BOTTOM-UP MODELLING OF URBAN FOOD-SYSTEMS AND THEIR ENVIRONMENTAL IMPACTS

Case study of the environmental impacts of Almere's food consumption

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ABSTRACT

The current food-system is highly unsustainable as it is responsible for up to 50% of all anthropogenic environmental pressure. Therefore, there is a need to transform the current food-system, in particular the demand-side. Cities form the agglomeration of food consumption with limited capacity for food production. Addressing urban consumption and the inherent environmental impacts are considered key factors for climate change mitigation. In order to develop sustainability strategies for a city, a baseline assessment of urban food consumption and environmental impacts is required. A bottom-up approach is suggested to be suitable for consumption-based accounting of urban food-systems. However, there is no consensus on this approach nor the implementation of it due to a lack of modelling experience and data on urban food-consumption.

The aim of this thesis was to explore the bottom-up modelling approach for consumption-based accounting of urban food consumption. Almere was used as a case-study to explore how a robust bottom-up model can be designed. Hereby, the study aimed to contribute to the debate on suitable modelling approach and the otherwise lack of urban food-systems studies. Lastly, it aimed to provide recommendations for Almere to develop sustainability strategies.

The hybrid UM-LCA method was used to develop a bottom-up model for Almere. Dietary data was used as a basis to model the annual consumption of the city and therefrom the associated food-system was modelled. Primary data acquisition on the food purchasing behaviour of the citizens of Almere was done by means of a survey (N=663).

The annual consumption of Almere is estimated at 156 k tons of food per year. This includes food that is eaten and wasted by retail, food-services and households. The environmental impacts on air, water and land were modelled for the food-system of Almere by using three indicators. The Global Warming Potential (GWP) was estimated between 351 - 411 k tons CO_2 eq. emissions per year. Freshwater Eutrophication Potential (FEP) was estimated between 153 - 169 tons P eq. deposition and the Agricultural Land Occupation (ALO) between 174 - 189 km^2 per year. However, further research is recommended for both the FEP and ALO to increase reliability.

Production and processing of the food were responsible for the largest share of environmental impact for each indicator (≥86%). The food categories with the highest impact were meat, dairy and beverages. Therefore, it is recommended to encourage dietary shifting in Almere. Besides production and processing, a considerable share of environmental impact was generated by the distribution of food to suppliers (15% of the GWP). In particular, air freight had a significant contribution and therefore it would be recommended to avoid this mode of transport. Additionally, grocery shopping had a considerable impact as the majority of travel was done by motorized modes, mainly cars. It is recommended to decrease this by encouraging modal shifting to bike and walking. Currently, only 0.85% of the consumed food is purchased directly at the farmer. Further research into the flows of regionally produce through other retailers is needed to determine the total share of regional production of Almere's consumption.

In general, it is relevant to explore the opportunities to receive consumption data from retailers, as dietary data is considered an essential element in bottom-up modelling of urban food-systems. It can be concluded that bottom-up modelling of food-systems is challenging but provides much-needed insights to start the transformation towards a sustainable food-system.

Keywords: Urban food consumption, Food-systems, Environmental impact, Consumption-based accounting, Bottom-up modelling, UM-LCA method, Almere

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LIST OF ABBREVIATIONS

ALO	Agricultural Land Occupation
CO_2 eq.	Carbon-dioxide equivalent
CBA	Consumption-based accounting
FEP	Freshwater Eutrophication Potential
GHG	Greenhouse Gases
GWP	Global Warming Potential
IE	Industrial Ecology
IO	Input-Output
LCA	Life-Cycle Assessment
MFA	Material Flow Analysis
P eq.	Phosphorous equivalent
UDC	Unique demographic combination
UM	Urban Metabolism

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1. INTRODUCTION

The current global food-system is highly unsustainable (Willett et al., 2019). Up to 50% of all anthropogenic environmental pressure is caused directly and indirectly by the global food-system (Campbell et al., 2017). Globally, the food industry is responsible for about 20-30% of the greenhouse gas (GHG) emissions (Gerber et al., 2013). Besides climate change, agriculture has a major role in crossing the planetary boundaries of biodiversity, land-system change and perturbation of the phosphorus and nitrogen cycles (Steffen et al., 2015; Campbell et al., 2017). Also, food demands are expected to rise by almost 70% as a consequence of the predicted global population growth to nearly 10 billion by 2050 (FAO, 2018). Apart from being unsustainable, the current food-system is also unhealthy and unequal, causing both malnutrition and overweight (WHO, 2016; Willett et al., 2019). Without a transformation of the global food-system, it is likely to fail the Paris Agreement and Sustainable Development Goals, and further degrade the planet for future generations (Willett et al., 2019). Thus, it is considered paramount to change the global food-system in order to stay within the planetary boundaries (Campbell et al., 2017).

The versatility of the problems with the current food-system indicates that a sustainable transformation should not solely focus on the production (supply-side) but also on the consumption (demand-side) (Willett et al., 2019; Boersma et al., 2018). The demand is formed by the consumers, in other words people. Currently, half of the global population is urban and this is expected to increase to 70% by 2050 (UN, 2018). In addition, not only the size but also affluence of urban populations continues to grow (Kennedy et al., 2014). This especially made Western diets more meat and dairy heavy, causing livestock farming to constitute about one-sixth of the global GHG emissions (Gerber et al., 2013). Furthermore, affluence and globalization have resulted in an almost endless variety and year-round availability of foods regardless of the season and origin (Steel, 2008; Westhoek et al., 2013), and especially regardless of the environmental impacts. Food consumption has become seemingly limitless and inconsequential (Steel, 2008). Similar to other resource usages, food consumption is concentrated in urban areas (Rees & Wackernagel, 2008). Therefore, cities are considered the designated place to start the transformation towards sustainable consumption (Garnett, 2011; Boersma et al., 2018; C40, 2018).

Before urban sustainability strategies can be developed, it is necessary to know what the current impacts of the urban food consumption are. A baseline assessment is needed to get an insight in what is urgent and relevant to tackle. To establish a baseline, it is essential to quantify the urban food consumption and determine all related environmental impacts involved in the production and supply of this food to the citizens (Goldstein et al., 2017). The quantification of embedded impacts of consumption is also called consumption-based accounting (CBA) (Davis & Caldeira, 2010).

CBA can be performed in different ways using a top-down or bottom-up approach (Larsen & Hertwich, 2009). The top-down approach uses national data on food production and trade to extrapolate the average consumption per capita and, thus, estimate the food consumption of a city. However, the top-down approach is considered relatively unspecific and undetailed (Jansen & Thollier, 2006). In a bottom-up approach on the other hand, data on food consumption behaviour is gathered in the city itself. Urban food consumption is formed by countless individual food choices of citizens (Steel, 2008; Wertheim-Heck & Lanjouw, 2018). These decisions are not solely about the type of food but also about the production origin (local or global), the type of food supplier to purchase from and the mode of transport used for shopping. Cultural background and urban context also strongly influence these food decisions (Darmon & Drewnowski, 2008; Dekker et al., 2011). As ethnic minorities are predicted to become the majority in most Western cities during this century (Smith & Waldner, 2018), incorporating urban population diversity when analyzing urban food-systems is considered important (Wertheim-Heck & Lanjouw, 2018). Thus, a bottom-up approach is arguably more suitable to assess the impacts of urban food consumption (Goldstein et al., 2017). Neglecting the urban context and diversity may result in inept strategies that will fail to transform the system (Wertheim-Heck & Lanjouw, 2018).

Urban food-systems are heavily understudied compared to other urban systems such as the energy, water and transportation system (Goldstein et al., 2017). Thus, there is a lack of data on urban food consumption and a lack of modelling experience. Therefore, there is no widely supported consensus on whether bottom-up modelling is more suitable and how to implement this approach (Larsen & Hertwich, 2009). Previously, urban bottom-up studies have mostly focussed on other urban systems or the broad consumption of commodities within cities in general (Jansen & Thollier, 2006; Hoekstra & Chapagain, 2007). Therefore it is important to investigate the implications of utilising a bottom-up modelling approach for CBA of the urban food consumption.

Problem Statement

There is a need to develop strategies to transform the current food consumption because of it is unsustainable. In order to develop such strategies for a city, a baseline assessment of urban food consumption and environmental impacts is required. A bottom-up approach is suggested to be more suitable for consumption-based accounting of urban food-systems. However, there is no consensus on this approach nor the implementation of it due to a lack of modelling experience and data on urban food-consumption.

1.1. Aim & Research Questions

To address this problem, the study aims to explore the bottom-up modelling approach for consumption-based accounting of urban food consumption. The objective of this study is to explore this in practice by means of a case-study. This provides modelling experience which can be used for learnings and as a comparison to other studies and general literature on bottom-up modelling. Hereby, the study aims to contribute to the debate on the suitable modelling approach for consumption-based accounting of urban food consumption. In addition, by developing a case-study model this research project aims to contribute to the otherwise lack of bottom-up food-system studies.

The Dutch city Almere was used as a case-study for the bottom-up modelling. Almere is the fastest growing and 8th largest city in the Netherlands (CBS, 2019a). It is situated at the edge of food consumption and production, as it is part of both the Metropolitan Region of Amsterdam (MRA) and the rural province Flevoland which has the highest arable farming yields (Boersma et al., 2018). The advantages and challenges of bottom-up modelling are investigated and it is explored what elements are essential to develop a robust food-system model. A robust model forms a strong and reliable foundation to assess the environmental impacts of the urban food-system of Almere and therefrom develop sustainable transition strategies. Models estimate potential impacts and can be used to describe the role of different aspects within the system and their impacts in proportion to each other. A robust model is a model that has a low sensitivity to changes in the assumptions and that is reliable enough to describe the proportional impacts despite the assumptions.

With the specific case-study of Almere, this research aims to contribute to the larger research project on the economic and environmental impacts associated with Almere's current and future food-system by PhD researcher Liesbeth de Schutter and Professor Dr. Ir. Eveline van Leeuwen in collaboration with Flevocampus. Lastly, this study aims to help Almere to bring their sustainable food ambitions into practice by providing recommendations for potential focal points for sustainability strategies.

Research Questions

The main research question for this thesis is as follows:

How can a robust bottom-up model for consumption-based accounting of urban food-systems be designed?

In order to investigate the main research question, three sub-questions have been derived:

1. What elements are needed to develop a robust bottom-up model?
2. What is the total annual consumption of Almere and what does the food-system associated with this consumption consist of?
3. What is the environmental impact of Almere's food-system and which aspects can be identified as potential focal points for sustainability strategies?

1.2. Outline of the report

In the following chapter, the theoretical framework used for this research will be discussed. The concepts supporting CBA and bottom-up modelling will be provided. Also, the method used for bottom-up modelling of the case-study will be introduced. In the chapter methodology, the implementation of the different methods to design the case-study model will be discussed in detail. This is followed by the results which consist of three chapters (Figure 1). First, the results from the survey on food-purchasing behaviour will be provided. Then the food-system model for Almere is presented, which answers the second research question. This is followed by the environmental impact assessment of the system, which answers the first part of the third research question. In the discussion elaborates on findings which need further research and which can be used as recommendations for Almere. In the discussion it also evaluated what elements are needed for bottom-up modelling in general, answering the first research question by the learnings from the case-study. Finally, in the conclusion, the main results from the bottom-up modelling experience will be summarized and recommendations are provided for the municipality of Almere.

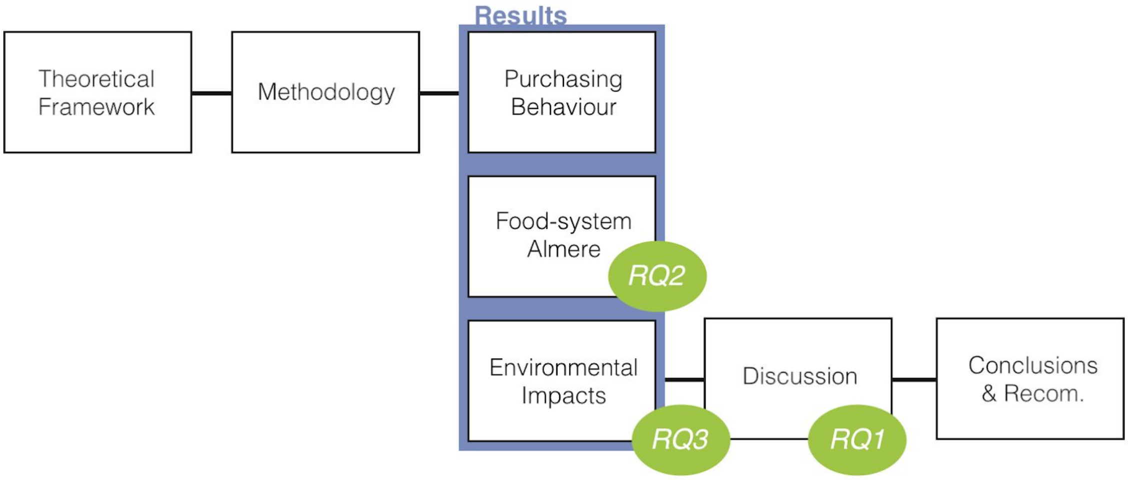

Figure 1. Diagram of the outline of the report.

THEORETICAL FRAMEWORK

2.

This chapter will provide the theoretical framework that serves as the foundation for this research. The framework has been developed to connect the relevant theories and concepts and form a funnel-shaped focus (Figure 2). It is used to determine the appropriate method for the case-study in this research. The theoretical framework starts from the General Systems Theory which through system-thinking provides the foundation for the field of Industrial Ecology (IE). Hereafter, the different levels of the frameworks are elaborated in detail, beginning with IE, followed by consumption-based accounting (CBA) and the two different modelling approaches within CBA; bottom-up and top-down. Finally, the hybrid method that follows from this converging framework will be introduced.

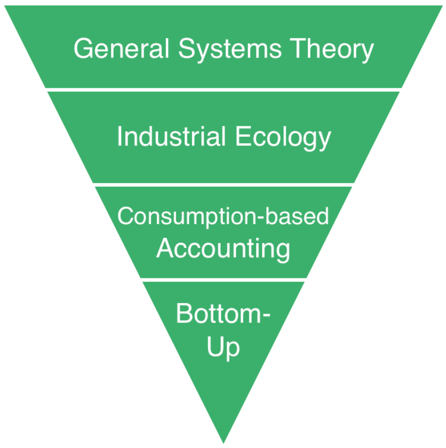

Figure 2. Conceptual illustration of the different layers in theoretical framework.

2.1 Industrial Ecology

IE is rooted in the General Systems Theory which was first mentioned by Bertalanffy in the 1960s and aims to provide concepts and principles that apply to all systems (Decker et al., 2000). Herefrom the concept of system-thinking arose, which forms an interdisciplinary analytical approach. System-thinking aims to analyse how parts of a system interact with each other and within the context of larger systems and the environment over time (Hammond & Dubé, 2012). This system perspective forms the foundation for the field of IE, which studies the nature and scale of material and energy exchanges between (different) socio-technical systems and their environment (Graedel & Allenby, 2010; Goldstein et al., 2017). The term IE is an analogy to biological ecology in which interactions between organisms and the physical environment are studied. A key aspect of inspiration is the natural cycles in which all substances are reused and waste is inexistent. Projected to industrial systems, IE seeks to optimise material cycles in order to develop a sustainable system (Graedel & Allenby, 2010). IE provides various concepts and methods for the examination of systems and accounting of environmental impacts.

2.2. Consumption-based Accounting

Traditionally, accounting has been based on an inventory of the impacts arising from the production in a certain country or region. This is known as production-based accounting (PBA) (Davis & Caldeira, 2010). A common example of PBA is national carbon accounting. Here, focus solely lies on the CO_2 emissions directly emitted by the country, whereas embedded emissions from production and distribution in imported goods are excluded (Davis & Caldeira, 2010). However, wealthy countries with high consumption patterns import many of the consumed goods from other countries, often called production countries. Therefore production-based accounting is considered unjust and misleading (Larsen & Hertwich, 2009; Davis & Caldeira, 2010; Barrett et al., 2013; Fan et al., 2016). Contrarily, CBA considers all the goods consumed in a region and includes all the embedded environmental impacts involved in their production and distribution (Davis & Caldeira, 2010) (Figure 3). In this way, CBA reveals the environmental impact of (over)consumption and aims to put the responsibilities of these impacts at the consumers rather than the producers (Barrett et al., 2013). Arguably, sharing responsibility can help solve concerns over emission inequities, enable global climate policies and thereby increase the chances of achieving the Paris Agreements and Sustainable Development Goals (Davis & Caldeira, 2010) Therefore, many researchers and organisations argue for CBA instead of PBA (Larsen & Hertwich, 2009; Davis & Caldeira, 2010; Barrett et al., 2013).

Some argue that the differences between PBA and CBA for carbon emissions are relatively small on a national level (Franzen & Mader, 2018). However, it is important to consider environmental impacts beyond carbon emissions, especially in the case of food. Food has a substantial impact on other aspects of the environment as well, such as usage and pollution of water and land (Campbell et al., 2017). Moreover, when studying the environmental impacts of cities instead of countries, the reason for applying CBA becomes evident. Cities typically form the agglomeration of intensive consumption with limited capacity for primary production (Steel, 2008). Hence, the majority of consumption-related impacts within cities are imported from other regions (Larsen & Hertwich, 2009; Mi, et al., 2016). And as urbanisation continues to grow, so will the environmental impacts of cities. Addressing urban consumption and the inherent environmental impacts are considered key factors within climate change mitigation (Larsen & Hertwich, 2009; Feng et al., 2014). Therefore, assessing the impacts of urban food consumption is only relevant when using of CBA (C40, 2018). There are different modelling approaches that can be used for CBA, which represents the final level of the theoretical framework utilised in this study (Figure 2).

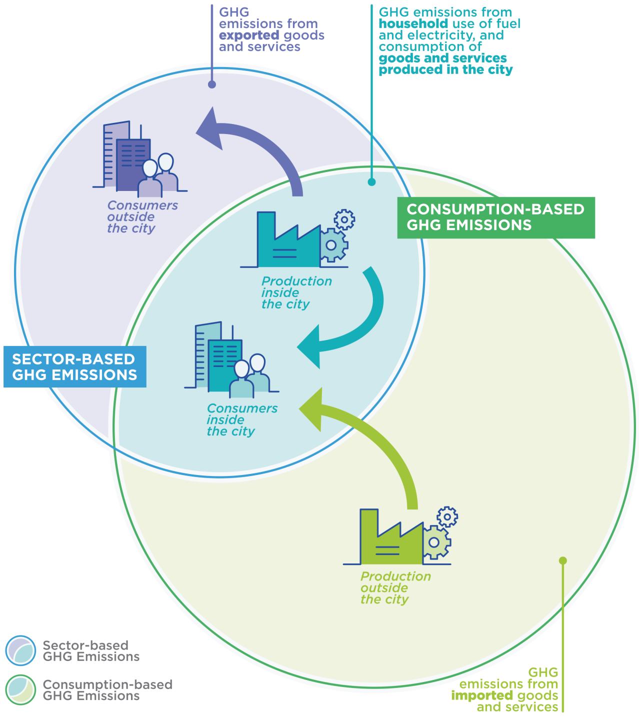

Figure 3. Illustration of the different scopes for Production (Sector) and Consumption-based accounting. (Source: C40, 2018)

2.3 Modelling Approaches

Within CBA, a distinction is made between bottom-up and top-down modelling approaches (Larsen & Hertwich, 2009). Top-down modelling allocates national consumption impacts to a certain region, like a city or municipality, based on the population. It is usually based on national data on production and trade, derived from so-called national Input-Output tables (Larsen & Hertwich, 2009) (Figure 4). When deducting the export from the production and adding the import, an estimation of the annual national consumption can be made. Based on the population, an estimation for a specific region can be derived.
Conversely, in bottom-up modelling, data on consumption (impacts) is gathered on a local scale (Larsen & Hertwich, 2009). Based on specific data on the consumption behaviour of (groups of) citizens, the annual urban consumption can be estimated (Figure 4). The impacts are often modelled by life-cycle assessments (LCA) per product or service (more detail on LCA will be provided in section 2.4.). The advantages and challenges of the different modelling approaches have been studied through literature research (Table 1).

