63 – 69.0*	8.63 – 69.0*	8.63 – 69.0*	~8.75

** Range of values*

Water

According to the Flemish department of agriculture and fishery (2019), the irrigation needs for 1 m^2 lies between 25.0 and 200 liters of water. This translates to approximately 8.63 L to 69.0 L per kg of carrot. This is partly in line with RIVM (2016), who state that the water use is determined to be 7.00 – 10.5 L of water per kg carrots using ReCiPe. In ReCiPe, the indicator water use describes the water that is consumed and the water availability at a certain location (RIVM, 2016).

Land

Carrots are produced in the bare soil, and different types of soil can be used to grow the vegetable. For example, clay soil, sand soil or loamy soils can be used to produce (different types of) carrots. Per type of carrot different hectares of land are needed, however not all research differentiates the specific type of carrot produced. According to RUG (2021), 0.345 m^2 is needed. Bos et al. (2014) state that 0.458 m^2/kg carrot is needed for organically produced carrot (**AFNs**). This gives an average of 0.402 m^2/kg carrot.

In the **conventional system**, on average 0.270 m^2/kg carrot is needed (RIVM, 2016; RUG, 2021; Blonk Consultants, 2018).

Global warming

Production

RUG (2021) affirms that the global warming potential for 1 kg of **organically produced** carrot is 0.550 kg CO_2-eq. This includes, among others, production, packaging, and transportation. However, no distinction between the different aspects has been made for this vegetable. Jareborg (2019) states the GHG emissions at farmgate are 0.0379 kg CO_2-eq. The latter does make a distinction between the different aspects, and therefore has been selected for further calculations.

More data is available for the **conventional system**, which ranges from 0.433 to 0.791 kg CO_2-eq per kg carrot (RIVM, 2016; RUG, 2021).

Transport

The emissions caused by transportation are calculated the same as for the tomatoes AFN. This results in 0.041 kg CO_2-eq/kg carrot for **Local2local**. **Groentetas** has emissions of 0.025 kg CO_2-eq/kg carrot. The maximum distance **VOKO** has its suppliers is 20 km, and the closest supplier is 4 km. An average distance of 12 km is assumed. The volunteers of VOKO pick up the produce with passenger cars and transport an average of 100 kg. The consumers pick up their produce by bike in the city centre (S. van Kempen, personal communication, December 13, 2021). The fuel consumption is 0.08 L/km (Li et al., 2018) and the emission factor for gasoline cars is 2.9 kg CO_2-eq/L (RVO, 2020). This gives 0.028 kg CO_2-eq/kg tomato. For **Herenboeren** the emissions are 0.26 kg CO_2-eq/kg carrot. The emissions for the **conventional** system are 0.0069 kg CO_2-eq/kg carrot.

Storage

In the Netherlands, the harvest period of carrots is relatively long, and carrots can be harvested until November. Karlsson (2012) affirm that the average storage time in the Netherlands is therefore two months. This leads to a total primary energy consumption of 0.26 MJ. Working with the assumption that most of the energy in the Netherlands comes from natural gas, which has an emission factor of 64 kg CO_2/GJ (RVO, 2020), this gives 0.017 kg CO_2/kg of carrot. The produce from most of the **AFNs** do not need storage on a large scale since all products are seasonal and consumed within a short amount of time. However, L2L does work with farmers that store their products. Therefore, again a value of 0.017 kg CO_2/kg of carrot is assumed.

Packaging

As for the tomatoes, the same packaging applies to the carrots, which is a multi-use plastic crate used in an **AFN**, giving 0.30 kg CO_2-eq/kg carrot. For the **conventional system** single-use plastic is used, approximately 4 gram of LDPE is needed to package 1 kg of carrot (Jareborg, 2019). Based on the research by Abbate et al. (2022) and Turner et al. (2015), between 4.23 and 5.57 kg CO_2-eq per kg LDPE is emitted. Taking the average of 4.90 kg CO_2-eq per kg LDPE, for 1 kg of carrots, 0.0196 kg CO_2-eq is emitted.

Eutrophication

Chatzisymeon et al. (2017) describe that the effect of eutrophication in open field organic agriculture is less significant than conventional systems. Research by Kowalczyk and Cupiał (2020) on the environmental analysis of conventional and **organic** carrot production in Poland, which has a similar moderate climate like the Netherlands, state that the eutrophication is 4.8E-06 kg P-eq/kg carrot. According to RIVM (2021) this is 6.5E-05 kg PO_4^{3-}-eq/kg carrot in the **conventional system.**

Acidification

Kowalczyk and Cupiał (2020) state that the effect of acidification is 2.97E-04 kg SO_2-eq/kg carrot when **organically** produced. It is assumed that most SO_2-eq emissions are a result of energy use and the use of fertilizers. In a **conventional system** this is approximately 3.62E-03 kg SO_2-eq/kg carrot (RIVM, 2016; RIVM, 2021).

Biodiversity

The effect on biodiversity is expected to be positive, as all **AFNs** confirm they are actively trying to have a positive effect on the biodiversity. No pesticides are used, which improves the impact on biodiversity. However, as stated in section 4.2.1, the introduction of alien species could form a threat for local biodiversity (Ibarrola-Rivas et al., 2020). Nevertheless, the absence of pesticide use does lead to less negative impact on biodiversity (Zhou et al., 2021).

The effect on biodiversity because of **conventional systems** is mostly negative as many pesticides and artificial fertilizers are used which are proven to harm the local biodiversity.

Soil quality

Since for all selected **AFNs** environmental conservation is considered, the soil quality can be expected to be of high standards. In organic agricultural systems, healthy farmland is an important starting point. With the absence of pesticides, the soil quality is also expected to be of a higher standard. It is known that the soil has a layered structure, which all have a function (Paustian et al., 2019). Deep-turning tillage is therefore almost not applied anymore, and shallow tillage is more common for preservation of the soil quality. At the same time, efforts are made to prevent structural damage (densification) (Mäder & Berner, 2012).