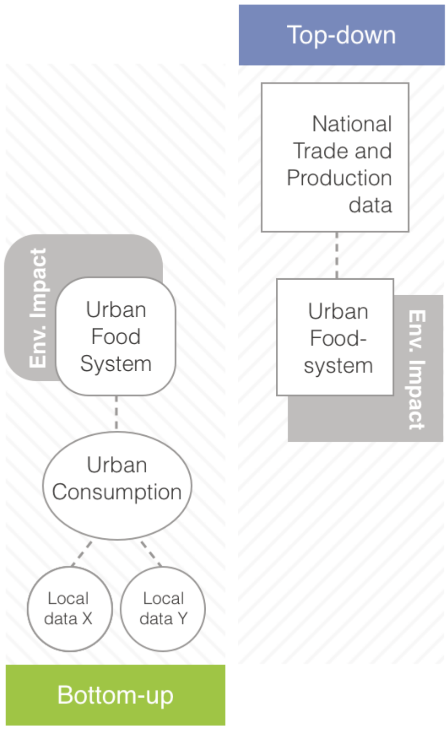

Figure 4. Conceptual illustration of the bottom-up and top-down approach.

The major advantage of the bottom-up approach is that it provides a highly detailed model with context-specific consumption information that connects to citizens their daily lives (Jansen & Thollier, 2006; Hoekstra & Chapagain, 2007; Larsen & Hertwich, 2009). This high level of detail enables to identify specific products (categories) or processes that have the highest environmental impact (Jansen & Thollier, 2006; Hoekstra & Chapagain, 2007). Also, the level of detail enables to develop scenarios in which tangible products or local parameters for processing can be altered, in order to model the effects of (proposed) product-specific or local policies (Jansen & Thollier, 2006). Theoretically, the detailed model also enables monitoring of the effects of such policies to determine the most effective strategy. However, this is often not feasible in practice due to time-related challenges.
Bottom-up modelling has proven to be extremely time-consuming due to several reasons (Jansen & Thollier, 2006; Yang et al., 2006; Larsen & Hertwich, 2009; Goldstein et al., 2013). Firstly, gathering consumption data on a local scale is highly time-consuming due to the immense number of diverse products and services, consumed within cities (Yang et al., 2006; Goldstein et al., 2013). Secondly, assessing the life cycle impacts of a single product is an extensive process, hence, the assessment of the impacts of all products consumed in cities is hardly possible within a reasonable time-frame (Jansen & Thollier, 2006; Goldstein et al., 2013). Therefore, repeating data collection and modelling regularly is challenging, making monitoring unfeasible in practice (Jansen & Thollier, 2006; Larsen & Hertwich, 2009). Without possibilities for monitoring and benchmarking on e.g. a yearly basis the model is less valuable and merely a snapshot (Larsen & Hertwich, 2009). Furthermore, bottom-up models are not comparable by definition, as there are no standards for the local data collection, the assumptions made nor the method used for the impact assessments (Larsen & Hertwich, 2009).

The top-down approach, on the other hand, is able to provide insight in the order of magnitude of environmental impacts of a given region using considerably less time and resources (Tukker & Jansen, 2006; Larsen & Hertwich, 2009). Therefore, top-down models are more easily repeated and practical for benchmarking between different regions or time periods. Furthermore, IO-matrices cover the entire economy of exchanges, thus, it avoids errors resulted from cutting off recursive loops which is inevitable in LCA's in bottom-up models (Larsen & Hertwich, 2009; Goldstein et al., 2013).
However, top-down models are relatively undetailed, as national data is often provided in broad categories and includes uncertainties because it is based on national averages that may not fit a given region (Tukker & Jansen, 2006; Larsen & Hertwich, 2009; Goldstein et al., 2013). Hence, it makes the modelling and monitoring of the effect of product-specific policies or local policies impossible (Larsen & Hertwich, 2009; Tukker & Jansen, 2006). Moreover, it is not possible to identify specific products and processes with a high environmental impact. However, comparative research has shown that on a higher level of broad product categories, very similar impact contributions are found for both models (Tukker & Jansen, 2006). The relatively rapid impact assessment produced in top-down modelling compared to the bottom-up approach makes it feasible for identifying categories having major environmental impacts (Tukker & Jansen, 2006). Lastly, the IO-matrices are often a few years old when they are published, so despite the time savings during modelling, top-down models are not necessarily more recent than bottom-up models (Larsen & Hertwich, 2009).

Conclusively, neither of the modelling approaches is generally preferable over the other, as they have rather opposite benefits and challenges (Table 1). Both approaches depend heavily on the quality of existing and gathered data. Depending on the goal and scope in combination with available time and resources for a certain project, a practical decision has to be made for an approach. When deciding on a bottom-up approach several methods are available of which one will be discussed in the last section of this chapter.

Table 1. The bottom-up and top-down approaches within CBA, their related advantages and challenges.

	Bottom-up modelling	***Top-down modelling***

Advantages	- Highly detailed model enables: [1,2,3]
	  - identification of impact contributions of specific products or processes
	  - scenarios development to calculate effects of proposed local or product-specific policy
	  - monitoring of the effects of local or product-specific policy and determine effective strategy (in theory)
		- Relatively fast order of magnitude of overall impact enables: [3,6]
		  - identification of categories with a high impact contribution
		  - benchmarking and monitoring on a higher level because repetition is feasible
		- avoids cut off errors by covering the entire economy of exchanges [3,5]

Challenges	- Extremely time consuming due to high amount of products to gather data on, that need LCA which is exhaustive process [1,3,4,5]
	  - difficult to repeat on yearly basis; monitoring is not feasible
	- Comparability issues [3]
	  - no standardisation for bottom-up data collection procedures
	  - assumptions in LCA scope and cut offs
		- Undetailed due to broad categories & uncertainties because it is based on national averages [3,5,6]
		  - only scenario making on broad categories is possible
		  - only high-level monitoring possible; can not measure the effects of local or product specific policy

1) Jansen & Thollier, 2006; 2) Hoekstra & Chapagain, 2007; 3) Larsen & Hertwich, 2009; 4) Yang et al., 2006; 5) Goldstein et al., 2013; 6) Tukker & Jansen, 2006.

2.4 A suitable bottom-up method

The field of IE provides several concepts and methods for CBA using a bottom-up approach. For the assessment of environmental impacts, the life-cycle assessment (LCA) is the most established method. For the analysis of urban systems, the concept of Urban Metabolism (UM) is widely used. Goldstein et al. (2013) suggest a hybrid method in which the concept of UM is embedded in the LCA, to complement each other and combine the strengths. First, the UM concept and the LCA will be discussed separately in their conventional form. Finally, the hybrid UM-LCA method will be introduced, which is proposed as a suitable method for this case-study in line with the theoretical framework.

2.4.1. Urban Metabolism

UM specifically focuses on material and energy exchanges between a specific urban area and its surrounding environment (Goldstein et al., 2017). Similar to Industrial Ecology (IE), the concept of UM is an analogy to biology. In biology metabolic analysis is the study of processes within certain boundaries, e.g. an organism or cell (Graedel & Allenby, 2010). The method commonly used for this is the Material Flow Analysis (MFA) (Graedel & Allenby, 2010). A MFA is an accounting of all material and energy flows that are going in and out of a socio-technical system. MFA is always executed for a specific system that is defined by location- and time-specific boundaries (Laner & Rechberger, 2016). In the case of UM, this system is always a city. Usually, only a selection of flows is studied, depending on the scope and aim of the project, because incorporating all urban flows is quite extensive (Goldstein et al. 2013). In addition to studying in- and output flows, UM also studies the metabolic processes, meaning the connections and transformations of these flows within the urban network (Graedel & Allenby, 2010). However, UM only describes material exchanges, and not the environmental impacts of them, which is considered a shortcoming (Goldstein et al., 2013).

2.4.2. Life Cycle Assessment

LCA is a method to quantify the impacts of a certain product, process or service on the environment (Hauschild, 2005). The concept of LCA was developed in the 1990s with the aim to widen the focus in environmental impact assessments from the production to the complete life cycle of products (Graedel & Allenby, 2010). Typically, a product life cycle consists of about five different phases; (extraction and) production, manufacture, distribution, use and end of life. The goal of LCA is to quantify material flows, specify their potential impacts on the environment and consider alternatives in order to decrease negative impacts (Graedel & Allenby, 2010).
In order to standardise the LCA method a framework has been determined by the International Standards Organization (ISO), which provides a framework containing four elements; goal & scope definition, inventory analysis, impact assessment and interpretation. The *goal & scope* determine the type of product or process that is studied, and the boundaries for the LCA in space and time, level of detail and the life cycle phases considered. In the *inventory analysis,* quantitative data is gathered on the energy and materials used throughout the life cycle and the resulting outputs to the environment, e.g. emissions. In the *impact assessment,* these outputs are translated into environmental impacts. Throughout, the entire process interpretation takes place resulting in iterations.
LCA has internationally been recognized as a complex but valuable and effective tool for impact assessment (Graedel & Allenby, 2010). However, it is usually used to evaluate specific products or processes rather than entire systems, such as an urban food-system.

2.4.3. UM-LCA method

The UM-LCA is as a hybrid of the two methods (Goldstein et al., 2013). The strength of the UM lies in the quantification of urban material and energy flows but it lacks the translation to environmental impacts, which is the strength of the LCA. By combining the methods they can complement each other and provide a method to analyse urban systems (Goldstein et al., 2013).

As mentioned, a life cycle usually consists of about five different phases; production, processing, distribution, use and end of life (Figure 5). Often transport occurs between all phases, which is accounted for. Since distribution towards the consumer is often the most significant transport, this is depicted as a separate phase. According to the UM-LCA method, the UM can be considered the use or consumption phase in the life cycle of an urban system (Figure 5) (Goldstein et al., 2013). The inputs and outputs analyzed in the MFA for the UM can be aligned with the inputs and outputs of the consumption phase. The results from the UM form the foundation for the other phases going upstream and downstream from the use phase. The upstream processes go 'backwards' into the life-cycle and consist of the phases distribution, processing and production. The downstream processes continue from the use phase and form the end of life. In this way, the use or consumption phase forms the starting point for the UM-LCA and enables bottom-up modelling for CBA of urban systems. It must be noted that the UM-LCA method is still relatively new and has mostly been compared to each method independently, but successfully shows to be more elaborate (Goldstein et al., 2013).

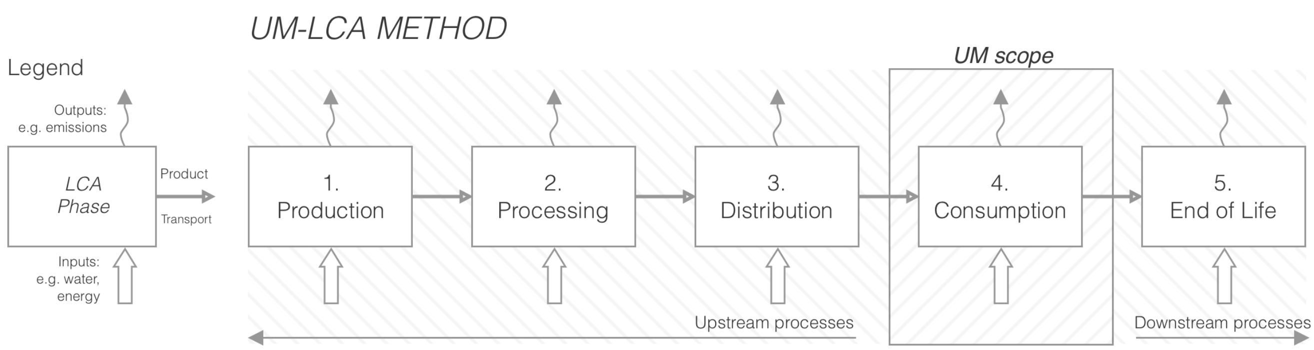

Figure 5. Life cycle phases in the UM-LCA method *(Goldstein et al., 2013).The urban metabolism (UM) scope is equal to the consumption phase.*

METHODOLOGY

3.

The aim of this research is to explore bottom-up modelling by using the hybrid UM-LCA method as described in the last chapter. First, a MFA of the consumption of Almere will be conducted, which results in the UM. The UM forms the foundation for the LCA in which the entire supply chain is modelled. For both methods, bottom-up data is required. According to literature, bottom-up data gathering is a challenging but essential aspect of this modelling approach. Due to limitations in time and resources, it is not possible to gather all the necessary data bottom-up personally. Therefore, a mixture of primary and secondary data was gathered. For the primary data acquisition, a survey has been developed and distributed in Almere. Additional data was gathered by using secondary data from existing bottom-up studies. Eventually, by combining various data sources, a bottom-up model could be developed.

This chapter will elaborate on the implementation and combination of these methods. First, relevant background information on the case-study Almere will be provided. Next, the primary data acquisition by means of the survey will be discussed. Lastly the execution of the UM-LCA method will be described in detail.

3.1. Case-study Almere

The municipality of Almere is used as a case-study to investigate the modelling approaches. Almere is the youngest city in the Netherlands but also the fastest-growing municipality and the 8th largest city with 203,990 inhabitants in 2018 (CBS, 2019a). The city possesses many characteristics of current and future urban challenges, such as urbanization. Further background on the history, population and location will be provided in order to illustrate this.

3.1.1. Historical background

Amsterdam experienced great population growth after the second world war resulting in a housing shortage (Cammen & Klerk, 2003). The southern parts of Flevoland had just been drained in the 1960s, offering opportunities just 30 kilometres away (Bazelmans, 2011). Almere was built as a refuge from the densely populated expensive capital, and the garden city design with multiple centres offered a green spacious environment (Van Dijk et al., 2017). The first houses were built in the late 1970s and Almere became an official municipality in 1984. Housing policy focussed on uniform, functional, inclusive housing, and therefore 80% was social-housing in the first years (Cammen & Klerk, 2003). This changed when new city districts were built and also more exclusive and 'free-sector' housing was provided. In 1990 the municipality had grown to 40,000 inhabitants, mostly former Amsterdammers, and in 2000 it doubled to a city of 100,000. In 2016, Almere reached 200,000 inhabitants and it still remains the fastest-growing municipality in the Netherlands (CBS, 2019a), with an expected increase to 350,000 in 2030 (PBL, 2016). Currently, the city consists of five districts, of which Haven is the oldest and Poort is the newest. Stad and Buiten are most densely populated and a sixth district (Pampus) is under development (Figure 6).

3.1.2. Population characteristics

A large share of the population influx of Almere has always come from people moving away from Amsterdam. About 28% of Almere's population was even born in Amsterdam (CBS, 2012). The spacious character of Almere and relatively affordable housing has since 2000 especially attracted citizens with a migration background (OIS, 2004). For example, in 2003 roughly 3700 people moved from Amsterdam to Almere, of them two-thirds had a migration background, of which half from Suriname. Hereby, Almere has not only become one of the largest cities, but also a highly diverse one, with 153 different nationalities and 181 different ethnic groups (Almere municipality, 2019). Currently, 41.6% of the population of Almere has a migration background (CBS, 2019b). The largest ethnic minorities in Almere are Surinamese (11.4%), Moroccan (3.9%), Indonesian (2.9%), former Dutch Antilles (2.5%) and Turkish (1.8%). This is interesting because it has been predicted that minorities will become the majority in many Western cities during this century (Smith & Waldner, 2018). Similar to other Western cities, Almere faces healthcare challenges, specifically in relation to welfare diseases such as obesity. In Almere 54% of the population is overweight and 15% of the population is even obese, which is both above the national average of respectively 49% and 14% (GGD, 2016).

3.1.3. Production Province

Almere is part of what is called the Metropolitan Region of Amsterdam (MRA). At the same time, it is located in the highly rural province of Flevoland. This is the newest province in the Netherlands, made by reclaiming land from the sea during the 20th century to create 'polders' for agriculture (Bazelmans, 2011). The nutritious sea clay soil is the reason why Flevoland has some of the most fertile agricultural land on earth (Boersma et al., 2018. Combined with a temperate climate and highly developed farming techniques, Flevoland has one of the highest arable farming yields in the world (Boersma et al., 2018). In Flevoland mostly potatoes and onions are cultivated, each forming about a third of the annual production of the province (Ten Brug et al., 2018). Similar to food-production in the rest of the Netherlands, the majority of this production is exported outside the country (Boersma et al., 2018). Despite the proximity of production and consumption, the food-system of Almere is just like other Western cities, determined by the global market with international supply chains rather than regional chains (Ten Brug et al., 2018).

Almere has the ambition to increase the share of regional production within the city's annual consumption. Van Dijk et al. (2017) estimate that currently at most 5% is produced in Flevoland, but local farmers estimate that it is rather only 1-3%, depending on the season (Ten Brug et al., 2018). Either way, Almere has the ambition to increase this share to 20% regional production by 2020, though there seems to be no strategy yet to achieve this (Wertheim-Heck & Lanjouw, 2018). Still, this sets Almere apart from most other Western cities that do often not express any targets or ambitions to transform their food-systems (Goldstein et al., 2017).

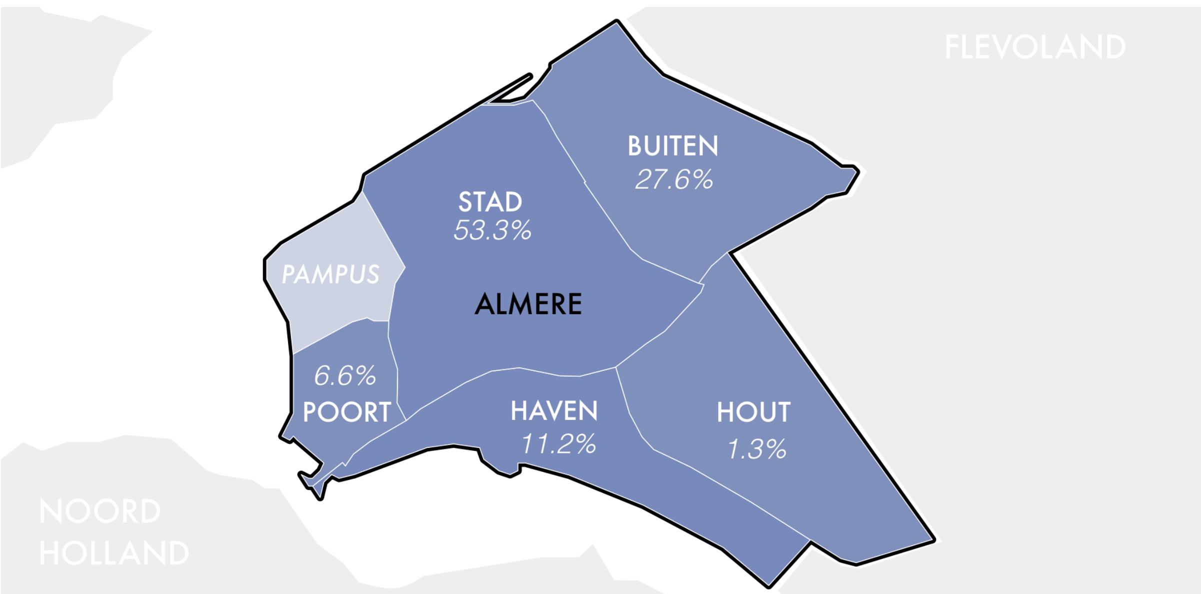

Figure 6. The municipality of Almere with its five districts Stad Buiten Haven Poort and Hout. Percentages indicate the share of the population in each district.