For the **conventional systems** this is more complicated. Research about the environmental impact of carrot production often does not include the tillage methods. When deep tillage is applied, the effect on the soil quality in terms of soil density and soil stability is negative. Crittenden et al. (2015) state: "Reduced tillage intensity systems, such as non-inversion tillage, therefore have the capacity to improve soil physical quality in terms of soil structure and soil water storage in both organic and conventional farming." (p. 143).

5. Discussion

5.1 Limitations and reflection on the assumptions

This research aimed to identify the potential contribution of AFNs in the transition to sustainable agriculture in The Netherlands from an environmental aspect. However, there were some limitations and uncertainties that influenced the results and thereby the answer to the main research question. The five most significant limitations and uncertainties of this study are shortly highlighted upon.

First, because of the travel restriction as a result of COVID-19, it was not possible to visit farms and interview more stakeholders. This resulted in interviews with AFN stakeholders around Utrecht. For more extensive research, it is recommended that a wider scope in the Netherlands is selected to interview more spokespersons of AFNs and investigate their organizations.

Second, another important factor was the limited available data which resulted in assumptions that needed to be made. One assumption was that the distance from supplier to consumer was the average of the maximum and minimum distance. By adjusting the distances, the outcomes will vary as well (Section 5.1.1). The same accounts for the assumed location of tomato production in Spain, Almería. One production location is considered, however in reality the tomatoes can come from multiple locations, which again will alter the outcome.

Third, no distinction is made between different types of tomatoes or different types of carrots. Mostly, because it was often not specified in the available databases. It is possible that different types of tomato or carrot have different environmental impacts, which may also depend on the country of origin. By increasing and improving the data, this research can be extended and more differences between the AFNs can be discovered. Now, the only differences between the AFNs are within the GHG emissions, which is an important factor, but other factors are, debatably, equally important. Furthermore, the analyzed impact categories were selected based on existing research about the impact food systems have on the environment. Nevertheless, other impact categories could have presented different results. For example, Eco-toxicity could have been considered and Marine eutrophication. It was decided to not include these because of limited available time, and because there is even less data available.

Fourth, another factor that could have changed the outcomes is the number of crop types. By extending the number of crop types or change the produce that was analyzed any differences between the AFNs and between AFNs and conventional systems would be more notable. However, by analyzing tomatoes and carrots an interesting overview has been given, especially since those are one of the most consumed foods in the Netherlands. The selected scope presents the best results at this moment, given the data that is available.

Fifth and final, since the limited available data, mostly the study by Zhou et al. (2021), RIVM (2016), Muñoz et al. (2007), and the database by Blonk Consultants and RIVM (2021) have been used. There was a lot of variation in data from the different studies. To clarify the values, an uncertainty analysis has been performed (Section 5.1.1). Moreover, this research is based on the study done by Poças Ribeiro et al. (2021), which identified different types of AFNs. These types have been used as distinction methods and therefore this research is more specified than other studies on AFNs.

5.1.1 Uncertainty analysis

The assumptions, lack of specific data and multitude of interpretations in previous studies have led to several uncertainties for the found results. Therefore, an uncertainty analysis has been performed on the selected data from multiple studies. All the input values for each impact category as found in the scientific literature and databases have been organized from lowest value to highest. Based on this range, the average was selected as input value for the impact category. To find the level of uncertainty, the input value was taking as the base value and the percentual differences of the lower bound and the higher bound of the range were selected. If the lower bound input value and higher bound input value are relatively close to the average a relative robust outcome was generated for that impact category. If the lower and/or higher bound input value have a large percentual difference with the average value, the outcomes were more uncertain. The results of the AFNs and the results of the conventional systems are presented in Figures 5-9. The subcategory Transportation of impact category Global warming has been separately displayed in Figure 10.

As can be seen in Figure 5, for the tomato production in an AFN, the findings were relatively robust since the outer bound input values did not differ largely from the average. Only for energy there was a difference of less than ten percent for the lower and higher bound input value. For the other impact categories, the outer bounds were the same value as the average. It can therefore be concluded that the findings for the tomatoes in AFNs are relatively robust.

For the carrot production in these AFNs, Figure 6, there is relatively high uncertainty for Water (90 percent difference to average for lower bound and 190 percent difference for higher bound). However, as will be discussed in Section 5.2, there is one outlier which seems to be not representative for this research. For the other categories, only one value could be found, or the values did not differ much from the average.