3.2. Survey on food-purchasing behaviour

This section will elaborate on the primary data acquisition by means of a survey. As mentioned, it is not feasible within this study to personally gather all bottom-up data, therefore a mixture of primary and secondary data will be used. A central aspect of urban food consumption are the diets of citizens (Steel, 2008). However, gathering dietary data is highly complex and requires assistance from nutrition experts. Also, it is highly time-consuming to gather enough data to establish reliable average diets for the population (Dekker et al., 2011). Fortunately, there are extensive dietary studies available that can be used as secondary data sources, which is further discussed in the inventory for the UM-LCA (3.3.2.).
Besides diets, urban food consumption is determined by the food purchasing behaviour of citizens; how and where do citizens buy their food. Almere is atypical from most Dutch cities because it was built as a spacious garden city with multiple districts. Therefore it is not as dense, enables mobility by car and has multiple city-centres with a.o. food retail and services. The two newest districts, Hout and Poort, have limited availability of food suppliers, while the others provide a large variety (Observations, April 2019). In addition to this, Almere is very close to food production, with some farmers right at the city borders. For these reasons the food purchasing behaviour of citizens, might be distinctly different from other Dutch cities. This behaviour significantly influences the upstream processes in the LCA. Therefore a survey was developed to gather primary bottom-up data for Almere. In the following sections the survey design, distribution and processing will be discussed.

3.2.1. Survey design

The survey focuses on food-purchasing behaviour which includes both grocery shopping and dining patterns. Initially, the survey also included disposal behaviour in order to cover part of the downstream processes. To test the survey before publication, it was taken as an interview by 10 random people in Almere. However, this showed that people tend to underestimate their food-waste because disposal is a relatively unconscious process and food-waste has a bad stigma. The (un)conscious underestimation of food-waste is a phenomenon that is well known in food-waste research (Hall et al., 2009). Therefore it was decided not to include disposal in the survey since the questions were perceived as too complex and the results would not be trustworthy.

The survey was executed online using Qualtrics XM survey software. The final survey consisted of 38 questions (Appendix A). The main parts of the survey focussed on grocery shopping and dining habits, and besides that basic demographics were asked. In the first sections it was investigated which channels are used for grocery shopping, how often and by which mode of transport. A distinction was made between different channels: supermarkets, speciality shops, markets, delivery services and farmers. After that, a specific section was made to focus on the purchasing of potatoes, vegetables and fruits, since these have the greatest potential to come through shorter supply chains. The second part of the survey focuses on dining habits. A distinction is made between preparation of food at home (AH) and out of home (OOH) at food services such as restaurants, fast-food and take-away services. Again it was investigated which services are used, the frequency of use and the transport mode used.
Respondents were asked to verify whether their food-purchasing behaviour covered their entire household or only themselves. In this way, each respondent will represent a household rather than a single citizen. In case respondents indicated that it only covers their personal food-purchasing behaviour these responses could be adjusted to cover the total number of household members they live with.

3.2.2. Survey distribution strategy

The survey was aimed for quantitative research since the data will be used for modelling. According to sample size calculations, a sample of at least 384 respondents was needed in order to generate a sample that is likely to be representative of the population of Almere (Appendix A). In order to attract enough respondents and increase completion rates, a dining gift card of 50 euros was raffled among the respondents. A dining gift card was considered a neutral prize that is able to appeal to everyone. Four different ways were used to distribute the survey (Table 2) (Appendix B).

Table 2. The four different distribution strategies and their effect.

Distribution	***Effectiveness***	***Details***
Flyers with QR codes on the streets of Almere	very ineffective (4 hours, 6 respondents)	flyering in person might result in bias even though it was attempted to approach people randomly
Postcard delivered to households in Almere	small effect (approx. 13% responded)	500 postcards (Figure 7) were distributed at a random selection of addresses that were made based on postcodes (Appendix B)
Posts on online platforms and communities of Almere	very effective (> 650 respondents)	platform owners were asked to share the survey to decrease potential bias caused by my personal profile
Survey taken as interview on the streets of Almere	small effect (2 days, 15 respondents)	due to a lack of 1 person households, an attempt to oversample was done by approaching people on the street

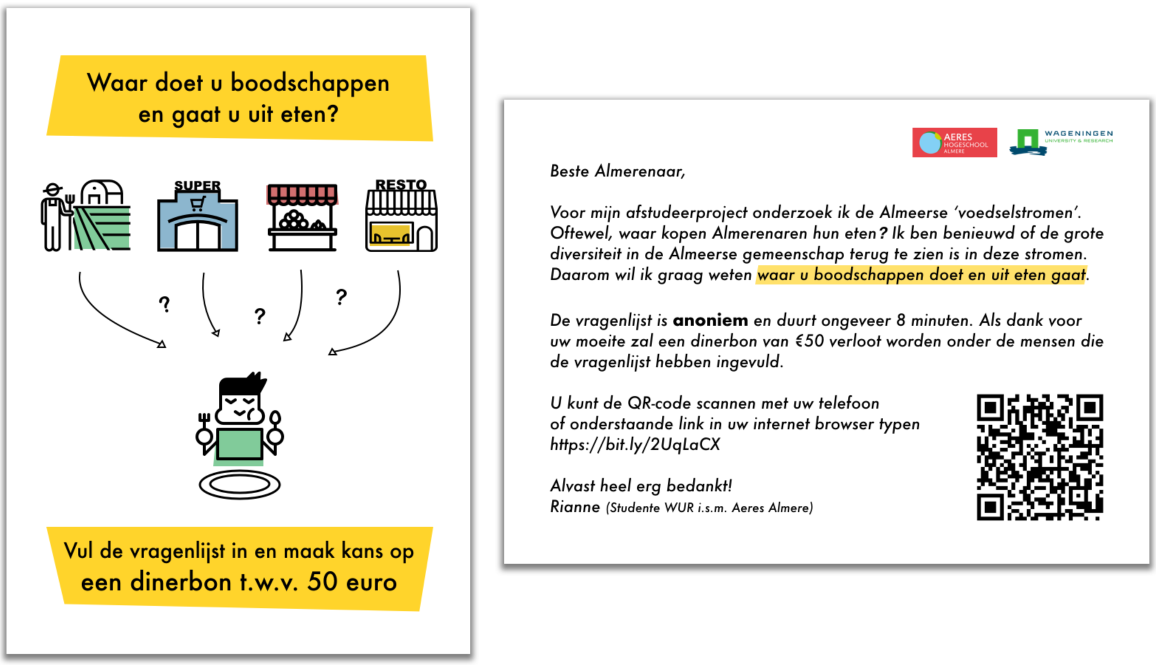

Figure 7. The postcard that was used for distribution. The front (left) was also used on online platforms. The text on the front says 'Where are you doing your groceries and are you going out for dinner?' 'Fill in the survey and get a chance to win a dining cheque worth 50 euros'.

3.2.3. Survey processing

The survey was filled in by 758 respondents and after data cleaning (Appendix C) 663 complete and valid responses remained, which is hereafter referred to as the sample that was gathered. The demographics of the respondents are important to determine whether the sample is representative of the entire population of Almere. The survey has been filled in by significantly more women (85%) than men, however, since each respondent represents a household this is not considered a problem. Besides gender, the distribution of basic demographic variables such as district of residence, household size and type, educational level, ethnic background, and age, have been investigated within the sample. Unfortunately, testing showed that the sample is not representative of Almere. Therefore it was decided to weight the sample on the demographic variables that significantly influence the purchasing behaviour.

Statistical Analysis

Several Logistic Regression and Chi-square Homogeneity tests were executed to analyse which demographic variables significantly influence food-purchasing behaviour (full analysis in Appendix D). The following demographic variables were tested for significance; district of residence, household type and size, educational level, ethnic background, and age. Age is assumed to represent the age group of adults in the household. It was decided not to test on gender since the respondents represent a household rather than one person.

Binominal logistic regression analysis showed that the mode of transport (active or motorized) used to visit supermarkets was significantly influenced by the city district and household size ($p<.05$). This was confirmed by performing a Chi-square Homogeneity test. The proportion of households using motorized transport for grocery shopping was statistically significantly higher in the districts Poort and Hout than the districts Stad, Buiten and Haven ($p<.05$). Also, the proportion of 1 person households using motorized transport for grocery shopping was statistically significantly lower than for ≥2 person households ($p<.05$). Similarly, Ordinal logistic regression analysis showed that the frequency of visiting supermarkets was significantly influenced by the city district ($p=.005$) and household size ($p=.008$).
Furthermore, Binominal logistic regression and Chi-square Homogeneity tests agreed that visiting markets was significantly influenced by the district ($p=.045$). In terms of visiting speciality shops, both tests agreed that the influence of educational level ($p=.034$) and background ($p=.001$) are significant. Finally, using grocery delivery services is significantly influenced by the district and household size ($p<.05$). Households in Almere Hout are 3.7 times more likely to order groceries than people living in Almere Stad. Furthermore, ≥2 person households are 2.4 times more likely to order groceries than 1 person households. Regarding dining behaviour, similar demographic variables were found to be influential. The visiting frequency for restaurants and fast-food services was significantly influenced by the household size ($p<.05$). E.g., ≥2 person households visit both restaurants and fast-food services more frequently than 1 person households ($p<.0005$).

The demographic variables that are repetitively significantly influencing different aspects of the food-purchasing behaviour are the district, background and household size of the respondents (Appendix D). The variables background and household can be categorised in various ways. Based on where the significant differences within variables were found during the statistical analysis the final categories were determined (CBS standards were followed);

- District: Stad, Buiten, Haven, Poort, Hout
- Background: Dutch, Western migration background, non-Western migration background
- Household: 1 person household, ≥2 person household

However, it was found that the sample is not representative of the population of Almere for any of these three demographic variables (Figure 8). The Chi-square goodness-of-fit test showed that the proportions in the sample for the districts ($p<0.001$), background ($p<0.001$) and household-types ($p<0.001$), are all significantly different from the population, and thus not representatie of Almere (Appendix D).

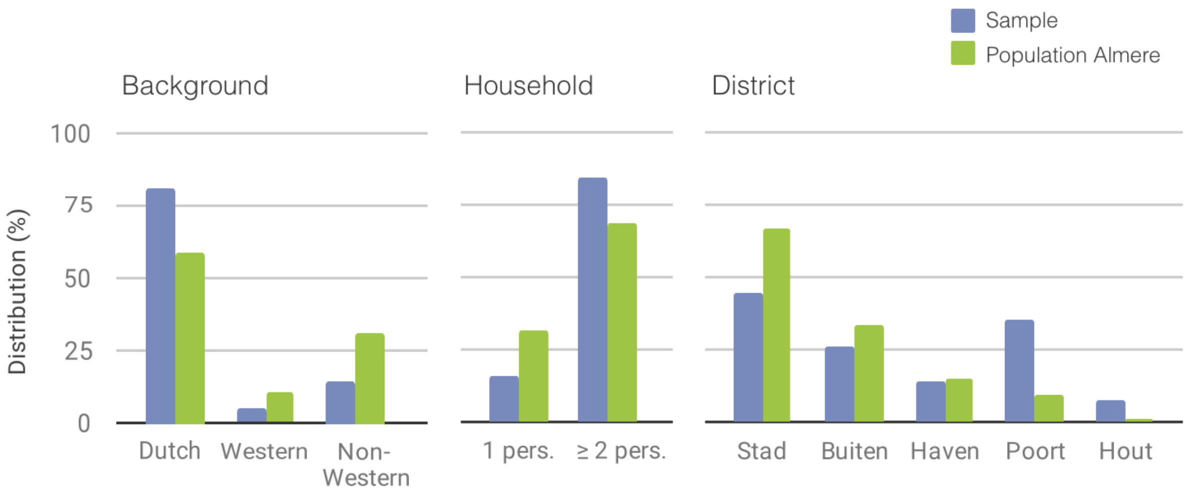

Figure 8. Distribution of the demographic variables Background, Household and District in both the sample and the population of Almere. This illustrates that the sample is not representative of the population.

Weighting

The survey has been filled in by 663 respondents, each representing a household. It was decided to weight the respondents on the three demographic variables; district, household size and background. In this way, the sample becomes more representative of Almere on the variables that significantly influence the purchasing behaviour. The variables each consist of a different number of categories, namely, five for district, three for background and two for household size. Herefrom, 30 unique demographic combinations (UDCs) can be formed (5x3x2) (Table 3). It is assumed that every household in Almere fits with one UDC. If the sample was an exact representation of the population, the same proportions of households for the UDCs are expected. However, this is not, currently, the case because the sample is not representative and thus has different proportions of households for the UDCs. The factors that are needed to transform the sample proportions into the expected proportions are called weight-factors.

Consequently, 30 different weight-factors were established using a micro-simulation approach (Appendix E). In short, existing demographic data from Almere was used to calculate the number of households that belongs to each of the 30 UDCs. This involved several necessary assumptions since there was no multivariate data available (Appendix E). Consequently, the proportions of households between the 30 UDCs was determined. Similarly, all respondents (households) from the sample were assigned one of the UDCs to determine the proportions of the sample. By using iterative proportional fitting (IPF) the weight-factors were determined for each UDC. Since the sample only contains 27 UDCs, only 27 unique weight factors could be determined. Thanks to the IPF approach, the absence of three UDC's was compensated for within the other weight factors. Hereby, the weight factors will ensure that the sample becomes as representative a possible. Finally, one of the 27 weight factors has been assigned to each survey respondent based on the respondents' UDC. Thereby, the sample proportions will approximate the expected proportions and thereby the sample will be more representative of the population. Consequently, the survey results in terms of food-purchasing behaviour are more likely to be an accurate representation of reality.

Table 3. Example of a district matrix. Each district contains six unique demographic combinations (UDCs).

City district X		**Household size**	
No. of households (N)		1 pers.	≥ 2 pers.
Background	Dutch	*UDC 1*	*UDC 4*
	Western	*UDC 2*	*UDC 5*
	Non-Western	*UDC 3*	*UDC 6*

3.3 UM-LCA Method

This section will elaborate on the implementation of the UM-LCA method that was used to create a bottom-up model. It will outline the stages according to the UM-LCA method by Goldstein et al. (2013), which is based on the ISO 2006 standard for LCA. As prescribed by the LCA framework, first the *goal & scope* will be discussed, followed by the *inventory analysis,* and lastly the *impact assessment* (Figure 9).

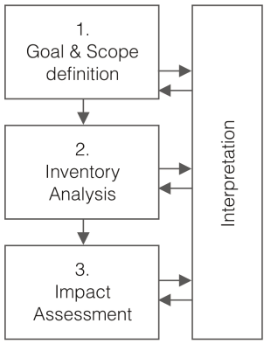

Figure 9. LCA framework.

3.3.1. Goal & Scope definition

The goal of this UM-LCA is to create a bottom-up model to make an assessment of the environmental impacts of the food-system of Almere. First, the annual food consumption of Almere, also called the cities' UM, will be modelled using preferably bottom-up data when this is available. From the UM, the corresponding food-system can be modelled with all up- and downstream processes related to the urban consumption. Finally, the impact of the system on the natural environment can be calculated. Three environmental impact indicators will be used to describe the impacts on the air, water and land, which will be discussed in detail in the third stage *Impact Assessment* (3.3.3.).

The scope for the food consumption (UM) is determined geographically by the municipal boundaries of Almere and the timeframe of one year. The year 2018 is used as reference year in which the municipality counted 203,990 citizens (CBS, 2019b). Food consumption includes all purchased food products, so not only what is eaten but also what is wasted by citizens. Food products include both solid foods and beverages, except for tap-water.
The Functional Unit (FU) is the gross annual consumption of the city of Almere in tons. In other words, it is all the food needed to eventually feed all citizens of Almere for an entire year, including all the food losses on the way. In some cases, it is more insightful to present consumption (impacts) on a per capita level. A conceptual average citizen of Almere is created by dividing by the population (203,990 citizens in 2018).
The system-boundary of this study is the life cycle from production to disposal (Figure 10). The standard LCA phases have been adjusted to fit the life-cycle food; 1. production, 2. processing, 3. distribution, 4. last-mile, 5. consumption and 6. disposal. For each life-cycle phase, more specific boundaries for the scope have been defined (Table 4). What each phase entails and how it was modelled will be explained in the second stage *Inventory Analysis* (3.3.2).

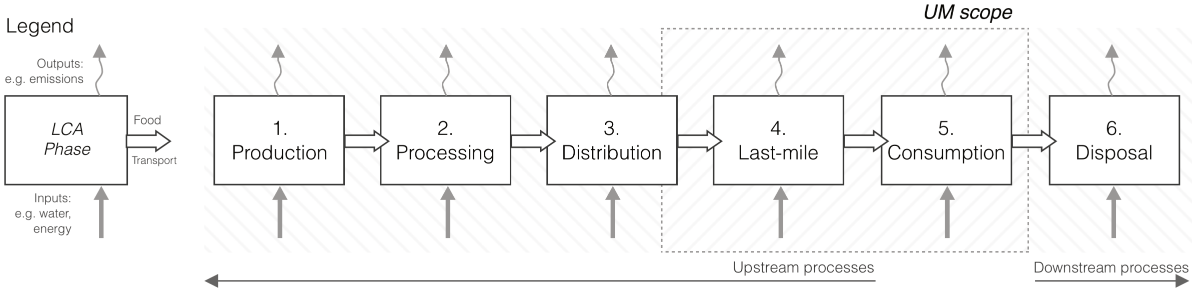

Figure 10. The six UM-*LCA phases. Adapted from Goldstein et al. (2013) and fit to the life-cycle of food.*

Table 4. Scope delineation for each life-cycle phase.

Phase 1. Production		*Additional explanation*
IN	Origin specific production for model products Regional production share	
OUT	Food losses at the farm or other production location	Complex as it depends on e.g. production country, techniques, climate etc. Also, it cannot be changed by urban policy.
Phase 2. Processing		
IN	Packaging and processing of highly processed products (e.g. bread, beer)	All is included in the literature studies used.
OUT	Packaging and processing of whole foods (e.g. potatoes, vegetables, fruits)	Excluded due to time constraints.
Phase 3. Distribution		
IN	Specific product origin for each model product Transport from the origin towards the Netherlands Within the NL transport to an imaginary distribution centre and then to Almere Storage (frozen and cooled) during transport as well as at the retailer	In case products are produced outside NL. Except for regional production that is directly purchased at the farmer.
OUT	No distinction between transport towards retailers and food-services. Storage at warehouses and distribution centres	Transport towards food-services might be less efficient, requires additional data. Requires data on average storage times.
Phase 4. Last-mile		
IN	Transportation movements for all grocery shopping	
OUT	Transportation between food-services and households	Requires additional research and data.
Phase 5. Consumption		
IN	The cooking of dinners (AH & OOH) Storage of food at home (cooled & frozen)	Average impacts based on literature
OUT	Food consumption of visitors in Almere Citizen consumption outside the city e.g. on holidays Tap-water intake in the diets (incl. in tea, coffee etc) Preparation of warm lunch, breakfast, other snacks Type of appliances, gas or electric cooking	Arguably citizen consumption outside Almere can roughly be replaced by that of visitors. Tap-water is rather part of the water system because of the way it is supplied to the city. Average cooking impacts have been used based on literature.
Phase 6. Disposal		
IN	Waste from all phases except production. Unavoidable and avoidable food waste. Food wasted through the sewage system and municipal waste collection. Waste management of residual and bio-waste.	Unavoidable food waste is included because these tons need to be distributed and processed.
OUT	Human excretion (digested food) Food donations (e.g. by retailers) Private composting or other unregulated disposals Waste management of waste-water from sewage	Donations form less than 1% of all food that is wasted (Soethoudt et al., 2014). Limited data on alternative management of food waste

3.3.2. Inventory Analysis

In the UM-LCA approach, the analysis starts in the consumption phase, which is the centre of the UM of the city. Therefore, the Urban Metabolism (UM) is, firstly, analysed to determine the inputs and outputs of the urban food-system. The results from the UM will form the foundation and starting point for the upstream processes (last-mile, distribution, processing, production) and downstream processes (disposal).
In the following paragraphs the inventory analysis will be described for each phase. This includes data acquisition and processing for the modelling. Most of the modelling was done using the SimaPro 8 software, which is further elaborated in *stage 3. Impact Assessment*. Firstly, the consumption phase will be discussed, followed by the phases disposal and last-mile, which are both directly linked to the consumption phase. Then the upstream processes; production, processing and distribution will be discussed in chronological order. Please note that the inventory process has not been as linear as is depicted in the diagram but was rather an iterative process, therefore it could sometimes not be avoided to reference forward.