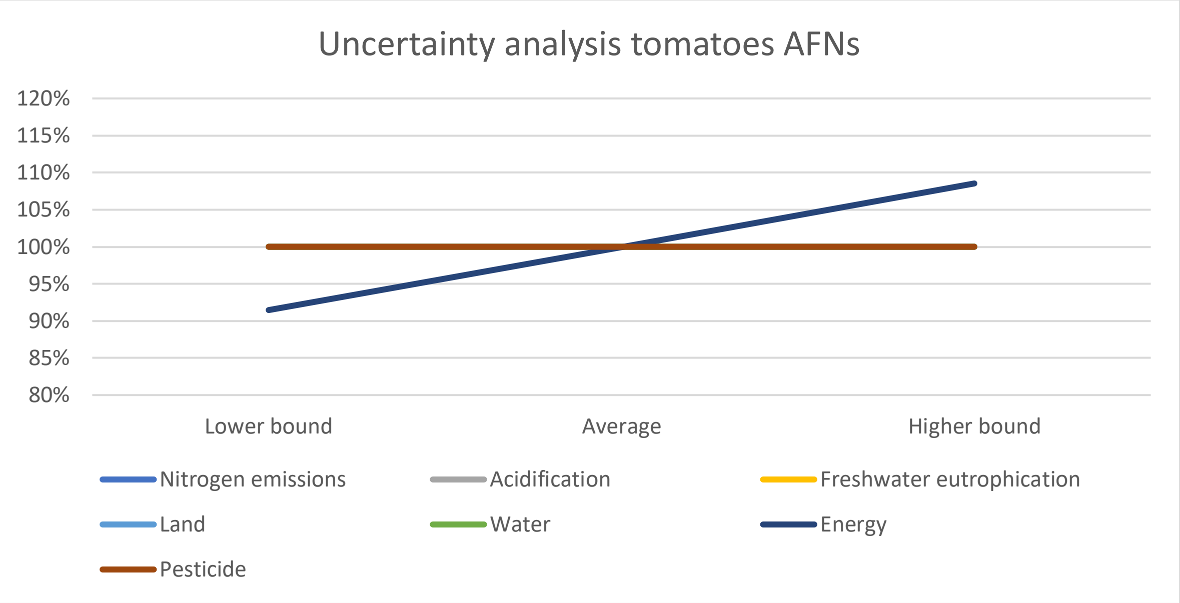

Figure 5. Uncertainty analysis for the findings of organic tomatoes in AFNs, focusing on percentage values of nitrogen emissions, Freshwater eutrophication, energy, Land, pesticide use, Acidification, and Water. The lines go from lower bound to higher bound, with the average in the middle.

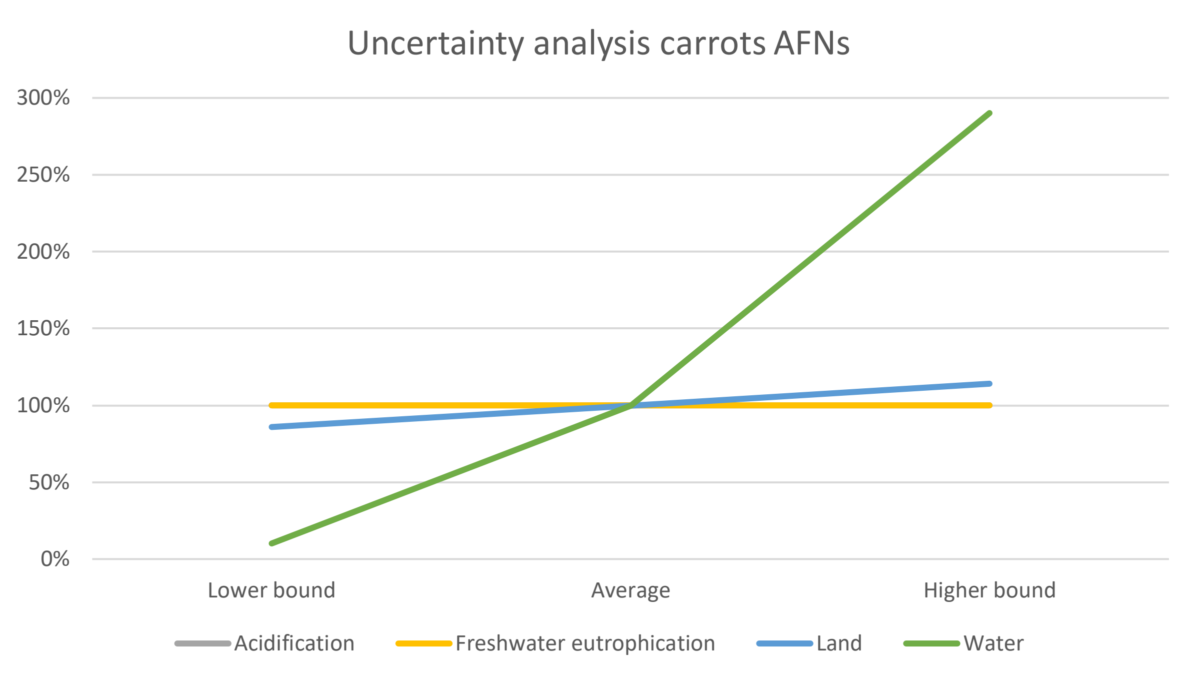

Figure 6. Uncertainty analysis for the findings of organic carrots in AFNs, focusing on percentage values of Freshwater eutrophication, Land, Acidification (behind yellow line), and Water. The lines go from lower bound to higher bound, with the average in the middle.

Figures 7, 8 and 9 present the result for tomatoes and carrots in a conventional system. In Figure 7, it shows the results for tomatoes in a conventional system in the Netherlands. The results for pesticide use, energy use, and Global warming are relatively robust since there are no large differences between the lower and higher bound. However, Water (80 percent difference to average with lower bound and 173 percent difference with higher bound) has an outlier in the results, which is not representative for this research since no explanation is given with its number in literature. This is further explained in Section 5.2. Freshwater eutrophication show relatively large uncertainties (90 percent difference to average with lower bound and 110 percent difference with higher bound). Freshwater eutrophication also differed much in found data, which results in a relatively large uncertainty that makes the results less robust. Lastly, Acidification is relatively uncertain as well. The lower bound input value has a similar percentual difference to the average as Water and Freshwater eutrophication and a difference of 84 percent between the higher bound value and the average.

Figure 8 shows the results for tomatoes in a conventional system in Spain. Uncertainties can be observed for Water (69 percent difference for lower bound and 132 percent higher bound), Acidification (69 percent difference for lower bound and 73 percent higher bound), energy (59 percent difference for lower bound and 73 percent higher bound), and Freshwater eutrophication (73 percent difference for lower bound and 73 percent higher bound). Water has an outlier of 179 L, which cannot be explained by the data since no clarification has been given. This will be further explained in Section 5.2. Since the differences between the lower bound and higher bound are relatively high, the results are not robust.

Figure 9 presents the results for carrots in a conventional system in the Netherlands. Only Global warming has relatively uncertainties when compared to the average, namely 30 percent difference to both the lower bound and the higher bound. The impact categories Acidification, Land and Water had differences for both the lower and the higher bound of twenty percent or less. Therefore, the findings for the carrots in the Netherlands were not particular uncertain but also not robust.

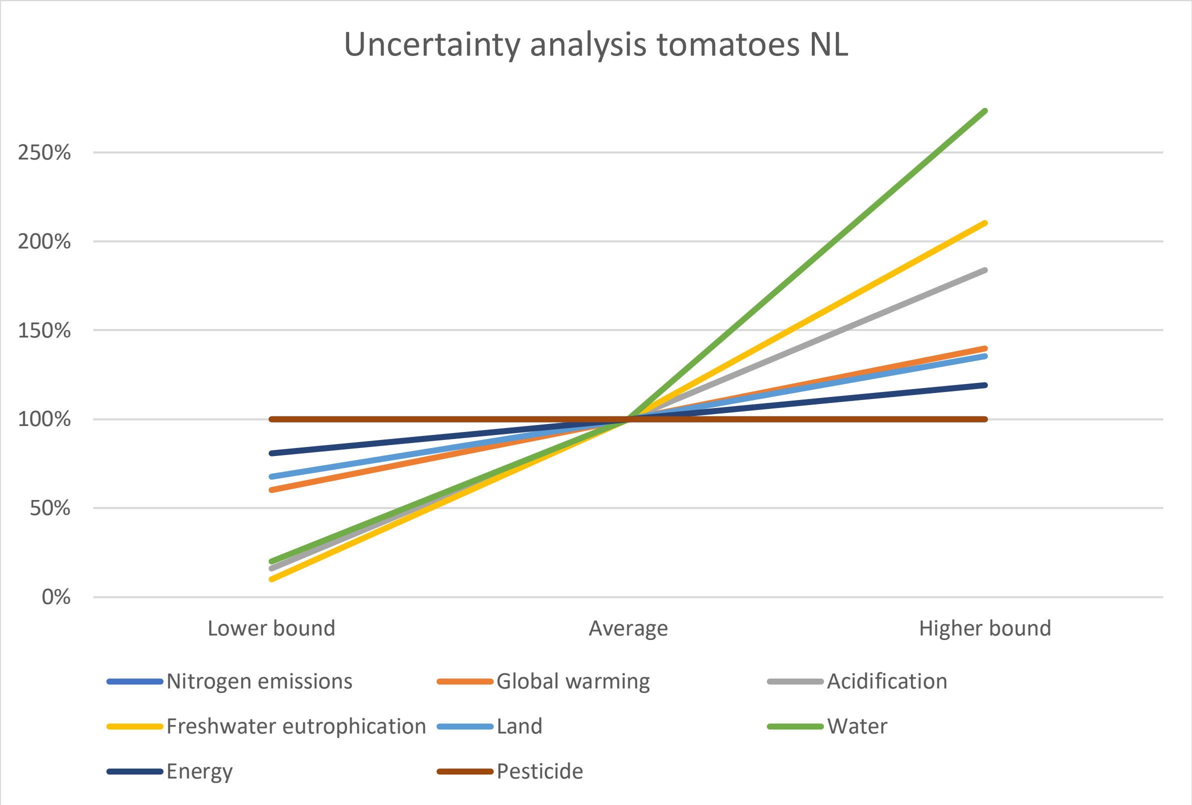

Figure 7. Uncertainty analysis for the findings of tomatoes in a conventional system in the Netherlands, focusing on percentage values of nitrogen emissions, Freshwater eutrophication, energy, Global warming, Land, pesticide use, Acidification, and Water. The lines go from lower bound to higher bound, with the average in the middle.

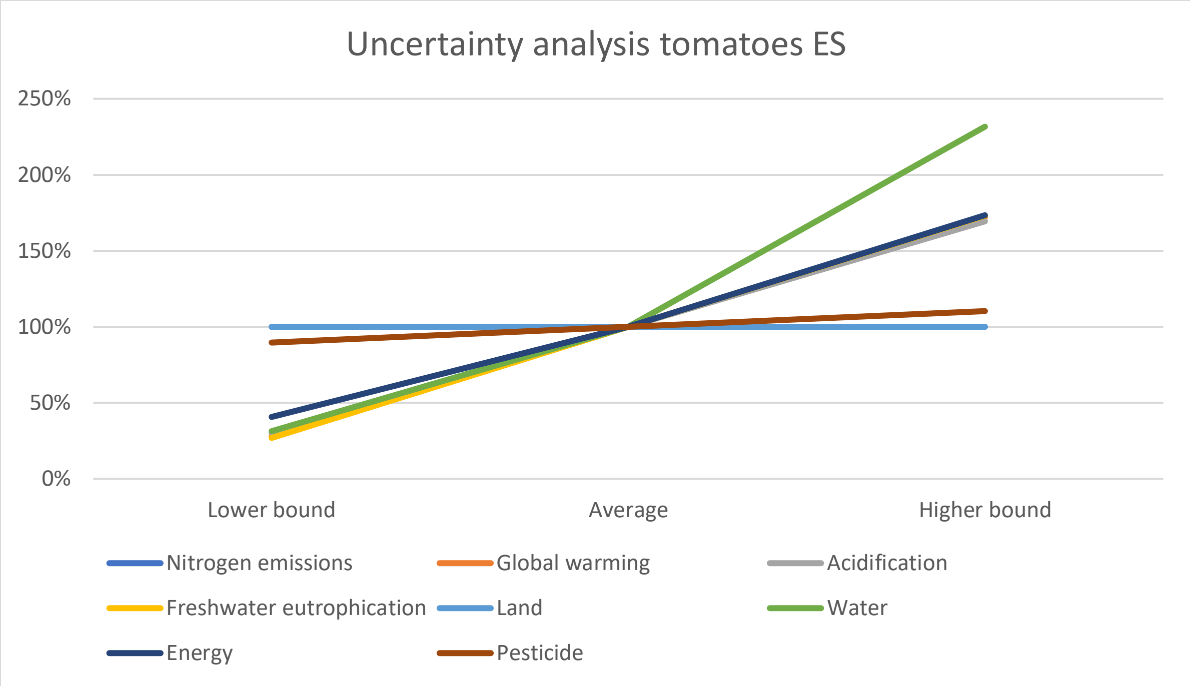

Figure 8. Uncertainty analysis for the findings of tomatoes in a conventional system in Spain, focusing on percentage values of nitrogen emissions, Freshwater eutrophication, energy, Global warming, Land, pesticide use, Acidification, and Water. The lines go from lower bound to higher bound, with the average in the middle.