PHASE 5: Consumption

The food consumption of a city does not only include the food that is eaten, but also food that is wasted. In other words; consumption consists of all the food that is being supplied to the city to fulfil the demands. No complete datasets on this could be found and therefore dietary data have been combined with wastage data in order to estimate the total annual consumption of the city (Figure 11). The inputs of the UM are thus the total of dietary intake and food-waste combined, and the outputs are simply the food that is wasted.

Diets
The MFA of the city is constructed by gathering bottom-up data on dietary patterns for the population of Almere. Various large-scale dietary studies have been conducted in the Netherlands, such as the Helius (2011) (Dekker et al., 2011) and VCP (2016) (Van Rossum et al., 2016. All proved that dietary research is a highly time consuming and complex process (Dekker et al., 2011). Considering the time-frame of this thesis, it was therefore decided to use an existing study and not gather dietary data in the case-study city even though this would be the most accurate bottom-up approach.

The Helius has been used because the diets seem to fit best with the population of Almere for several reasons (Dekker et al., 2011). Firstly, the Helius study is conducted in the city of Amsterdam and thus describes urban diets, which fits the urban context of Almere. Additionally, Almere is part of the greater metropolitan region of Amsterdam (MRA) and many citizens are former Amsterdammers (see 3.1). Furthermore, the Helius study distinguishes between five different population groups determined by their ethnic background: Dutch, African-Surinamese (*Creools*), Indian-Surinamese (*Hindoestaans*), Moroccan and Turkish Amsterdammers. These ethnic groups also represent some of the major shares in the population of Almere, where 58% is Dutch, 11% Surinamese, 4% Moroccan and 2% Turkish (CBS, 2019b). Diets are largely influenced by cultural background (Darmon & Drewnowski, 2008) and in this way, a large part of the urban diversity can be included.
The Helius study resulted in an extensive data-set of five average diets for the different ethnic groups (Dekker et al., 2011). Each diet consists of an average dietary intake per citizen per day for 17 food-categories, which together have more than 30 sub-categories. Tap-water intake (incl. in tea, coffee and lemonade) have been deducted from the diets since it is outside the scope of this food-system study. By assigning a diet to all 203,990 citizens and multiplying them by 365 days the total average consumption for the entire city of Almere can be estimated (Appendix F).
However, these five ethnic groups do not cover the entire population of Almere but only about 75%. Besides this, another 15% of the people have a migration background from other non-Western countries, and 10% has a migration background from Western countries in Europe, North America or Australia (CBS, 2019b).

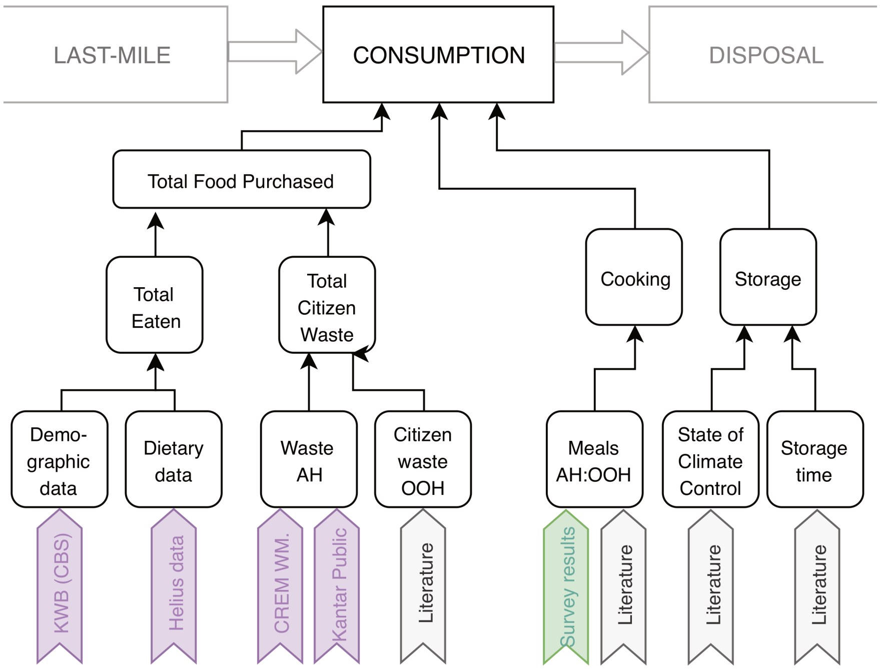

Figure 11. Diagram showing the different modelling steps and data sources for the Consumption phase.

Several assumptions have been made in order to assign a diet to the entire population (full overview Appendix G). People with a Western migration background are assumed to have a diet similar to the Dutch diet. And people with a non-Western migration background are assumed to have a diet similar to the average of all other diets. A sensitivity analysis has been done on these assumptions which shows that shifting the other 25% of the population to different diets has a minor influence on the total annual consumption (<0.5%) and on the consumption of categories (Appendix H).

Another verification for the annual consumption was done by making a similar model but using dietary data from the VCP study (Van Rossum et al., 2016) instead. The VCP study describes the average Dutch diet in the Netherlands. It is thus not specifically urban nor specific in terms of ethnic background, but it is more recently conducted than the Helius study. Using the VCP data resulted in a rather similar total amount of food consumed, but with differences between the shares of food categories. This confirms that people eat roughly the same amounts, however, what they eat is essentially different. Therefore cultural dietary differences are significant (Darmon & Drewnowski, 2008; Dekker et al., 2011). Thus, the Helius data is considered most suitable for this model.

Waste

In order to estimate the amount of food consumed in the city, the diets alone are not enough. What people eat in addition to what they waste is what they initially purchased and thus what they consume. Unfortunately, municipality specific data on food-waste is unavailable for Almere. Therefore it was decided to use the results of the national research (CREM Waste Management, 2017) on food-waste in Dutch household waste. The study has been conducted in 13 different municipalities and is rather detailed because it is separated in food-waste found in residual and bio-waste, and for each distinguishes between the shares of unavoidable (inedible for humans, e.g. bones, peels etc.) and avoidable (e.g. leftovers, out of date, perished foods etc.) food-waste. Within these four main categories, 18 different food categories are distinguished. These are rather similar to the categories in the dietary study and can therefore easily be added to estimate the total that was purchased, in other words, the total consumption.

In addition to food-waste in residual and bio-waste, households also dispose of food through the sewage system. Kantar Public (2017) estimates the number of beverages and liquid foods that are wasted through the sewage system. In the case of beverages and liquid foods, almost all waste is avoidable because these are completely edible except for the coffee grind and tea leaves. Again, tap-water used for tea and coffee has been deducted from the total waste volumes because this is not included in the scope of this food-system study. The studies of CREM Waste Management (2017) and Kantar Public (2017) are combined to determine the total waste by households (Appendix I).

Besides wasting food at home, citizens also waste food outside of their home at food services such as restaurants, hotels, catering and institutions. This is not included in the studies above since these only consider household waste. Naturally, consumers are not responsible for all the food-waste caused at food-services but only for the food they purchased and leave on their plate. The share of waste that consumers are responsible for was estimated using multiple literature sources. In *Phase 6. Disposal,* the waste of food-services will be discussed in more detail. Eventually, the total amount of food-waste by citizens was determined by adding the total waste in households to the total that is wasted by consumers at services.

Cooking & Storage

Besides food inputs and waste outputs, which can all be expressed in biomass, food is also being stored and prepared before being eaten. Cooling or freezing food to store it, as well as cooking food, requires energy en results in emissions and heat. In terms of storage, Rivera et al. (2014) was used as a reference for the average storage time of certain product types at home (Appendix J). It was assumed that 1 kg is on average equal to 1 litre in order to define the storage in liter*days. In order to model this in SimaPro, the small refrigerator from the EcoInvent 3 database was used. In this study, a distinction is made between the preparation of food for dinner at home compared to out of home (OOH) e.g. restaurants, catering or take away food. Studies by Calderón et al. (2017) and Rivera et al. (2014) on the impacts of different cooking locations were combined to estimate the footprint of the preparation of dinners at home and OOH (Appendix K). The proportion of dinners prepared AH compared to OOH could be determined on the basis of the survey results on dining behaviour.

For the total consumption of OOH prepared food, the study of VCP by Van Rossum et al (2016) was used because this data also includes breakfast, lunch, snacks, drinks and other in-between consumption OOH. According to this study 22% of the food is eaten OOH, of which 14% is eaten at school and work. However, this does not necessarily mean that this food was purchased and prepared at school or work. The survey showed that in Almere at least 50% of the food consumed at school and work was brought from home. Therefore 7% was deducted from the OOH, resulting in an estimated 15% OOH preparation and 85% AH. This was used to calculate the amount of food purchased OOH and wasted by citizens.

PHASE 6: Disposal

Food-waste occurs throughout the entire supply chain - unfortunately. This means not every food product passes through all of the life cycle phases. Since this study analyzes an entire system and not just one food product this increases complexity. The output from the consumption phase forms a direct input for the disposal phase. Indirect inputs for disposal come from distribution and processing (Figure 12). Waste at production is outside the scope of this research and it has been assumed no food is wasted during the last-mile.

For Europe, it is estimated that approximately 20% of the total food consumption is wasted (Gustavsson et al., 2011). All the food-waste can be brought back to an average amount of waste per capita per year (kg/c/y). Estimations range from 115 kg/c/y (Gustavsson et al., 2011) to 160 kg/c/y (Quested et al., 2013) and 173 kg kg/c/y (Stenmarck et al., 2016). About half of this waste

occurs during processing and distribution so before even reaching the citizens, and the other half is wasted by the citizens themselves (Gustavsson et al, 2011). It was calculated in the consumption phase that the waste generated by citizens is approximately 88 kg/p/y (Appendix I). If this is estimated to be half of the total waste per capita it seems that the high end of the range (173 kg/c/y) is most suitable. Therefore it has been assumed that another 88 kg/c/y is wasted during processing and distribution, including retail and services. This results in a total food-waste of 176 kg/c/y. It is estimated that processing and distribution are responsible for 23% (Stenmarck et al., 2016) to 39% (EC, 2011) of the total food-waste and thus 31% was used as an average. Services are responsible for 12% (EC, 2011; Stenmarck et al., 2016) of the total food wasted, which leaves 7% for food retailers (Appendix L).
Food-waste at services can be generated in the kitchen of the service or by the consumers not finishing their plate. It is estimated that 5-10% of the food purchased by services is wasted before reaching the customers (Baldwin et al., 2011). Hereby, the shares of waste generated by the kitchen and customers at services could be determined. It was assumed that 8% of the purchased food at services was wasted in the kitchen. This means that 45% of the total waste by services is generated in the kitchen and 55% by the customers.

Within household food-waste a distinction is made between avoidable (previously edible) and unavoidable (inedible food parts) food-waste (CREM Waste Management, 2017). It was assumed that all liquid foods and beverages disposed of through the sewage were avoidable since these are entirely edible. Furthermore, a distinction is made in the waste management of residual and bio-waste. The management of food-waste in the sewage system is outside the scope of this research. The waste separation rates for households are taken from the CREM Waste Management report (2017). It has been assumed that services have the same separation rates as households. Retailers have been assumed to dispose of all food-waste through residual waste. Processors usually have secondary destinations for food-waste such as animal feed (Quested & Parry, 2011), therefore, the management of this is not included (Appendix L).
Residual waste is transported by trucks to the incinerator for household-waste in Alkmaar (approx. 70 km away) and bio-waste to the anaerobic digestion plant in Lelystad (approx. 40 km away) to generate biogas and compost (Gemeente Almere, 2018). The incineration and anaerobic digestion of food-waste were modelled in SimaPro using the EcoInvent 3 database. Also, the transport of the food-waste to the respective plants by truck was modelled using the EcoInvent 3 database.

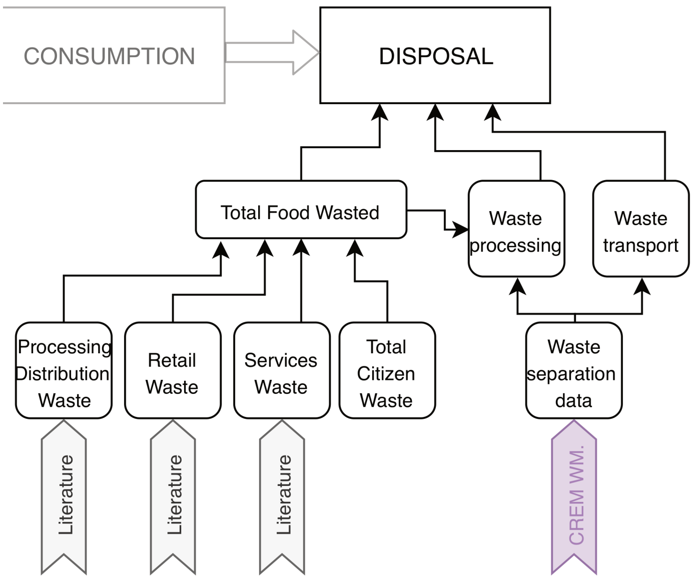

Figure 12. Diagram showing the different modelling steps and data sources for the Disposal phase.

PHASE 4: Last-mile

The results from the survey on purchasing behaviour were used to model the last mile. A distinction was made between three different modes of transport for the last-mile: active modes (walking and biking), public transport (buses, trams and trains) and private motorized transport (cars, scooters, taxi). For each transport mode, the average travel distance could be calculated by using the average travel time given by respondents in combination with the average speed of each mode inside urban areas. In combination with the frequency, the average annual travel distance could be determined for each mode. First, this was done for a conceptual average citizen and then for the entire municipality by multiplying by the population. Hereby, the total distance travelled by the three modes for grocery shopping (the last-mile) could be estimated for the entire municipality of Almere for one year (Appendix M) (Figure 13). Due to a lack of data and time constraints, the transport of citizens from and to food-services for OOH consumption was not included in the last-mile. A rough estimation of this has been made which will be elaborated on in the discussion.
In contrast to other transport in the LCA, the amount of weight that is transported over a certain distance does not matter because the frequency of visits is predetermined through the survey results. When calculating the impact of the last-mile transport for one product it would matter how much groceries are transported, since efficient transport lowers the impact. However, for the total impact of the last-mile from all citizens Almere, the shopping efficiency per trip is irrelevant. Arguably, a very heavy load (many groceries and passengers) could use more fuel, however, this was assumed to be neglectable. Therefore, simply the total distance travelled by the different modes for grocery shopping was used.
The EcoInvent 3 database was used to model the total distances travelled by the three transport modes in SimaPro. For the private motorized transport, a car was used as a model vehicle since this was the vehicle most indicated in the survey (94%). For public transport, a bus was used as a model vehicle because this was the only mode of public transport indicated in the survey. For the active modes, a bike was used as a model vehicle since walking does not require a vehicle. It was assumed that roughly the same infrastructure is needed for walking as for biking and therefore the environmental impacts are comparable.

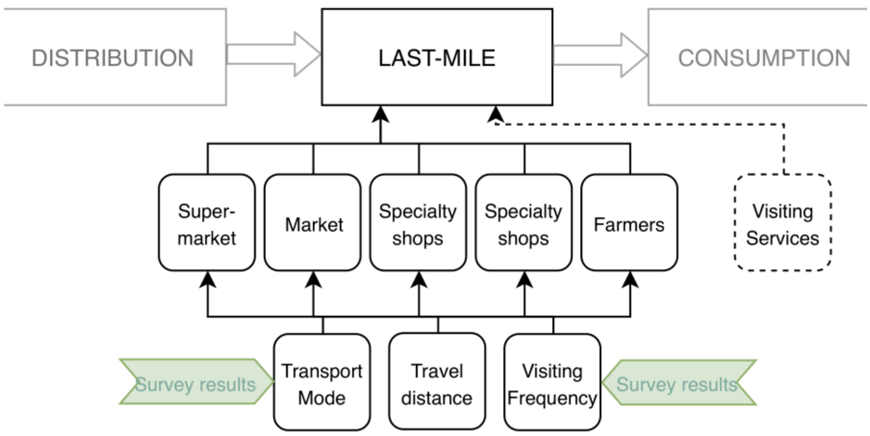

Figure 13. Diagram showing the different modelling steps and data sources for the Last-mile phase.

PHASE 1: Production

The total food production that is required for the city is the sum of the city's food consumption and all food that is wasted before reaching the city. This has been estimated in the phases consumption and disposal. The total food production that is required consists of more than 40 (sub-)categories, adopted from the dietary data. However, in order to model the production in SimaPro, specific products are needed instead of categories. For some categories, additional data on specific products were available in the Helius data. For others, model-products were used to represent product groups (Appendix N). For example, carrots represent the sub-category root-vegetables, since >90% of the root-vegetables consumed are carrots (Dekker et al., 2011).

The origin of the different food-products consumed in Almere is a key aspect to model the production. The origin can be determined based on the survey results. According to the survey the majority of potatoes, fruits and vegetables are bought in regular supermarkets, which is also confirmed by other studies (Ten Brug et al., 2018). Even though the survey results indicate that a significant share of fruits (18%) is bought at markets, most of these are conventional markets. The majority of vegetables and fruits on conventional markets is not regionally sourced but purchased at the same wholesalers that supermarkets use (Wertheim-Heck & Lanjouw, 2018). Observations that were done in supermarkets and the market in Stad confirmed this (Appendix N). Almost all fruits and vegetables had the same origin in supermarkets as on the market, sometimes even the exact same cardboard boxes were observed in both places.
Consequently, the production origin of food was determined by a combination of the observations and existing research (Figure 14). Milieu Centraal (2017) provides an extensive data-set that includes the various possible origins throughout the seasons for vegetables and fruits sold in the Netherlands. Almost all of the observed origins, were in accordance with the origin for this season suggested by the data from Milieu Centraal (2017). In this way, the production origins could be determined for the potatoes, vegetables and fruit. In order to determine the origin of other (processed) foods, the observations were combined with data from the World Atlas (2019) and product specific literature studies. Besides information on the origin and transport, the data-set from Milieu Centraal (2017) also provides information on the type of cultivation typically practised per food type and country throughout the seasons. For example, tomatoes produced in the Netherlands are cultivated in heated greenhouses, while tomatoes produced in Spain are cultivated under nets or polytunnels (Milieu Centraal, 2017).

With this data, most wholefood products could be modelled in SimaPro using the databases *EcoInvent 3*, *AGRIBALYSE*, *Agri-Footprint* and *LCA Food DK*. However, not all food products are available in the databases. Therefore some wholefoods were joined together to be represented by one model product (Appendix N). For example, despite having data on the consumption of different fruit-vegetables (e.g. tomato, paprika, zucchini) there is only a model-product available for tomatoes. However, as 45% of the fruit-vegetables consumed are tomatoes it is considered a suitable model-product. Furthermore, the databases mostly contain wholefoods, so processed food products (e.g. bread, biscuits, beer, soup etc.) are not available. In *Phase 2. Processing* it is further discussed how these were modelled.

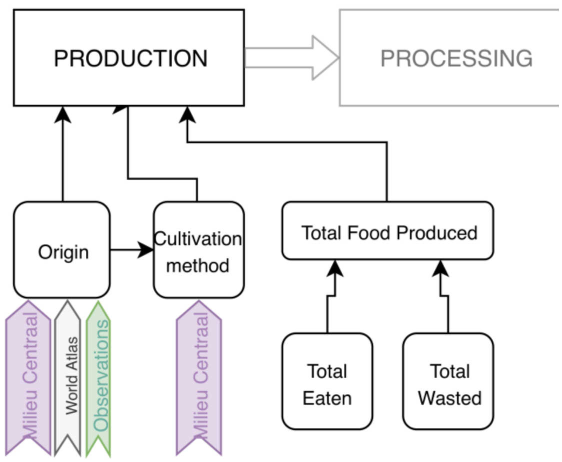

Figure 14. Diagram showing the different modelling steps and data sources for the Production phase.

PHASE 2: Processing

As mentioned, the SimaPro databases mostly contain whole foods and barely any processed foods. Therefore, literature studies have been used to fill this gap. Initially, the aim was to personally model the missing processed food products in SimaPro. In this way, the same method for the calculation of environmental impacts could be used later on. This was done for pasta by using the study of Bevilacqua et al. (2007). However, SimaPro requires highly detailed inputs and therefore the process of entering new products is complex and time-consuming. Due to time constraints of this research, it was therefore decided to directly use the impact results from the literature studies instead (Appendix O). The available amount of LCA studies on processed food products is limited, thus it was necessary to use model-products that represent (sub-) categories (Table 5). The impact assessment calculations are further discussed in stage 3.

Table 5. The model product chosen for each of the different (sub-)categories.

Food (sub-)categories	Model product	Literature study used
Breakfast cereals, Cereal snacks	Breakfast cereals	Jeswani, et al. (2015)
Margarine	Margarine	Nilsson et al. (2010)
Confectionary	Chocolate confectionary	Konstantas et al. (2018)
Cakes & pastry	Cakes	Konstantas et al. (2019a)
Biscuits & cookies	Biscuits	Konstantas, et al. (2019b)
Juices	Orange juice	Doublet et al. (2014)
Soft drinks, Mineral water	Soft drinks	Amienyo et al. (2013)
Beer	Beer	Amienyo & Azapagic (2016)
Wine	Wine	Amienyo, et al., (2014)
Sauces	Ketchup	Andersson & Ohlsson (1999)
Soups	Soup canned	Canals et al. (2011)
Miscellaneous	Ready meals	Rivera et al. (2014)

PHASE 3: Distribution

The distribution consists of both the transport and storage of food. Even though distribution is the third life-cycle phase, it does not only occur in between processing and the last-mile but also between production and processing. All of this is included in modelling the distribution. In the production phase, the total required amount of food has been determined, and model-products and their origin have been established. The survey results concluded that the majority of food is bought through conventional supply chains at wholesalers. According to the survey results only, 3.7% of the potatoes, vegetables and fruits are purchased directly at the farmers in Flevoland. Therefore these shares of mass have been excluded from the distribution.

The transportation mode and corresponding distance were determined per model-product (Figure 15). The data-set from Milieu Centraal (2017) provides information on the transport mode that is typically used to transport a certain vegetable or fruit to the Netherlands. The majority of these modes have been adopted for fruit and vegetables (Appendix P). However, Milieu Centraal (2017) does not include any air freight, while it is estimated that in Europe about 6% of the fresh produce that is produced outside the EU is flown in by air (Marriott, 2005). Air freight increased by 140% between 1992 and 2002 (Saunders & Hayes, 2007). And it is assumed that the air freight has continued to increase significantly since 2004 (Saunders & Hayes, 2007; AirCargoWorld, 2017; The Economist, 2017). Therefore, a selection of food products that are typically flown (Marriott, 2005), have been assigned air transport in such a way that 10% of all fresh produce is transported by air (Appendix P). Besides fresh produce, other food products have been assigned transport modes based on the ITC report (Saunders & Hayes, 2007).

Depending on the transport mode the food travels by air, land or sea, and this influences the distance that is travelled to go from the origin to the Netherlands. For each product, travel distances were determined in relation to the mode by using Searates (2019) and Google Maps (2019). The exact location of production within the country of origin was (usually) not known and therefore the central region of a country was taken as an average. Furthermore, it was assumed that sea freight will deliver at the harbour of Rotterdam, air freight at Schiphol and trucks at Eindhoven. Within the Netherlands, food is often distributed from wholesalers to smaller distribution centres and eventually to retail and services in Almere. It was assumed that on average an additional 100 km by truck is travelled within the Netherlands.

Lastly, when modelling the transportation of food, not only the mode of transport is important but also the state of climate control during transport. For the state of climate control, a distinction is made between normal, refrigerated and frozen transport. To determine the state of climate control for each food product the guidelines in Cargo Handbook (2017) have been used.
For each food product, the transport is modelled in ton*kilometers (tkm) by a specific transport mode and state in SimaPro (Appendix P). The three modes of transport (plane, ship, truck) in combination with the three types of climate control (normal, refrigerated and frozen) have been modelled using the EcoInvent 3 database.

Finally, in addition to transport also the storage at retailers is included in the distribution. The state of climate control was adjusted for the retail based on observations. For example, apples are transported refrigerated but are not refrigerated at the retailer. For the duration of storage Rivera et al. (2014) was used as a reference for average storage times (Appendix J). To model this in SimaPro, the big refrigerator from the EcoInvent 3 database was used.

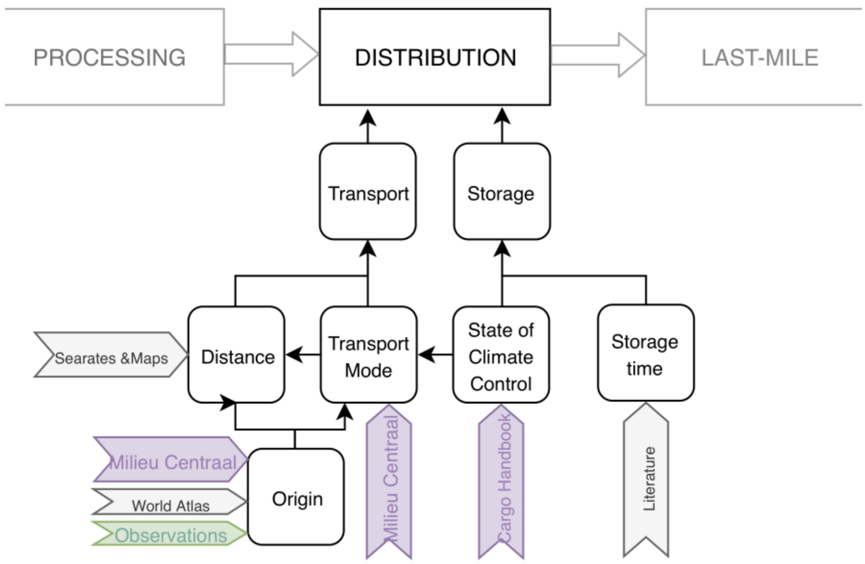

Figure 15. Diagram with modelling elements and data inputs for the Distribution phase.

3.3.3. Impact Assessment

Most of the products and processes in the LCA have been modelled in the life-cycle modelling software SimaPro 8. Several different methods can be used to assess the impact of the system, each using different indicators to express the impact. First, the impact indicators are discussed followed by the ReCiPe 2008 method that is utilised for the impact assessment.

Impact indicators

For the communication of the results midpoint indicators are most suitable (Hauschild, 2005; Goldstein et al., 2013). Midpoint indicators are calculated by converting all the in and outputs gathered in the LCI using characterization factors. A typical example of a midpoint indicator is global warming potential, expressed in CO_2 equivalent emissions. Another option is to generate endpoint indicators that indicate the pressure on the environment, material resources and human health. However, these endpoint indicators are relatively complex to communicate to citizens and policymakers who are more familiar with midpoint indicators. Sustainability targets such as the Paris Agreements usually use midpoint indicators as well. Therefore, many LCA studies use midpoint indicators (Hauschild, 2005).

The impact indicators that have been used to assess the environmental impact of this system are global warming potential (GWP), freshwater eutrophication potential (FEP) and agricultural land occupation (ALO).
For sustainability assessments, GWP is the most commonly used impact indicator (Hauschild, 2005). It is useful in relation to the Paris Agreement for which targets are often expressed in GWP and for comparison with other studies. Besides GWP, food-systems generate a significant impact on other aspects of the environment (Campbell et al., 2017). Therefore this model aims to assess impacts beyond GWP and include impacts on the land and water resources as well.
The FEP describes the eutrophication of fresh-water bodies due to phosphorus pollution. Phosphorus is an essential element for food production, but leakage into the environment causes eutrophication. Beside essential but polluting, it is also a scarce resource since it is non-renewable and reserves are limited (Campbell et al., 2017). The phosphorus cycle is currently pushed beyond its planetary boundaries and in combination with scarcity, it is relevant to assess the impacts in terms of FEP of food-systems (Van Dijk et al., 2017).
The ALO describes the occupation of arable land on a yearly basis. Cropland and pastures cover about 40% of the earth's land surface and are a major driver for land-use change (Foley et al., 2005). Furthermore, the impact in ALO of food consumption is heavily depended on the livestock intensity of diets (Gerber et al., 2013). It is therefore relevant to create insight into the hinterlands that cities occupy in order to feed the population (Steel, 2008).

Arguably, these impact indicators could individually describe the sustainability of the system as well. However, there are many interconnections between these indicators which are easily neglected when studying them individually (Kramer et al., 2017). For example, the ALO can be reduced by using greenhouses instead of open field cultivation, however greenhouses significantly increase energy requirements and thereby increase the GWP (Kramer et al., 2017). To represent this complexity in the model it is relevant to use multiple indicators. Especially, if the model is to be used for scenario making in the future it is necessary to have multiple indicators.
Initially, it was intended to also describe the water depletion, however, due to a lack of consistent data on water usage in the literature sources used for the inventory it was not possible to accurately calculate this. Nevertheless, the three indicators GWP, FEP and ALO, will describe the environmental impacts of the system on air, water and land, respectively.

ReCiPe 2008 method

The ReCiPe 2008 method was chosen as it is broadly accepted internationally. Furthermore, it is one of the most recent methods, provides midpoint indicators, and offers three different perspectives for the impact assessment.
The ReCiPe method was developed to combine the benefits of the CML (midpoint indicators) and Eco-indicator 99 (endpoint indicators) methods and in the process of combining them, all models were also updated (Goedkoop et al., 2013). In order to incorporate uncertainties and different (cultural) choices three different perspectives were developed for the impact assessment; Individualist, Hierarchist and Egalitarian (Goedkoop et al., 2013). The Individualist perspective is focussed on the short term and optimistic that technology will be able to solve future problems. The Egalitarian perspective on the other hand is the most precautionary and focuses on the long-term impact of humanity's actions on the environment. The Hierachist perspective takes a middle ground between the two perspectives. For example, to calculate the global warming potential different time-frames are used for each perspective resulting in 20 years for the Individualist, 100 years for the Hierarchist and 500 years for the Egalitarian. For this study, it was decided to use a precautious attitude and therefore the Egalitarian perspective since the impacts of the food-system are rather overestimated than underestimated.
Besides the different perspectives to include risks and uncertainties it is also possible to choose between the general model or a specific European-scale model. In the latter, regional specific conditions and parameters for Europe are included (Goedkoop et al., 2013). This is relevant for environmental impact indicators like e.g. acidification, eutrophication, land and water usage which are dependent on regional conditions. The European scale is suitable for this model since the majority of the food-system related processes take place within Europe.
In the ReCiPe method, the unit for GWP is kg CO_2 equivalent emissions (kg CO_2 eq.). The unit for FEP is kilogram Phosphorus equivalent deposition (kg P eq.). The unit for ALO is square meter * year (m^2a).

Not all products could be modelled in SimaPro, as mentioned before some processed foods are taken from literature. Literature sources were selected that used the ReCiPe or CML method. The indicators of the CML method are similar to the ReCiPe method. Only the FEP is expressed in kg PO_4 eq. instead of kg P eq. deposition. Fortunately, this could easily be converted based on the atomic mass.

FOOD PURCHASING BEHAVIOUR

4.

In this chapter, the results from the survey on food purchasing behaviour are presented. The survey sample consisted of 663 valid responses that each represent a household. The sample is approximately 0.8% of the 85,475 households in Almere. The responses have been weighted on the district, household size and ethnic background of respondents in order to be more representative of Almere, as described in *3.2.3 Survey Processing*.
First, the purchasing at retail is discussed, which includes grocery shopping behaviour followed by a specific section on potatoes, vegetables and fruits. Then the purchasing at food-services will be discussed which includes dining behaviour and a small section on lunch.

4.1. Purchasing at Retail

4.1.1. Grocery Shopping

The citizens of Almere shop their groceries at different types of retailers. A distinction was made between five types of retailers; supermarkets, markets, speciality shops, delivery services and farmers. Speciality shops include a wide variation of shops ranging from bakeries and butchers to shops with foreign products also known as Toko's. Farmers include all producers of food ranging from arable, greenhouse and livestock farmers to beekeepers producing honey.
Not every citizen uses all of these different types of retailers for their grocery shopping (Figure 16). Most people shop at supermarkets, only 0.2% never does grocery shopping there. Also, the majority of people do shop at markets (65.3%) and speciality shops (81.6%). In contrast, most people never use grocery delivery services (64.4%) and never shop at farmers (96.5%).

For each retail type, the mode of transport in combination with the visiting frequency was solely investigated for the share of households that do visit the retail type. Of the people that visit supermarkets, the majority uses private motorized transport (50.4%) and active modes (44.6%) i.e. walking and biking. Only a small share uses public transport (5.0%) (Figure 16). The frequencies range from 13 visits/month for users of motorized modes, 15 visits/month for active modes and 16 visits per month for public transport users. The average return trips range from 7.4 km for users of private motorized modes to 2.2 km for users of active modes.
Of the households that visit markets, 41.1% uses active modes, 38.5% private motorized modes and 20.4% public transport (Figure 16). The share of public transport usage to visit markets is considerably higher than for supermarkets. Furthermore, the frequency of visiting markets is considerably lower than for supermarkets, ranging between 2 to 3 times per month. Similar results can be found for speciality shops. When households utilise grocery delivery services, the mean frequency is 2.5 times per month (Figure 16). Lastly, of the households that visit farmers, 56.5% uses active modes and 43.5% uses private motorized transport. No one uses public transport since this is probably not available to farms.

An average household in Almere visits food-retailers 226 times a year, which equals more than one visit every other day (Table 6). The majority of these visits is to supermarkets (74%). In total, all households in Almere combined visit food retailers about 19.4 million times a year (Table 6). The majority of annual visits is by private motorized (46.8%) and active modes (45.7%), and only a small share by public transport (7.5%) (Table 7).

Population (%)	*Retail type*	*Transport mode (%)*	*Frequency (times/month)*
99.8% visits	Supermarkets	44.6%	14.8 x / month
		50.4%	13.0 x / month
		5.0%	16.1 x / month
65.3% visits	Markets	41.1%	2.8 x / month
		38.5%	1.9 x / month
		20.4%	1.8 x / month
81.6% visits	Specialty Shops	40.3%	3.8 x / month
		40.3%	2.8 x / month
		19.4%	2.4 x / month
35.6% uses	Grocery delivery	100%	2.5 x / month
3.5% visits	Farmers	56.5%	2.4 x / month
		43.5%	1.4 x / month

Table 16. Grocery shopping behavior of Almere households at different retailers. On the left it is indicated what share of households occasionally visits each retail type. In the middle it is indicated what transport modes households use. On the right it is shown per transport mode what the mean visiting frequency is per month.

Table 6. Visits annually per retail type.

Supplier	Annual frequency (visits/year) Mean household	Almere total
Supermarket	167	14,294,985
Market	17	1,484,999
Speciality shops	31	2,610,358
Delivery	11	900,312
Farmer	1	68,120
Total	**226**	**19,358,774**

Table 7. Visits annually per mode

Almere annual total Mode	visits / year
Active	8,842,864
Public transport	1,461,730
Motorized (private)	9,054,179
Total	**19,358,774**
	19.4 M

4.1.2. Potatoes, Vegetables and Fruits

In Almere, 8% of the households never buy potatoes, 2.0% never buys vegetables and 1.8% never buys fruit (Table 8). However, this does not necessarily mean that these hous eholds never eat these foods. They might be consumed in processed foods and at food services, however, these are not included in this.

Potatoes, vegetables and fruits can be purchased at four different retailers; supermarkets (incl. their delivery services), regular markets, speciality shops and at the farmer (incl. the farmers' market) (Figure 17). The majority of potatoes, vegetables and fruits are purchased in the supermarket, 83.0%, 77.1% and 70.8% respectively. It is striking that 18% of the household s buy the majority of their fruit on the market, while the share for vegetables and potatoes bought at the market is considerably smaller. Contrarily, 4.9% of the households buy the majority of their potatoes at the farmer, compared to just 3.5% for both v egetables and fruits.

Table 8. The share of households t hat occasionally purchases potatoes, vegetables and fruits.

Households (%)	**Potatoes**	**Vegetables**	**Fruits**
Occasionally buys	92.0 %	98.0 %	98.2 %
Never buys this	8.0 %	2.0 %	1.8 %

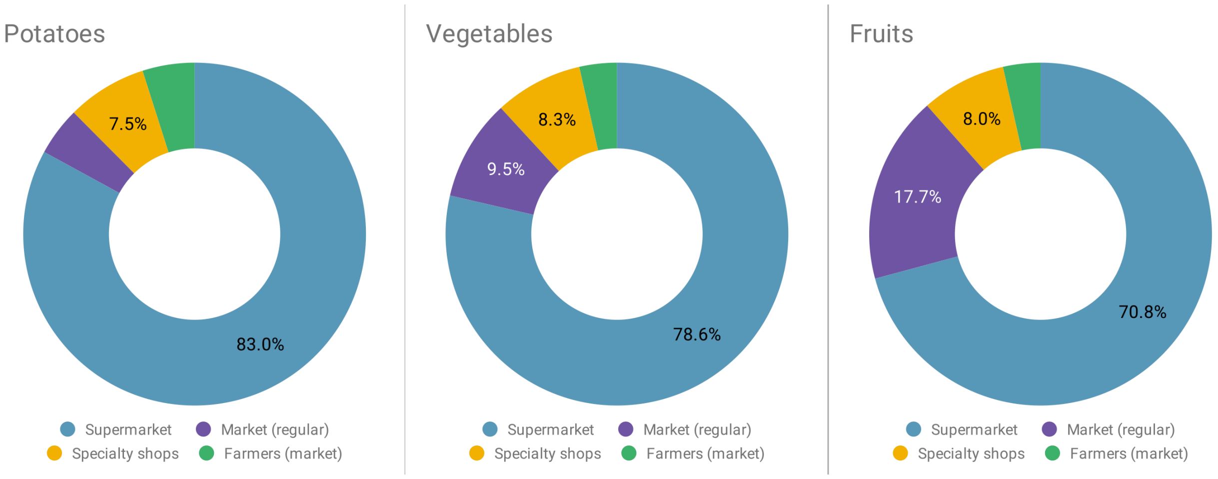

Figure 17. Share of households purchasing their potatoes, vegetables and fruits at different retail types.