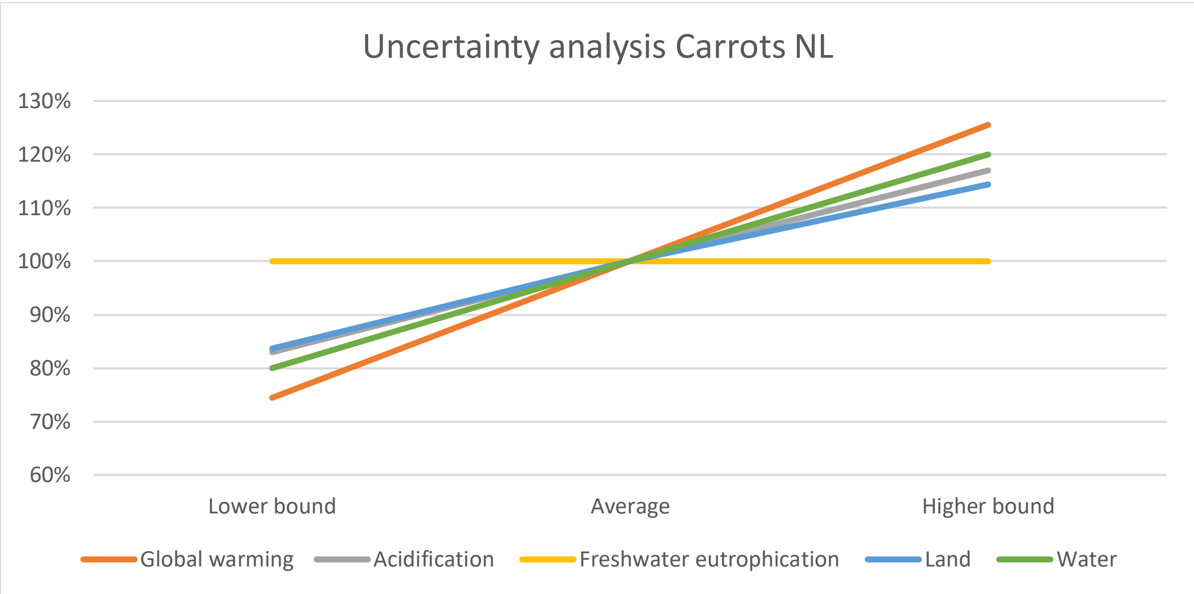

Figure 9. Uncertainty analysis for the findings of carrots in a conventional system in the Netherlands, focusing on percentage values of nitrogen emissions, freshwater eutrophication, energy, Global warming, Land, pesticide use, Acidification, and Water. The lines go from lower bound to higher bound, with the average in the middle.

Figure 10 presents the impact of emissions due to transportation in comparison to the total number of GHG emissions in all systems. This is presented to indicate what the effect is of transportation on Global warming in comparison to the other aspects of the Global warming indicator. As can be seen in the figure, transportation does not largely influence the total amount of GHG emissions. Only when Herenboeren consumers pick up their produce by car, the emissions are relatively high. The same accounts for both carrot and tomatoes. The impact of transportation in a conventional system in the Netherlands is especially low, particularly when compared to transportation in the AFNs. However, when produce needs to be transported from Spain to the Netherlands, the impact is higher.