4.2. Purchasing at Food-Services

4.2.1. Dining behaviour

In Almere most households occasionally use restaurants, snackbars (including fast-food chains), and take-away services for dinner (Table 9). The share of households that never visit fast-food services (24.7%) is substantially higher than households never visiting restaurants (3.8%). Furthermore, 14.5% of the households never utilise take-away services for dinner (including pick-up and delivery).

Table 9. The share of households occasionally using restaurants, snackbars or take-away services for dinner.

Households (%)	**Restaurant**	**Snackbars**	**Take-away**
Occasionally uses	96.2 %	75.3 %	85.5 %
Never uses	3.8 %	24.7 %	14.5 %

A distinction is made between dinners that are prepared at home (AH) and out of home (OOH). Preparation at home includes cooking but also simply heating ready-meals that are purchased at retailers. In an average household in Almere, 83% of the consumed dinners are prepared AH and 17% are prepared OOH (Figure 18). This means that an average household in Almere purchases dinner at food-services on approximately five days a month. Of these five days, the average household in Almere visits restaurants and take-away twice a month and snackbars once a month. (Figure 18). Lastly, the main mode of transport used for OOH dinners are private motorized modes (69.9%).

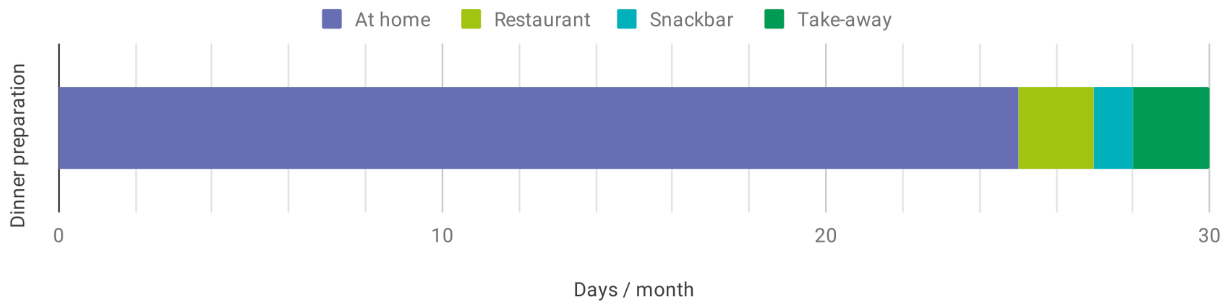

Figure 18. Monthly dining behaviour for an average household in Almere.

4.2.2. Lunch during work

The majority of Almere's citizens work or go to school and therefore lunch is often consumed OOH. However, most citizens bring lunch from home (67.1%) (Figure 19). Again, even though it is eaten out of home, it has been prepared at home. Of the remaining 32.9% that purchases lunch OOH, the majority buys lunch in the canteen at work or at a nearby supermarket.

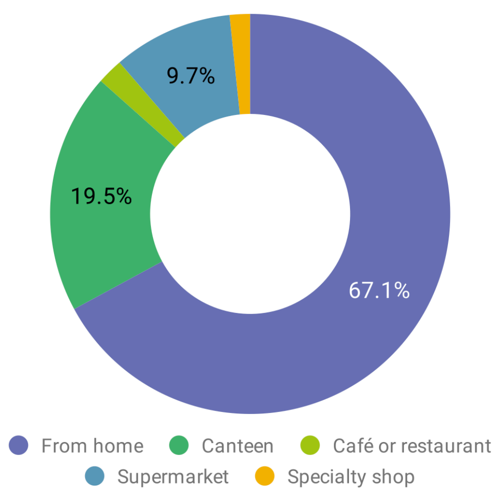

Figure 19. Sources for lunch during work or school

ALMERE'S FOOD-SYSTEM

5.

In this chapter the food-system of Almere is presented. This is the result of the bottom-up modelling as described in section 3.3 UM-LCA. First, an overview of the total annual food flows through the entire system is presented. Next, the annual food consumption of the city, in other words, the UM, is discussed in detail. This is followed by the results for the distribution, last-mile and disposal.

5.1. Total food flows

The total amount of food that is required to meet the annual demands of Almere is 167.2 k tons (Figure 21). This includes all the food that is eaten and wasted, except for losses at production. The 167.2 k tons of food is, thus, the production that successfully leaves the producers. However, some of this food is already wasted before even reaching the city. This food waste occurs during processing and distribution and equals roughly 6.5% of the production. In this way, 156.1 k tons of food enter the city which forms the annual consumption of Almere. About 16% of the urban food consumption is wasted. When the city's waste is combined with the food wasted before reaching the city, in total about 21.5% of the initial production of 167.2 k tons is wasted annually. This means that in the end, about of 36 k tons of food is wasted each year.

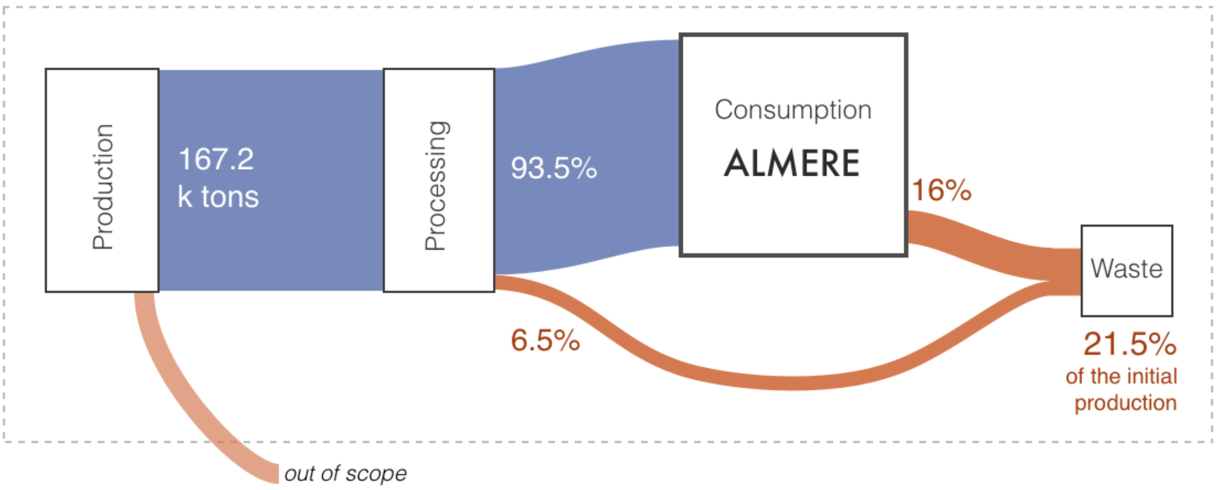

Figure 21. Overview of the total food flows within the food-system. About 21.5% of the initial production of 167.2 k tons is wasted.

5.2. Urban Metabolism Almere

Based on the Helius study (Dekker et al., 2011) and waste studies (CREM Waste Management, 2017; Kantar Public, 2017) the total annual food-consumption of Almere has been estimated at approximately 156.1 k tons of food (Figure 22). About 4.4 k tons (2.8%) are wasted by retailers and food-services, and the remaining 151.8 k tons of food is purchased by citizens. This equals approximately 744 kg of food purchased per citizen each year, of which on average 85% is purchased at retailers and 15% at services. Citizens in their turn waste about 13.4% of all the food they purchased, of which the majority is wasted in households, and a small share at services. This results in 132.8 k tons of food that is actually being eaten by the citizens. In total, nearly 25 k tons of food is wasted inside the city, which is roughly 16% of the initial inputs into the city. In other words, more than one sixth of the total consumption of Almere is wasted each year. This includes both avoidable and unavoidable food-waste.

With regards to the inputs, *Dairy & Eggs* (18.7%) and *Sodas & Juices* (17.1%) have the largest shares of Almere's total consumption mass (Figure 22). In total, 36.4% of the consumption are beverages when combining *Milk, Sodas & Juices* and *Alcoholic drinks*. This is a considerable share of the consumption, especially considering the fact that this does not include any tap-water consumed by citizens.

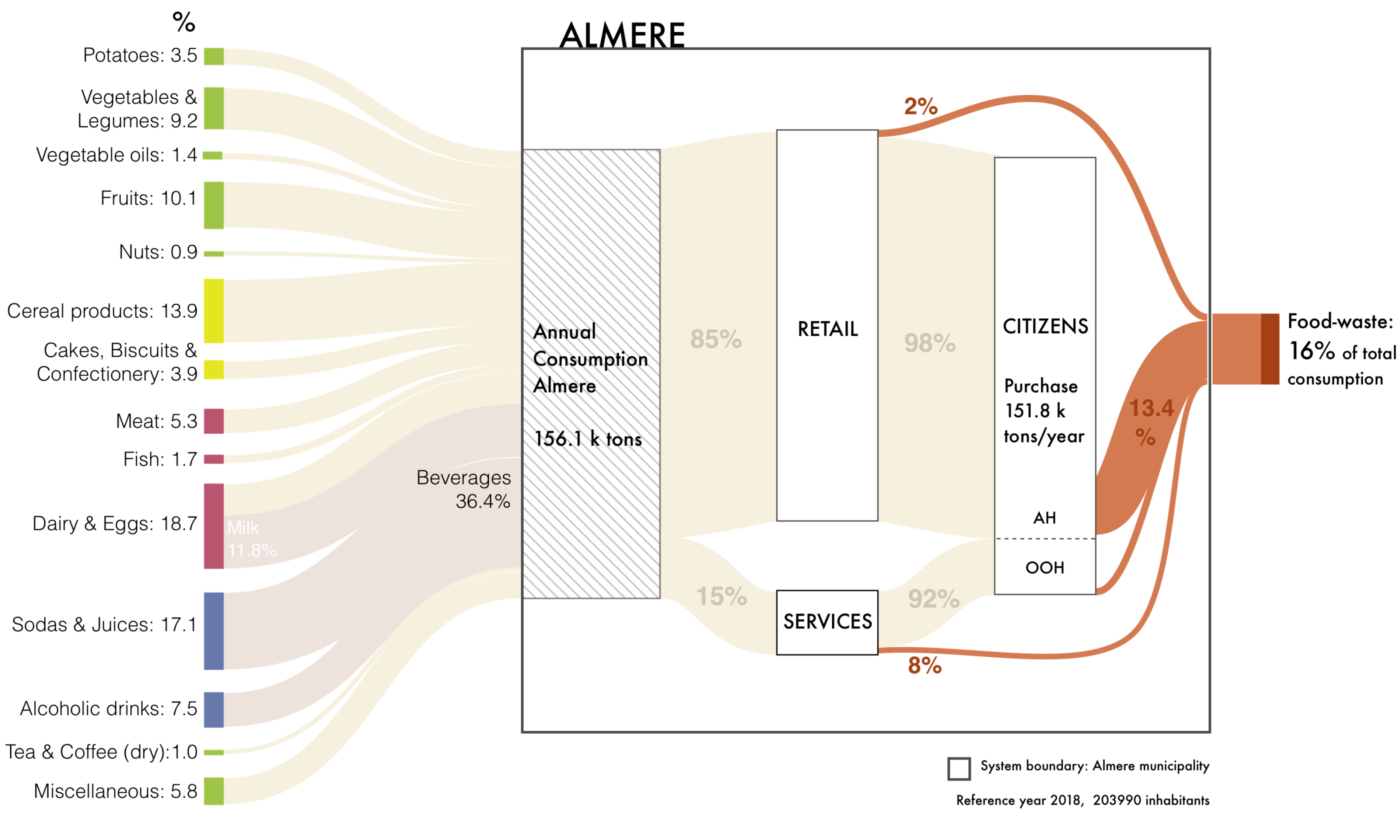

Figure 22. Total annual consumption of the municipality of Almere.

5.2.1. Citizen Waste

As mentioned, it was estimated that citizens waste 13.4% of the purchased food. This equals about 20.3 tons of food-waste. The majority of this is wasted in households (11.8% of purchased). The shares of specific food-categories within household waste were determined based on the studies (CREM Waste Management, 2017; Kantar Public, 2017). About 69% of the food-waste from households is avoidable and 31% is unavoidable. The largest share of avoidable waste is dairy products (37%), which mostly concerns milk disposed of through the sewage system (Figure 23a). This is followed by cereal products (21.2%) of which more than half is bread and a third is pasta and rice. Unavoidable food-waste consists mostly of inedible parts of fruit and vegetables (59.5%) and tea and coffee grind (23.6%) (Figure 23b).

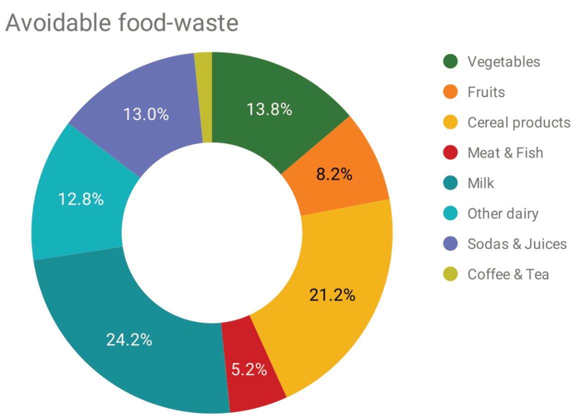

Figure 23a. Avoidable food-waste of households.

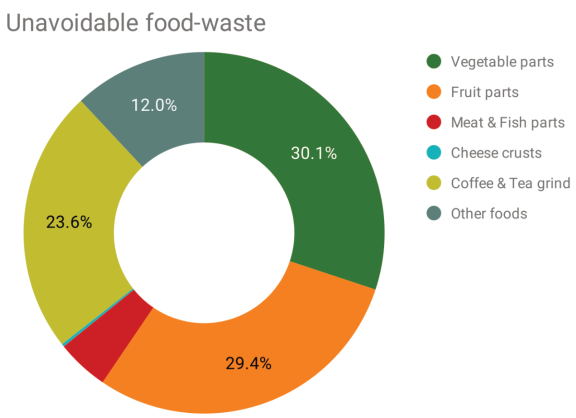

Figure 23b. Unavoidable food-waste of households.

5.2.2. Citizens Eat

The dietary intake of the average citizen in Almere (Figure 24) is slightly different from the inputs into the city because waste occurs. The waste by citizens is not in the same proportions as the inputs (Figure 23), which causes the difference between dietary intake and consumption. In total, 132.8 k tons of food are actually being eaten by the citizens of Almere each year. This equals to an average of 650 kg of food eaten per citizen per year. On average 85% of this food is prepared at home (AH) and 15% is prepared out of home (OOH).

The diet of an average citizen includes 8.3% *Vegetables & Legumes* and 7.3% *Meat* and *Fish* products (Figure 24). However, a healthy diet should consist of less meat and fish products and twice as many vegetables (Voedingscentrum, 2019). Furthermore, 37.9% of the dietary intake are beverages, which is excluding tap-water intake. However, a healthy diet should mostly include tap-water to drink both plain and in tea and coffee (Voedingscentrum, 2019).

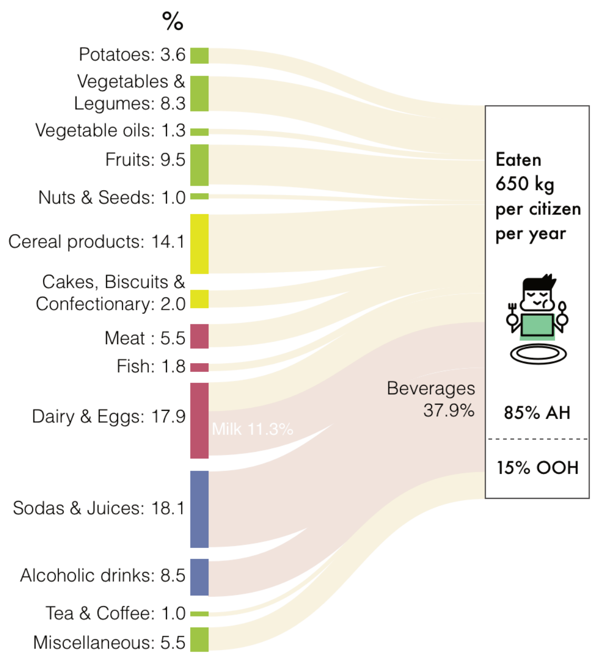

Figure 24. Dietary intake of an average Almere citizen for one year. Based on the Helius study (Dekker et al., 2011).

5.3. Distribution

The total production of 167.2 k tons of food, needs to be distributed from the producers, optionally to processors and eventually to food retailers and services in the city. This food can be transported using different modes; plane, ship or truck, and different states of temperature control; none (N), cooled (C) or frozen (F). The majority of the food is transported by truck (86.4%) (Figure 25a). However, most of these foods are transported from within Europe or even the Netherlands. Therefore, the distances travelled by truck are often shorter than the distances travelled by ship or plane. However, the transported amount of weight in combination with the travel distance is most relevant for the distribution. Freight, in ton*kilometers (tkm), describes moving one ton of load over a distance of one kilometre. While only 11.2% of the food (tons) is transported by ship, 61.3% of the freight (tkm) is by ship (Figure 25b). Similarly, only 2.4% of the food (tons) is transported by plane, but 11.3% of the total freight (tkm) is by plane.

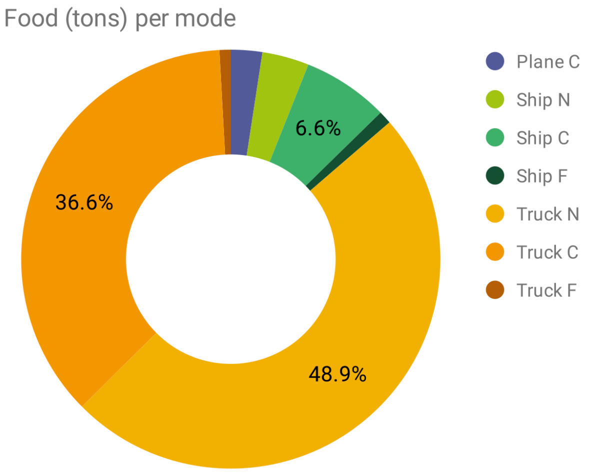

Figure 25a. The different modes relative to the total amount of food (tons).

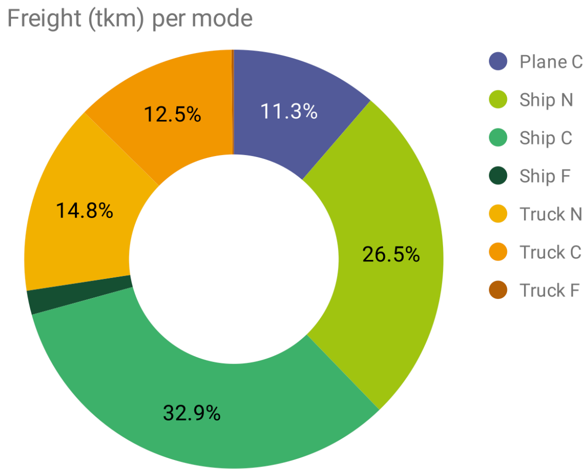

Figure 25b. The different modes relative to the total freight (ton*kilometers).

5.4. Last-mile

Based on the survey results the last-mile was modelled (Appendix M). The last-mile concerns the final transport of food from retailers to households. In total, the visits to food retailers of all households in Almere accumulate to 19.4 million visits per year (Table 10). This results in a total last-mile of about 89.5 million km travelled for grocery shopping. While the majority of visits is by motorized (45.7%) and active modes (46.8%), the vast majority of kilometres for the last-mile are travelled by motorized modes (68.1%). The total distance travelled by motorized transport for grocery shopping is 61 M kilometres each year. This is equal to roughly 1500 trips around the planet every year.

Table 10. Total annual frequency and distance travelled per mode for grocery shopping in Almere.

Almere annual total		
Mode	Frequency (visits / year)	Distance (km)
Active	8.8 M	19.7 M
Public transport	1.5 M	8.8 M
Motorized	9.1 M	61.0 M
Total	**19.4 M**	**89.5 M**

According to the survey, the share of households that usually buy their potatoes, vegetables and fruits (fresh produce) at farmers is relatively low compared to other retail types (section 4.1.2). There are more households that purchase their potatoes directly from farmers (4.9%) than their fruits and vegetables (3.5%). However, fruits and vegetables are consumed in larger volumes than potatoes. Therefore, the total share of the consumed fresh produce that is purchased directly at the farmer is only 3.7% (Table 11). This does not necessarily mean that this is the only food consumed in Almere that is regionally produced. Regional production can also be sold through other retail types such as supermarkets. However, it does mean that this is the only share of potatoes, fruits and vegetables that are purchased directly at the farmer and thus through a short supply chain.

Table 11. The share of consumed fresh produce directly bought at the farmer each year.

	Total purchased (tons/year)	Purchased at farmer (tons/year)	Purchased at farmer (%)
Potatoes	5290	259	4.9%
Vegetables	13699	479	3.5%
Fruits	15095	528	3.5%
Total fresh produce	**34084**	**1267**	**3.7%**

5.5. Disposal

Food is wasted at different phases in the food-system by various parties (Figure 26). Approximately half of the food-waste is generated in households. However, citizens do not only waste food in their own households but also at food-services. More than half of the food-waste generated at services is caused by consumers not finishing their plate. In this way, citizens in the role of consumers are responsible for about 57% of all food-waste generated (Figure 26). It must be noted that food losses at the farm are not included in this model. Another considerable fraction is wasted during food-processing (31%) before reaching the city.

In the city, food-waste is disposed of in residual waste, bio-waste and the sewage. Thereafter, it is processed at different plants, respectively an incineration plant, anaerobic digestion plant or waste-water treatment plant. The majority of food-waste ends up at the incineration plant (57%) (Figure 27). Only a small share is separated as bio-waste (16%) and is anaerobically digested. Roughly, 27% of all food-waste, mostly milk products and other beverages, is disposed of through the sewage system ending at the waste-water treatment plant. Bio-waste is transported by trucks to the digestion plant in Lelystad, about 40 km from Almere. Residual waste is transported by trucks to the incinerator in Alkmaar, about 70 km away. This results in an additional freight of 1.1 million tkm per year.

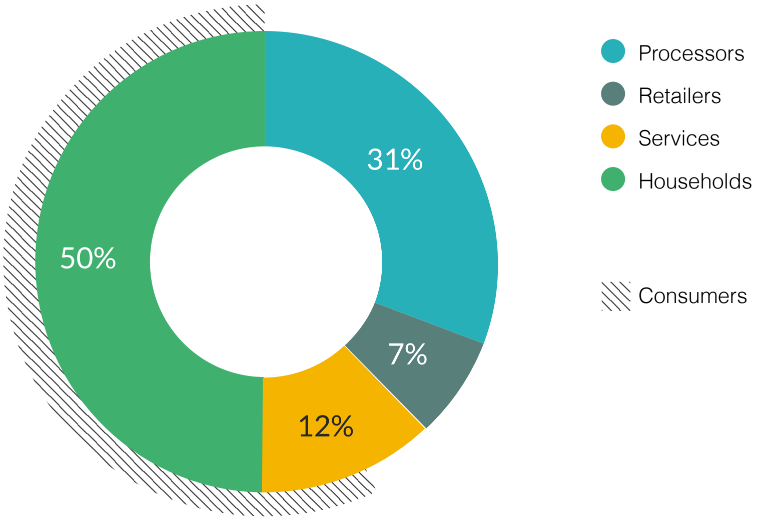

Figure 26. The food-waste shares by different actors. Consumers are responsible for the majority of food-waste, generated mostly at home and some at food-services. Note that losses during production are not included in this model.

Figure 27. Waste flows from different actors in the city (retail, services and households) towards different waste treatment plants (incineration, anaerobic digestion (ADP) and waste-water treatment plant). Separation rates at food-services have been assumed to be the same as at households.

ENVIRONMENTAL IMPACTS

6.

This chapter presents the potential environmental impacts of Almere's food-system according to the bottom-up model. First, the impacts of the entire system are presented followed by the impacts per food category. Then the impact of the life cycle phases distribution, last-mile, consumption and disposal are presented. Lastly, the results of sensitivity analyses and the impact ranges that follow from this are provided.

6.1. Total Impacts

The annual potential environmental impacts of the food-system of Almere can be determined using the developed bottom-up model. This model includes the life-cycle phases production, processing, distribution, last-mile, consumption and disposal. In chapter 3 the specific boundaries of this LCA have been defined. In addition it is important to realise that within these boundaries many assumptions have been made. According to the model based on the initial assumptions, the food-system of Almere has a Global Warming Potential (GWP) of 376 k tons CO_2 eq. emissions per year. The Freshwater Eutrophication Potential (FEP) is estimated at 152 tons of P eq. deposition. And the Agricultural Land Occupation (ALO) is estimated at 181 km^2 of arable land.
However, the model is an estimation providing potential impacts rather than actual impacts. This is useful to identify product categories and life-cycle phases with a high impact but should not be considered as exact truth. Therefore, a sensitivity analysis has been done for various aspects of the model in order to develop impact ranges, which is detailed in the last section (6.7.).

The different life-cycle phases do not have an equal contribution to the different potential impact indicators. The major impact for all three indicators is caused by the production & processing of the food, for ALO this is even 99.5% (Figure 28). In terms of GWP, production & processing is responsible for 65% of the impact, and consumption (15.0%), distribution (14.6%) and the last-mile (5.3%) also have a significant impact.

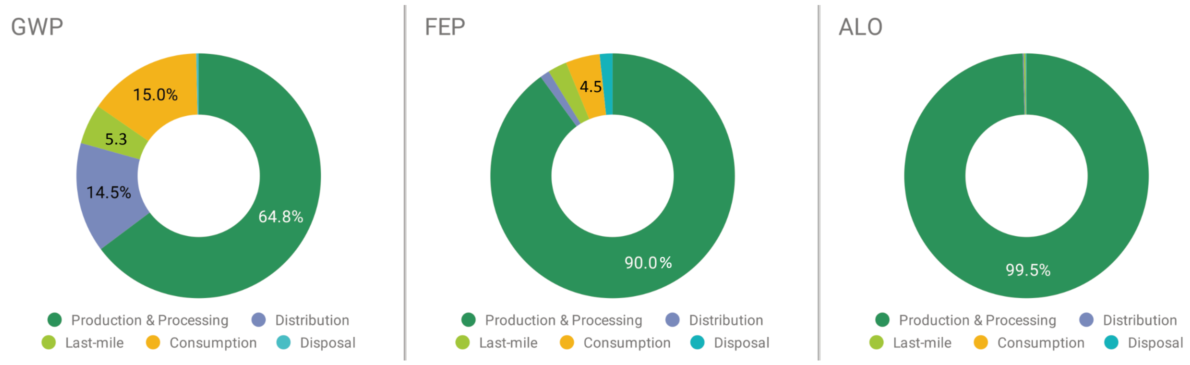

Figure 28. The impact shares of the different life cycle phases for the total GWP, FEP and ALO of the system.

6.2. Impacts per food-category

To determine which food categories have the highest environmental impacts, the share of mass is compared to the share of GWP, FEP and ALO respectively (Figure 29). The impacts for each food category are determined by the production, processing and distribution of the food category. The last-mile, consumption and disposal are not modelled per food category but only as a whole. If the impact of these phases would be attributed relative to the mass of each food category it would not influence the proportion of impact shares between the different food categories.

In terms of GWP, *Meat products* clearly have the highest impact. While its share of the total mass is only 5.3%, *Meat products* are responsible for 26.7% of the GWP. Similarly, *Fish products*, *Fruits* and *Cakes & confectionery* have a relatively high impact in relation to their mass. *Dairy & eggs* are responsible for the second-largest share (16%) of GWP, but also represent a large share of the consumed mass (18.7%) and are therefore less a hotspot than *Meat products* are.
The category *Other food products* has the largest share of FEP impact (43%), especially in relation to its mass of only 7.5%. The second-largest FEP share is generated by *Beverages* (27.5%), however, they also represent a larger share of the consumed mass (24.6%). *Coffee & tea* might seem to have a relatively small impact with an FEP share of 2.52%, however, compared to their small share of mass (1%), this is relatively high.
The shares of ALO are relatively high for *Dairy & eggs* (33%) and *Meat products* (5.3%) compared to their shares of mass, 18.7% and 5.3% respectively. Their share of the total ALO is about double their share of the total mass. Also, *Cereal products* have a relatively large share of the ALO (20.5%) compared to their share of mass (13.9%).

These comparisons show that the share of impacts is not equal to the share of the mass of the food categories. This is in accordance with literature, in which various research projects have shown that certain food categories have a larger impact than others. For example, it is well known that meat and dairy products have a relatively high GWP and ALO (Meier & Christen, 2013; Willett et al., 2019). There is not one category that has the highest impact for both GWP, FEP and ALO, and therefore not one category can be identified as the main hotspot. However, vegetables can be identified as having the lowest environmental impacts overall in relation to their share of mass. While the vegetable share of mass is 12.7%, the shares of GWP, FEP and ALO are only 4.4%, 3.6% and 5.5% respectively.

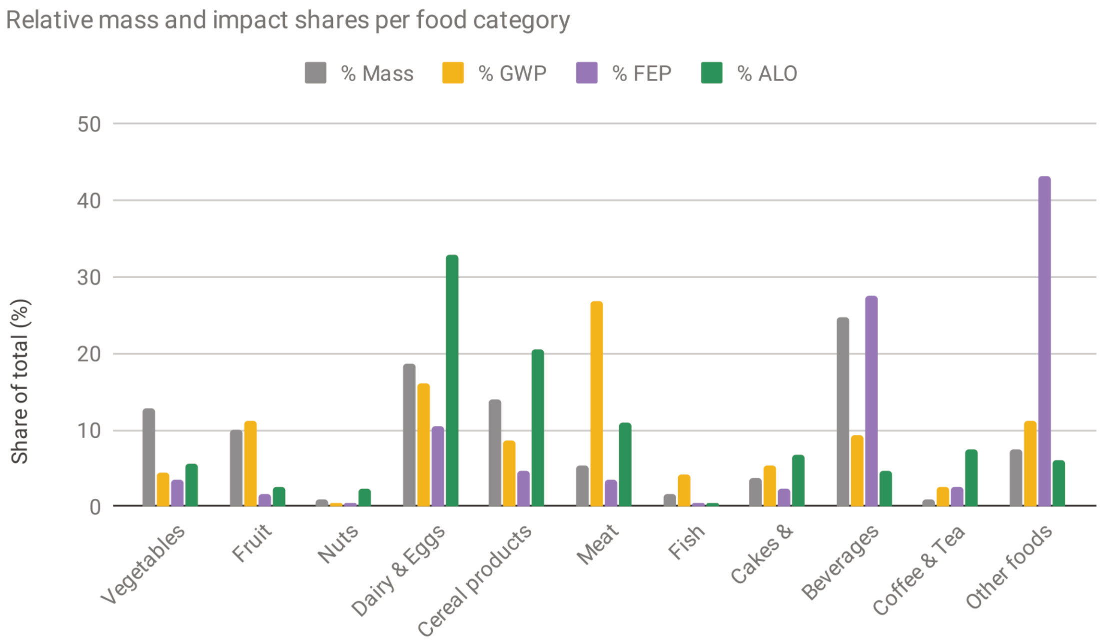

Figure 29. Share of mass, GWP, FEP and ALO for each food category of the total consumption impacts. Note that this graph includes impacts from the phases production, processing and distribution. Beverages are excluding milk, this is in dairy.

As mentioned, the impacts for each food category are determined by the production, processing and distribution of the food category. The contribution of these phases to the environmental impacts is not the same for each food category (Figure 30). For most food categories the majority of impact is generated by the production and processing of foods. *Fruits* have a relatively high GWP compared to its share of mass (Figure 29). The majority of the GWP of fruit is caused by the distribution (89%) (Figure 30a). Also, for *Vegetables* and *Fish products* a significant contribution to the GWP comes from the distribution, 38% and 46% respectively. For all food categories at least 95% of the FEP impact is generated during production and processing, with the exception of *Fruits* (39%) and *Fish products* (30%) again (Figure 30b). *Vegetables, Fruits* and *Fish products* are the only food categories for which some products are transported by plane which explains the deviation. For ALO the vast majority (>97%) is caused by production & processing for all categories (not shown).

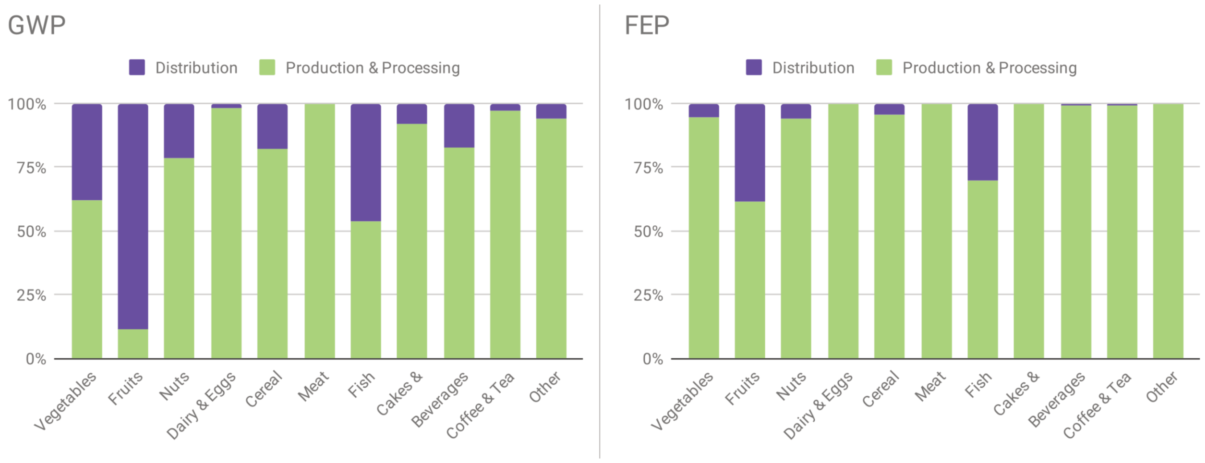

Figure 30ab. The contribution of production & processing relative to distribution for the GWP and FEP.

6.3. Impacts of Distribution

Distribution is responsible for about 14.5% of the GWP, 1.3% of the FEP and 0.2% of the ALO of the entire food-system (Figure 28). The different transportation modes and state of climate control used for the distribution have a distinctly different impact on the environment (Figure 31). Transportation of food by plane generates the highest GWP, FEP and ALO. Even though only 11% of the freight (tkm) is by plane, this generates the majority of the total GWP (72%), FEP (42%) and ALO (38%) impacts of distribution. Since *Fruits, Vegetables* and *Fish* are the only foods that are occasionally flown, this explains the high contribution of distribution to their environmental impacts. In contrast, distribution by ship has a relatively low impact. Even though the freight (tkm) by ship with cooled climate control (C) is three times larger than the freight (tkm) by plane (C), the share of GWP is 18 times smaller. Furthermore, the impact of the state of climate control during distribution is considerable. While 26% of the freight (tkm) is by ship without temperature control (N) and 33% of the kilometres are made by ship (C), the impact shares double for the cooled transport.

6.4. Impacts of Last-mile

The last-mile is responsible for approximately 5.3% of the GWP, 2.5% of the FEP and 0.2% of the ALO of the entire food-system (Figure 28). The majority of the last-mile is travelled by private motorized modes (68.1%). Additionally, the environmental impacts per kilometre are the largest for private motorized transport modes compared to the other modes, especially active modes. The environmental impact of car travel is about three times larger than the impacts of public transport and about 30 times larger than the impacts of biking. Therefore, motorized modes generate the vast majority of impact for the GWP (94%), FEP (97%) and ALO (96%) of the last-mile.

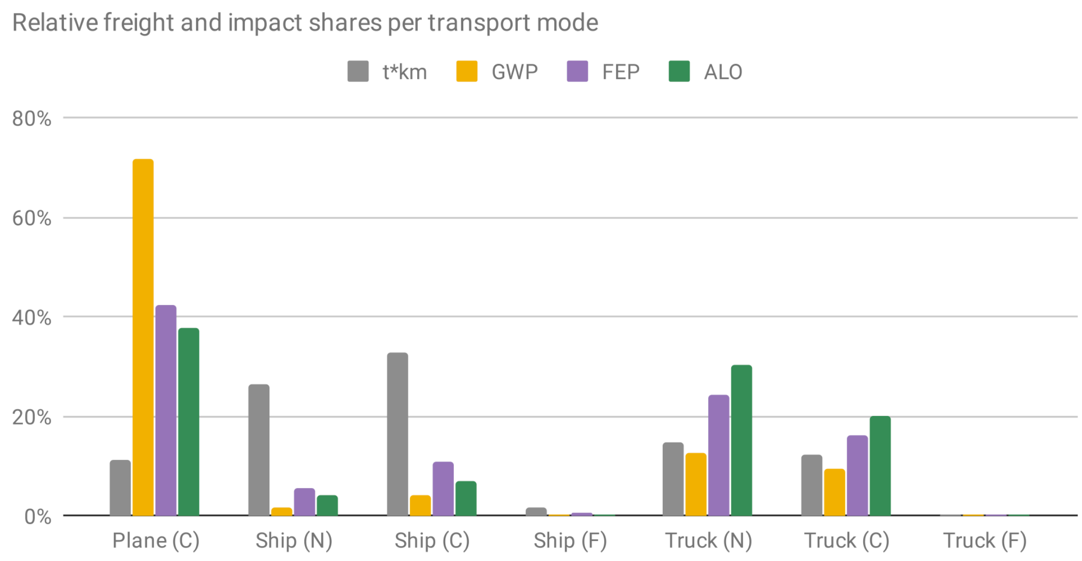

Figure 31. The share of freight (tkm) relative to the share of GWP, FEP and ALO impacts of distribution for the different transport types. There are 7 different types due to the different modes (plane, ship and truck) in combination with the state of temperature control (none (N), cooled (C) or frozen (F)).

6.5. Impacts of Consumption

Consumption is responsible for about 15% of the GWP and 4.5% of the FEP of the total food-system (Figure 28). Consumption includes impacts from refrigerated and frozen storage, and the cooking of dinners both AH and OOH. However, the GWP of storage of food AH and OOH is 100.000 times smaller than the impact from cooking and therefore the share of storage becomes relatively neglectable. The impact in terms of GWP per dinner cooked AH is twice as large as for dinners cooked OOH at services. Additionally, the majority of dinners is prepared AH (83%). Therefore, 90% of the GWP is generated by cooking dinners AH.