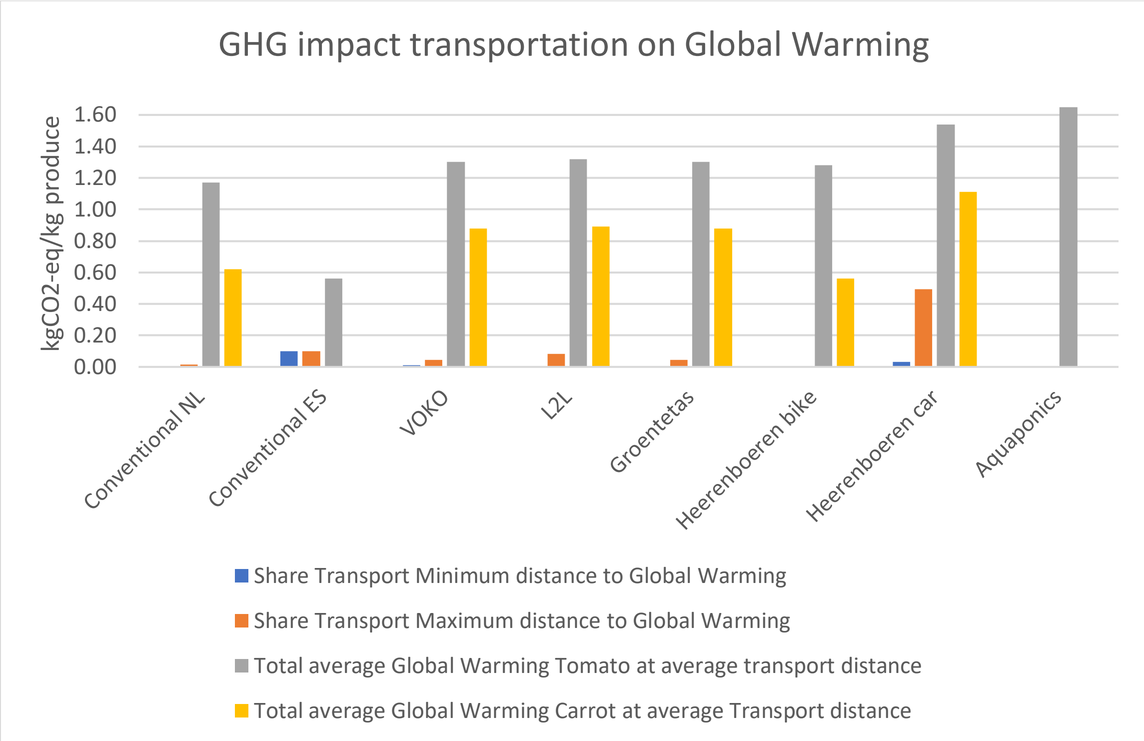

Figure 10. The impact of GHG emissions due to transportation in AFNs and in conventional systems. The share of Transport with the minimal distance for Global warming is shown, as well as the share for the maximum distance. Also, the total average Global warming is shown for tomato and for carrot.

5.2 Reflection on the results

Definition

This thesis proposes an innovative and general definition for the concept Alternative Food Network. Based on an extensive literature study and an empirical study, the characteristics and possible indicators have been identified and by combining those, a definition could be formulated. By doing so there can be specific communication about the concept of AFNs to make future research more thorough and effective. This proves necessary since multiple studies have different principles in their research. For example, Fourat et al. (2020) discuss AFNs to have short food supply chains and a sustainable food commitment, while on the other hand Kajzer Mitchell et al. (2017) talk about AFNs as organic, 'slow food', and fair trade. By adopting a general definition, misunderstandings can be avoided, and research can be more clearly specified. Furthermore, with the objectives to be achieved regarding agriculture, like the SDGs and the nitrogen policy in the Netherlands, it can help if there is a general definition so that clear agreements can be made regarding policy.

Tomato

The results of the environmental impact assessment point out that only for the impact category Global warming, the results differ between the different types of AFN that make use of organic high-tech greenhouse systems. The individual parties do not have data available about their specific practices which resulted in a general organic production systems analysis. This impacted the reliability of this research but does point out the positive impact AFNs can have on the environment. Moreover, the results differ for the aquaponics system and the remaining AFNs since aquaponics uses a different farming system than the other AFNs.

First for Water, the results show that relatively large quantities of green water are in the aquaponics systems, nonetheless the water remains in the system since the system is circular and gets cleaned by bacteria and fish. Only small losses are observed by evaporation and uptake from plants. Furthermore, the water level in the system remains relatively constant so there is no need to refresh the water or refill the tank unless a disease is spreading among the fish, which occurs rarely (D. Herrewijnen, personal communication, October 21, 2021). The interviewee also stated that 85 percent less water is used in his system, compared to traditional cultivation. This would mean that the water consumption from the Aquaponics centre is 3.3 L/kg tomato. Furthermore, the water use for the other AFNs depends on the water use efficiency, and the recirculation of nutrient solution. However, there is hardly any data available about the water use for organic tomato production, which makes the results less significant. Furthermore, the available data does not distinguish between green or blue water which makes it even more difficult to assess the environmental sustainability.

The same accounts for Global warming because of organic production of tomatoes in greenhouses used in an AFN. Energy consumption is related to primary energy use for heating and electricity use of the greenhouses and the energy required to produce organic fertilizers. Overall, the energy required is less than for synthetic fertilizers, however this greatly depends on the manufacturing process (Zhou et al., 2021; Walling & Vaneeckhaute, 2020). Diacono et al. (2019) found that the greenhouse gas emissions are mostly produced by irrigation, fertilization, and harvesting. Thereby, emissions could be decreased by enhancing water use efficiency (drip irrigation, sub-irrigation, e.g). Diacono et al. (2019) also state: "[..] to reduce evaporation losses, the adoption of conservation tillage with residues of the mulch left on the soil surface can be a solution and should be further evaluated and implemented." (p. 13). Nonetheless, one of the core characteristics and indicator of AFNs is that they only sell seasonal produce. This means that heating in the greenhouse is probably less than presented in the results (Chapter 4.2), since heating is required to less extend in the summer, which is when tomatoes are in season. Unfortunately, it was not possible to take this into account in the calculations because available data was generalized for a whole year.

Additionally, transport in the studied AFNs has, in comparison to conventional systems, a relatively large contribution to the GHG emissions. The use of Diesel delivery vans for relatively small distances and relatively small vehicles to distribute the produce which causes the share of produce in the vehicle to be small, leads to increased GHG emissions. Especially, Herenboeren has lower emissions if the consumers get their produce by bike or by public transportation. They do claim that they advise people to find a Herenboeren organization that is close by their home, but it is not obligatory. It must be noted that L2L affirmed that transportation is not the most important or relevant factor in the transition to sustainable agriculture (M. Klop, personal communication, November 9, 2021).

What is notable is that Eutrophication in organic high-tech greenhouse systems is almost ten times higher than in conventional high-tech greenhouse systems. This is confirmed by multiple studies; however, a clear explanation is not given. The hypothesis is that it has to do with the difference in yield and higher nutrient losses. Foteinis and Chatzisymeon (2016) describe that when using kg of produce as functional unit, instead of per hectare of cultivation, organic production will seem to have higher environmental impact. They state: "This is attributed to the fact that the organic system, due to its lower crop yields, requires significantly larger cultivation area to achieve the same crop production with conventional.” (p. 2462).

For tomato produced in a conventional greenhouse system, the results for the impact categories for Spain and the Netherlands vary per impact category and thereby the impact the production and distribution have on the environment. It therefore depends on what is viewed more significantly to determine whether production in Spain or in the Netherlands is more environmentally friendly.

In the case of Water, RIVM (2016) makes a combination of water that is consumed and the water availability in a certain location. Moreover, the actual impact of water use can be measured instead of the actual water that is used for production. Since the Netherlands, arguably, is a relative wet land, the water demand will therefore also be relatively low. On the other hand, Blonk Consultants and RIVM (2021) state a water demand of 77 L/kg of tomatoes produced. They affirm the water consumption is based on blue water used for irrigation. However, the database does not clarify the numbers, so therefore this number will be seen as an outlier since the other numbers are 5.8 and 14 - 16 L/kg tomato (Zhou et al., 2021; RIVM, 2016). Spain is a relatively dry area, and therefore the impact of water use will be higher. Again, no clear distinction is made between green water and blue water.

The same accounts for energy use and Global warming; in the Netherlands the energy use is dependent on the local climate: less sun hours leads to more heating and supplementary lighting. Greenhouses that make use of CHP often exceed electricity production, which is then transferred to national electricity grid. Therefore, the corresponding GHG emissions “[..] can in some instances be halved by using such offsets in both conventional and organic systems [..]” (Zhou et al., 2021, p. 5). Overall, it can be stated that less heat is required considering the tunnels are not heated in Spain because of the climate. However, the resources used to provide for heat, machinery, and watering pumps where mainly oil and natural gas (Muñoz et al., 2007). The main energy source in the Netherlands in greenhouses is natural gas. Furthermore, in Spain, for the outcomes of the impact category Global warming, research differs in including the materials needed to build the greenhouse structure (Muñoz et al., 2007) and not including it (Zhou et al., 2021). This is because most greenhouses in Almería are temporary plastic-based greenhouses, and thus material is needed each time the greenhouses are build. However, since most research does not distinguish what the different inputs are for their energy use and GHG emissions, this makes comparison between research complicated.

Eutrophication is relatively high in Spain in comparison to the Netherlands. Over-application of fertilizers and free drainage cause nutrient losses, which leads to eutrophication of freshwater systems. Zhou et al. (2021) specify: “[..] the entire greenhouse production area around Almeria in Spain has been classified as a Nitrate Vulnerable Zone by the European Union.” (p.8). Eutrophication because of low-tech conventional greenhouse systems is twenty percent higher than that because of high-tech conventional greenhouse systems. The European Commission stated in 2021 that local water bodies in Spain are heavily polluted by nitrates. Zhou et al. (2021) claim that the value for eutrophication is 0.79 g PO_4^{3-} -eq, while Muñoz et al. (2007) state that the eutrophication because of 1 kg of tomato production is 0.123 g PO_4^{3-} -eq. A possible explanation for this difference is that Zhou et al, explicitly state that Spain mostly makes use of low-tech greenhouse systems, while Muñoz et al do not specify that type of greenhouse. High-tech greenhouses will have lower nutrient losses, and thus lower eutrophication values.

Carrot

For the results of the environmental impact assessment of tomatoes, there was not much data available for the assessment for carrots. Therefore, the outcomes from the AFNs are similar to the impact categories Acidification, Freshwater eutrophication, Land, and Water.

The results show that there is no consensus concerning the water demand, green or blue, to produce carrot, however this is due to an outlier of 69 L (Flemish department of agriculture and fishery, 2019), in comparison to 7 L (RIVM, 2016), 8.62 L (Flemish department of agriculture and fishery, 2019), and 10.5 L (RIVM, 2016). It does show consensus that organically produced carrots need more land than carrots produced in a conventional system. However, since different types of soil can be used, and there is limited data about land use and the type of soil that is used, more data is crucial to be able to compare the differences better.

The same accounts for the calculations for Global warming, the available data did not specify the contribution of each aspect. Therefore, a large range in the calculations was found, since the energy required during the production has not been considered. The data for the conventional system had a large range, for which a sensitivity analysis is performed (section 5.1.1). Since the little data that is available, it shows even more how important it is to analyze multiple crops to indicate the environmental sustainability of AFNs.

In the results it is assumed that the AFNs do not need storage, which is therefore not considered in the calculations. This is because of the short food supply chains and the contact with consumers, which results in more customized delivery of products.

6. Conclusion and recommendations

This study investigated the potential contribution of AFNs in the transition to sustainable agriculture in The Netherlands from an environmental aspect. The environmental impact of conventional food networks was analyzed, as well as the environmental impact of AFNs. Two crops have been studied for direct consumption: tomatoes and carrots. This study was executed by performing a literature review and an environmental impact assessment. Moreover, the different characterizations of AFNs from multiple studies have been evaluated and a new definition has been formed to understand what exactly it entails to make use of an AFN. By doing an extensive literature study and combining the information from the interviews, corresponding characteristics of AFNs have been found and thereby potential indicators to argue whether a food network can be defined as an AFN. This way, a general definition has been proposed to specify research and promote unambiguous communication about AFNs. The new definition reads as follows:

An Alternative Food Network is a food network that opposes the conventional modern food networks. It is a system that operates within short supply chains, in which food is produced and sold locally and fresh. There is an intent to preserve the environment and there is more emphasis on preservation of biodiversity. Transparency within the network is essential and there is active interaction between all parties within the network.

From the available data, little difference was found between conventional food systems and organic AFNs. This is notable since all AFNs state to be environmental conscious. This seemingly has to do with the limited available data from literature and the limited knowledge from the interviewees about the farmers practices. Moreover, the data can be deceiving since the nitrogen emissions seem to be higher in organic production, but this is only when it is addressed per kg and not per hectare. When looking at the absolute values, the nitrogen emissions are lower for organic production.

The organizations act sustainable, in that they strive for locally produced food that does not need long-term storage since mostly seasonal produce is sold. This reduces the GHG emissions. Since there are no pesticides used, the soil quality and the local biodiversity benefit. Unfortunately, there is no clear method to determine the impact on biodiversity, but it is assumed the biodiversity is less impacted with AFNs than with conventional systems since little to less pesticides are used, and the soil quality is looked after. The AFNs can therefore also support the achievement of SDG 2.4 (ensure sustainable food production systems) and SDG 12 (sustainable consumption and production), since AFNs can be categorized as sustainable. The results of the environmental impact assessment are mostly representative for all AFNs in the Netherlands, with exception of transportation and packaging. However, as can be seen in the results, the values of emissions are relatively close to each other.

It can be concluded that this research partly contributed to filling the research gap, since research about the environmental impact of AFNs was lacking. Also, with the proposed definition, a good starting point is created for further research. However, it is necessary that more data is gathered, and that the study is extended with multiple crops, since different crops might have different impact on the environment when comparing conventional food networks and alternative food networks. This will improve the research and give more insight in the potential contribution AFNs can have in the transition to sustainable agriculture in the Netherlands.

Moreover, all selected AFNs state they consider soil quality and biodiversity to be of great importance, however clear agreements between farmers and organizations are lacking.

Therefore, it is strongly recommended to get more insight in the quantitative data of production in AFNs, and that agreements are made about environmental sustainability. It could be favorable for all AFNs to make unambiguous agreements about environmental benefits, because currently, the organizations mostly have a 'gentlemen's agreement' about the environmental preservation practices. All interviewees believe expending their businesses would be beneficial for a more sustainable relation with the Dutch food production and to pose an alternative for the Dutch conventional food systems. However, the interviewees of the non-profit AFN also stated that expanding their business is not likely to happen on the short term, considering that it requires a change in organisation which is difficult when the business is run by volunteers.

Lastly, to reduce the GHG emissions, the way of transportation of the produce in an AFN should be improved. Since the distances are relatively short, it would be beneficial to change the mode of transport, like electric vehicles, or in the case of VOKO, not individual passenger cars. Most benefit to reduce the GHG emissions can be found in the production of the crops. However, since general organic production was investigated, the AFNs might have lower GHG emissions due to their own production methods. Nonetheless, this data was not available, so it is recommended that the AFNs investigate and devise their own networks more thoroughly.

Differences between the environmental impact of conventional food networks and AFNs are not large but AFNs make use of seasonal products, which are produced and sold locally and fresh, lead to more transparency, and actively preserve the environment and local biodiversity. Because of their positive impact on the environmental and large potential AFNs are an essential aspect in the transition to environmentally sustainable agriculture in the Netherlands.

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Appendix A

First the questionnaire is presented that was used during the semi-structured interviews. The transcripts of the interviews can be requested by the author of this thesis.

<u>Questionnaire AFN stakeholders*</u>
* This is a general format of questions that were asked. Interview itself is semi-structured and more conversation based.

General

1. Can I record this conversation?
2. Can I use your (organisations) name in my study? (if you change your mind after the interview, please let me know)
3. How would you describe your company/organization?

[Farmers]

4. What kind of vegetables/fruit do you produce?
5. Do you only sell seasonal produce, or do you make use of a greenhouse or other methods that ensures diverse produce all year?
6. Where do you sell your produce?
    a. Would you say your products are more expensive than in the supermarket?
        i. If so, why do you think that is?
7. How are the produce transported to the place it is sold?

[Intermediary organization]

8. What kind of products and service do you sell?
9. Where are your products coming from? (biological, conventional, other, closeby, far away)
10. Do you only sell seasonal products?
    a. N: Where do the out of season products come from?
11. How do you select your producers?
    a. Do you collaborate with conventional farmers?
12. What is the distance (on average) from the farmers to your location?
13. Where do you collect the produce?
14. Where do you sell the produce?
15. How are the produce transported?
16. Are you a profit or non-profit organization?

Alternative Food Network

17. Have you ever heard of the term AFN?
    a. Y: How would you explain it?
    b. Y: Would you consider yourself to be part of an AFN?
        i. Which type?
    c. N: [Explain] – do you recognize yourself as such network?
18. *[You do have a different way of farming (non-conventional), why do you think there are still so many businesses that do not take action in regard to alternative ways of farming?]*
19. *[Do you get funding for your way of practicing agriculture?]*

Circularity

20. When do you think an agricultural practice is circular?

21. Do you think your business/practices are circular?
22. How do you think your business/practices could become more circular?
23. *[Do you know if 'your' farmers take circularity into account?]*

Environmental sustainability

24. When I talk about environmental sustainability, what do you associate with that?
    a. Can you give an example?
25. Do you take actions to secure environmental sustainability in your core business/practices?
    a. If so, why and how?
    b. If not, why not?
26. *[Do you use fertilizers?]*
    a. If so, why and what kind?
    b. If not, why not?
27. *[Do you use pesticides?]*
    a. If so, why and what kind?
    b. If not, why not?
        i. How do you overcome pests?
28. How do you describe biodiversity?
    a. Do you consider biodiversity when practicing your way of agriculture?
    b. Is it a prerequisite that farmers take biodiversity into account?
29. Do you know how much CO_2 your practice emits (storage, electricity of the building, type of transportation)?
    a. If so, how much?
    b. If not, how come?
30. *[Do you know how much water you use?]*
    a. If so, how much?
    b. If not, how come?
31. *[How do you measure the quality of your soil?]*
    a. If so, how much?
    b. If not, how come?

Quality of product and upscale

32. *Do you think the quality of your food is better than that of conventional farming?*
33. Do you consider expanding your agricultural practice/your business?
    a. How?

Closing

34. Do you have relevant data/literature that I can use for my study?
    a. May I use this data for my research. If wished for, I will anonymize your organization
35. Do you have questions for me?