6.6. Impacts of Disposal

The impact of disposal is relatively small compared to the other life-cycle phases. Disposal is responsible for only 0.3% of the total GWP, 1.7% of the FEP, and 0.1% of the ALO (Figure 28). Disposal includes both waste-management and waste transport. Transport contributes 14.3% of the GWP (Figure 32) and less than 1% for both FEP and ALO of disposal. Waste-management is either anaerobic digestion or incineration of food waste. While only 22% of the food-waste is anaerobically digested, this generates 51.4% of the GWP of disposal. However, anaerobic digestion has other positive by-products such as biogas and compost. Compost contains important nutrients, such as phosphorus that can be recycled in this way, while these nutrients are lost in the incineration process.

Furthermore, the impact of food-waste is larger than simply the management of the waste. Every year the city of Almere wastes about 16% of the annual consumption. The majority of this is wasted by citizens (78%). Roughly 70% of the food-waste generated by citizens is avoidable. The food that is wasted is responsible for a considerable share of the total GWP (7.1%), FEP (7.5%) and ALO (8.7%) (Appendix R).

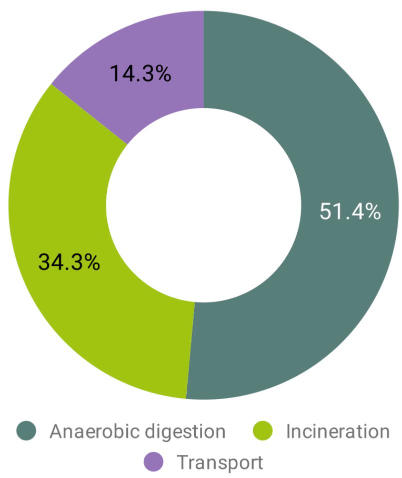

Figure 32. Share of GWP impact of disposal

6.7. Sensitivity Analyses

According to the model, the major environmental impacts are caused by the production and processing. In the case of GWP, this is followed by distribution and consumption. For all of these phases, assumptions have been made during the modelling process. As mentioned, the model is an estimation providing potential impacts rather than actual impacts. The model can be used to identify product categories and life-cycle phases with a high impact but should not be interpreted as exact truth. Sensitivity analyses have been done for various aspects of the model to investigate to what extent the assumptions influence the results and to develop impacts ranges for the GWP, FEP and ALO.

Production and Processing together, are responsible for the largest impact shares of the GWP (64.8%), FEP (90.0%) and ALO (99.5%). The Helius study (Dekker et al., 2011) used to determine the total amount of food eaten provides good quality dietary data due to the large scale and professional execution of the research. The total amount of food eaten by the citizens is relatively certain despite the assumptions that were made when ascribing diets to the population groups. Sensitivity analysis showed that ascribing different diets had little effect (0.4%) on the total amounts of food consumed (Appendix H). Similarly, it was shown that the total amount of food eaten did not change considerably (2.5%) when using VCP data instead.
The total amount of food that is required to be produced for Almere was estimated by combining the amount of food eaten with the total amount of food wasted. To determine the total amount of food-waste many assumptions have been made based on different data sources. Therefore a sensitivity analysis was done by changing the amount of waste by 20%. If 20% more or less food is wasted, the total production and related impacts changed with 4.2%. For the entire food-system, the impacts changed with 2.72% for GWP, 3.8% for FEP and 4.2% for ALO. This shows that the ALO is most sensitive for the assumed amounts of food-waste. Which is logical since more waste requires more production and this is the part of the food-system that mainly determines the ALO impacts. Contrarily, other aspects of the system have a considerable effect on the GWP and therefore this indicator is less influenced by the food waste assumption.

Besides production & processing, a considerable share of the total GWP (14.5%) is generated by the distribution. The shares of the total FEP (1.3%) and ALO (0.2%) are relatively small. The results showed that within distribution especially transport by plane has a relatively large impact. A sensitivity analysis was done by decreasing the amount of food (tons) that is distributed by plane by 20%. Instead, this amount of food was transported by ship and truck from the same location. When 20% less food (tons) is distributed by plane, the impacts of distribution decrease with 12.0% for GWP, 6.6% for FEP and 5.5% for ALO. For the entire food-system the impacts decrease with 1.8% GWP, 0.1% FEP and 0.01% ALO. Considering that the plane was only responsible for 11% of the freight (tkm) this is a considerable change. Since the impact of air freight is so large the model is sensitive for the assumptions on air freight and more detailed research into air freight of food would be recommended.
Furthermore, estimations have been made for the distribution in terms of travel distances. If the travel distances for all food decreased by 20%, the impacts of the distribution phase decrease with 17.0% for GWP, 18.2% for FEP and 18.0% for ALO. Naturally, the distribution is very sensitive to changes in transportation distances. The total impacts of the food-system decrease with 2.5% for GWP, 0.2% FEP, 0.03% ALO. Again, this illustrates the strong sensitivity of the model for air freight. Shifting only 20% of the amount of food away from air travel can achieve approximately half of the impact reductions of what can be achieved when *all* travel distances for the entire distribution are reduced by 20%.

Lastly, the consumption phase is responsible for a considerable share of the total GWP (15.0%) and a small but still the second largest share of FEP (4.5%). Consumption impacts are almost entirely generated by cooking since storage is neglectable compared to cooking impacts. Only the preparation of dinners has been included in the model and therefore consumption is likely to be an underestimate of reality. A sensitivity analysis was done by increasing the number of meals that are cooked with 20%. The impacts from the consumption phase simultaneously increase with 20% for both GWP and FEP. This is to be expected since the dinners are the only parameter the consumption is built on. The impacts of the entire food-system increase with 3.0% for GWP and 0.9% for FEP. Additional research into the consumption phase and in particular cooking, in general, is suggested.

Similar sensitivity analyses have been done for other aspects of the model such as the last-mile (Appendix S). When the different assumptions are all assumed to be on the low end (e.g. 20% reduction as mentioned above), a lower range of environmental impacts can be calculated. When the different assumptions are all assumed to be on the high end (e.g. 20% increase), an upper range of environmental impacts can be estimated (Table 12). These ranges form a more reliable answer to the potential environmental impacts of the food-system of Almere.

Table 12. Estimated environmental impact ranges for the GWP, FEP and ALO of the food-system of Almere.

	Almere total per year	**Average citizen per day**
GWP	351 - 411 k tons CO_2 eq.	4.7 - 5.5 kg CO_2 eq.
FEP	153 - 169 tons P eq.	2.1 - 2.3 gram P eq.
ALO	174 - 189 km^2a	2.3 - 2.5 m^2a

DISCUSSION

7.

The discussion consists of two main parts. First, the case-study model is discussed in terms of reliability and suggestions for further development of the model are provided. In the second part, general suggestions for future bottom-up modelling are presented based on the learnings from the case-study. With this second part, this study hopes to contribute to the general debate on modelling approaches for impact assessment of urban food-systems.

7.1. Case-study model

In the last section of the results, the robustness of the model was assessed by means of sensitivity analyses. To further investigate the robustness and reliability of the model, the impact results will be compared to other studies. Furthermore, the data gathering will be discussed. Finally, suggestions for further research are provided based on all this.

7.1.1. Comparing the impacts

To further assess the robustness and reliability of the model, the environmental impacts in terms of global warming potential (GWP) and agricultural land occupation (ALO) have been compared to other studies. The studies used for comparison are not necessarily representing the exact reality either, however, it is relevant to see whether they broadly agree. Disagreements do not necessarily prove the model wrong but provide starting points for further research. The freshwater eutrophication potential (FEP) could not be compared because no equivalent study was found. Therefore the results of the FEP should be treated with caution and future benchmarking would be recommended to increase certainty.

Global Warming Potential

According to the developed food-system model for Almere, the annual GWP ranges between 351 - 411 k tons CO_2 eq. per year. This equals 4.7 - 5.5 kg CO_2 per average Almere citizen per day. According to Temme et al. (2014), the GWP is between 3-5 kg CO_2eq. per day for the average Dutch diet. For the LCA similar phases have been included in Temme et al. (2014) compared to this bottom-up model. However, it is not surprising that the average for Almere lies slightly higher, as not only the dietary intake has been considered but also the impacts of all the food that is wasted was included. Subtracting the GWP of all the food that is wasted throughout the life-cycle (21.5% of the total production), results in an average of 3.9 - 4.6 kg CO_2 per average Almere citizen per day, which is in good agreement with the study by Temme et al. (2014).
Meat, dairy and drinks contribute most to GWP of the diets according to Temme et al (2014). In this model, meat and dairy contribute by far the most, at distance followed by fruit, other foods and drinks, with relatively similar shares. It has been shown that the GWP share of fruit is likely to be overestimated due to the freight by plane. *Other foods* contains many different categories which can therefore not fairly be compared. In this sense the model agrees with the conclusions of Temme et al (2014).

When considering the food-system model as a whole, the various life-cycle phases share different responsibility for the total GWP impact. This can be compared to a breakdown of the GWP of the UK food-system model by Garnett (2008) (Figure 33b). When the production, manufacturing and packaging of the UK model are combined this results in 64%. A share that is very similar to the estimated share of GWP generated during production and processing in the model for Almere (64.8%) (Figure 33a). Also, the share of consumption is very similar as the consumption in the model for Almere (15.0%) includes both AH and OOH, and can thus be compared to the combination of services (6%) and consumption (9%) from Garnett (2008). The last-mile is absent from the UK model and retail is absent from the Almere model, while both seem to have considerable impact. Generally, it can be concluded that the models are in agreement. And the last-mile and retail are aspects that are most interesting for further research, especially since both take place within the city.

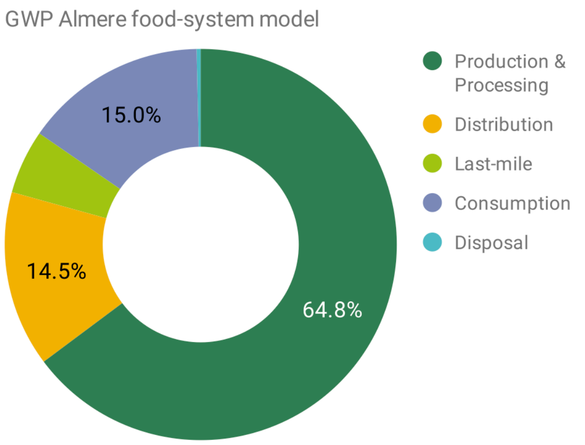

Figure 33a. GWP of the Almere food-system model

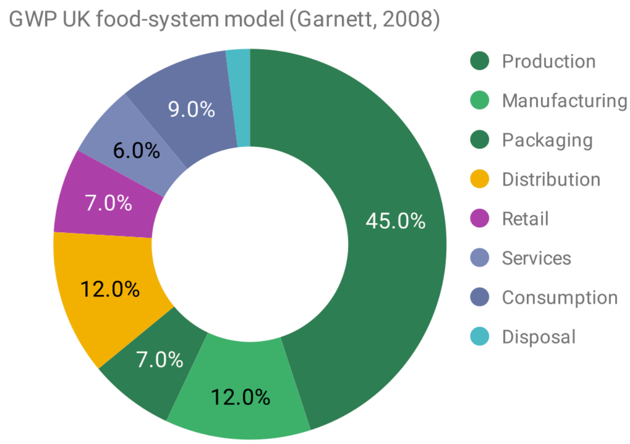

Figure 33b. GWP of UK food-system model (Garnett, 2008).

Agricultural Land Occupation

According to the Almere model, the annual ALO ranges between 174 - 189 km^2a arable land. This equals 2.3 - 2.5 m^2a for an average Almere citizen per day. According to the scenario for Almere by Van Dijk et al. (2017), in the future a total of 4.4-4.7 m^2a per citizen per day would be required. A similar estimation is made by Kramer et al. (2017), who estimates that for the average Dutch diet currently about 4-5 m^2a per citizen per day is used. The estimated ALO of these two studies is roughly twice as much as the estimate from this Almere food-system model. Thereby it can be concluded that the ALO of the food-system of Almere is heavily underestimated. This can in part be explained by the fact that food loss at the farm has not been included. It is estimated that on average 10% of the total food production is wasted at the farm (FAO, 2018). This would increase the initial production and thereby the annual ALO. However, this is not enough to double the ALO and approximate the other models. Land-use is also strongly influenced by production efficiency and thus the cultivation method and origin play an important role as well. Further research into this is recommended and the results of this model in terms of ALO should be treated with caution.

7.1.2. Data gathering

Data that is locally gathered in Almere is essential for bottom-up modelling. There is only very limited data available on the food-system of Almere. Therefore a combination of primary and secondary data acquisition was done. An important data gap on food purchasing behaviour was filled by primary data acquisition through the survey. The survey consists of a considerable sample (0.8% of the households) and has been made more representative by weighting the responses. Repeating the survey would be recommended in order to confirm the findings and increase reliability. Also, in case sustainability strategies are developed it would be interesting to repeat the survey in order to monitor the effects.

Most secondary data that was used comes from studies that did not gather data specifically in Almere. It has been attempted to use studies that are as representative of Almere as possible. For example, the Helius study (Dekker et al., 2011), that was used to model the diets for the consumption of Almere, is a bottom-up study on Amsterdam. As described in the Methodology, many population characteristics of Amsterdam are equivalent to those of Almere and therefore this is considered a relatively good fit. However, it is acknowledged that it would be more accurate to gather this data in Almere itself. Also because diets and purchasing behaviour do not function in isolation from each other but rather in interaction.

The SimaPro databases were used to model the majority of products for the LCA. The ability to use these databases saved significant amounts of time and contributed to the reliability of the model thanks to the data quality of the databases. However, for some aspects it was necessary to use top-down data to fill data gaps. This was done when neither specific data for Almere nor appropriate bottom-up studies were available, e.g. to model the food-waste from suppliers. Naturally, it would be more accurate to use bottom-up data, preferably even specific for Almere, however, this would have required additional primary data acquisition which was not possible during the timespan of this research.

7.1.3. Further Modelling

Generally, a major aspect of the food-system model that requires further research is the consumption out of home (OOH) at food-services. This could be used to refine the life-cycle phases distribution, last-mile, consumption and disposal in the model. The last-mile currently only includes the transport of food from retailers to home. For completeness, it should also include the transport of citizens to food-services. Based on the dining behaviour from the survey, an estimation could be made of the last-mile impact of dining. This would increase the travel by motorized transport for the last-mile with 20-40% (assuming an average travel distance of 5-10 km). Thereby the last-mile share of GWP within the total model would increase from 5.3% to 6-7%. In relation to the entire food-system, the last-mile to services is thus not highly relevant. However, if sustainability strategies are developed specifically for the last-mile, it could be relevant to explore this further. An increase of the last-mile impacts by 20-40% is considerable, and it is probably even larger when other OOH consumption besides dining is included.

In the current model, food-waste by food-services is estimated based on top-down data sources. The food-waste generated at services forms a considerable share (12%) of the total food-waste, especially considering that only 15% of the food consumption takes places here. It would be interesting to investigate the amounts of avoidable and unavoidable food-waste, the share of waste that customers are responsible for and the separation rates for different food-services. If food-waste at services is to be reduced it is important to know whom to target in order for sustainability strategies to be successful.

Furthermore, it would be interesting to explore the share of regional production. The municipality of Almere has ambitions to increase this share to 20%. From the survey it could be estimated that 3.7% of the potatoes, vegetables and fruits are purchased directly from the farmer. However, it should be noted that the survey asked citizens to indicate where they usually purchase the majority of these products. It can be difficult for citizens to estimate this over the course of an entire year which can lead to both under and overestimations. Furthermore, this does not necessarily mean that *only* 3.7% of the consumed produce is regionally produced. Other retailers, such as supermarkets, can also sell regional produce. However, in this case it is not a short supply chain anymore. The fresh produce is only a part of the total food consumption; only 0.85% of the total food consumption is purchased directly at the farmer. Van Dijk et al. (2017) estimate the share of regional production at 5% of the consumption. Local producers estimate that it is rather only 1-3% (Ten Brug et al., 2018). If 0.85% is indeed purchased at the farmer, this would suggest that 2-4% of regional production is sold through other retail channels. Additional research into the exact flows is needed to draw reliable conclusions and therefrom develop strategies to increase the share. Either way, it confirms the idea that the current regional production share is far from the ambitioned 20%. The majority of food is purchased at supermarkets and the short supply chain is not necessarily more environmentally friendly due to the inefficient use of motorized transport for the last-mile (Akkerman et al., 2019). Therefore it would be recommended to start investigating the flows of regional production at supermarkets and the opportunities to increase them.

7.2. Bottom-up modelling

The modelling experience from this case-study can be used to develop general suggestions and a roadmap for the bottom-up modelling of food-systems. It is acknowledged that the practical learnings from this research are based on the experience of just one case-study. This case-study does not necessarily contain all aspects of bottom-up modelling nor does it claim to have encountered all possible advantages and challenges. Additional case-studies would be needed in order to further explore the bottom-up modelling approach for the purpose of modelling urban food-systems.

7.2.1. Suggestions for further exploration

This study initially aimed to compare the developed bottom-up model to a top-down model to further evaluate the advantages and challenges. However, it proved quite challenging to develop an equivalent top-down model and thus fair comparison. It is still considered interesting to develop a top-down model by using national average data such as the VCP study (Van Rossum et al., 2016) and compare this to the current model. In this way, it could be investigated for which aspects the food-system of Almere is significantly different from the national average. And whether it is significantly different from the national average at all. This could contribute to the debate on whether a bottom-up approach is more suitable or whether a top-down approach is able to describe the same trends and focal points.
Another way to develop a top-down model is by using national Input-Output (IO) tables. This was initially attempted for the comparison. From this attempt, it became clear how different the categories are, especially because they are very broad and have a high data aggregation level. A comparison was therefore considered not equivalent and irrelevant. Rather than comparing these different models, it would be interesting to investigate to what extent they can supplement each other. IO tables are praised for being more complete in terms of impacts since they avoid cut of errors (Larsen & Hertwich, 2009). If bottom-up models could be used to detail the broad categories this could provide useful insights on different levels. Hopefully, this study can be used to explore this in the project of PhD researcher Liesbeth de Schutter.

In terms of environmental impact accounting, this research aimed to go beyond carbon accounting and include impacts on the land and water as well. Therefore not only GWP but also FEP and ALO were used. Unfortunately, it was not possible to include the actual water usage since the literature sources used for some of the model-products provided incomparable data. Different indicators were used ranging from blue and green water usage to water depletion and water footprint. Currently, there is no method to convert these different indicators into one another. Water is an increasingly scarce resource and therefore the water usage of systems should be incorporated in environmental impact assessments. In order to describe the water usage impacts, it would be necessary to align these indicators. In this way, water usage impacts can become more accessible for policy makers to consider in their strategies.

Finally, the availability of bottom-up data on urban food-consumption in Almere, and cities, in general, is limited (Goldstein et al., 2013). However, data is not necessarily inexistent. Food suppliers such as retailers and services gather bottom-up data in cities on a daily basis through digital sales systems. Some retailers even gather data on an individual level by means of customer cards. If such data could be available for modelling this would eliminate a large data gap and save significant resources that would be required for primary data acquisition. Furthermore, as data is gathered on a continuous basis this would allow for monitoring which is essential to measure the effects of strategies. Therefore it is suggested to explore how existing urban data can become available for this purpose.

7.2.2. Design for bottom-up modelling

Based on the modelling experience from the case-study in combination with the suggestions for future modelling, a roadmap for bottom-up modelling of urban food-systems can be developed (Figure 34). The roadmap should be seen as a suggestion for the elements needed in a bottom-up model rather than a definite framework. Additional case-studies would be needed to expand this roadmap and finetune the different elements required. Also, it is unlikely that it is possible to design one roadmap that fits every urban food-system, precisely because the bottom-up approach allows for context-specific differences and details. If a city plans to model their urban food-system on a yearly basis, a roadmap like this could be the starting point to standardize procedures.

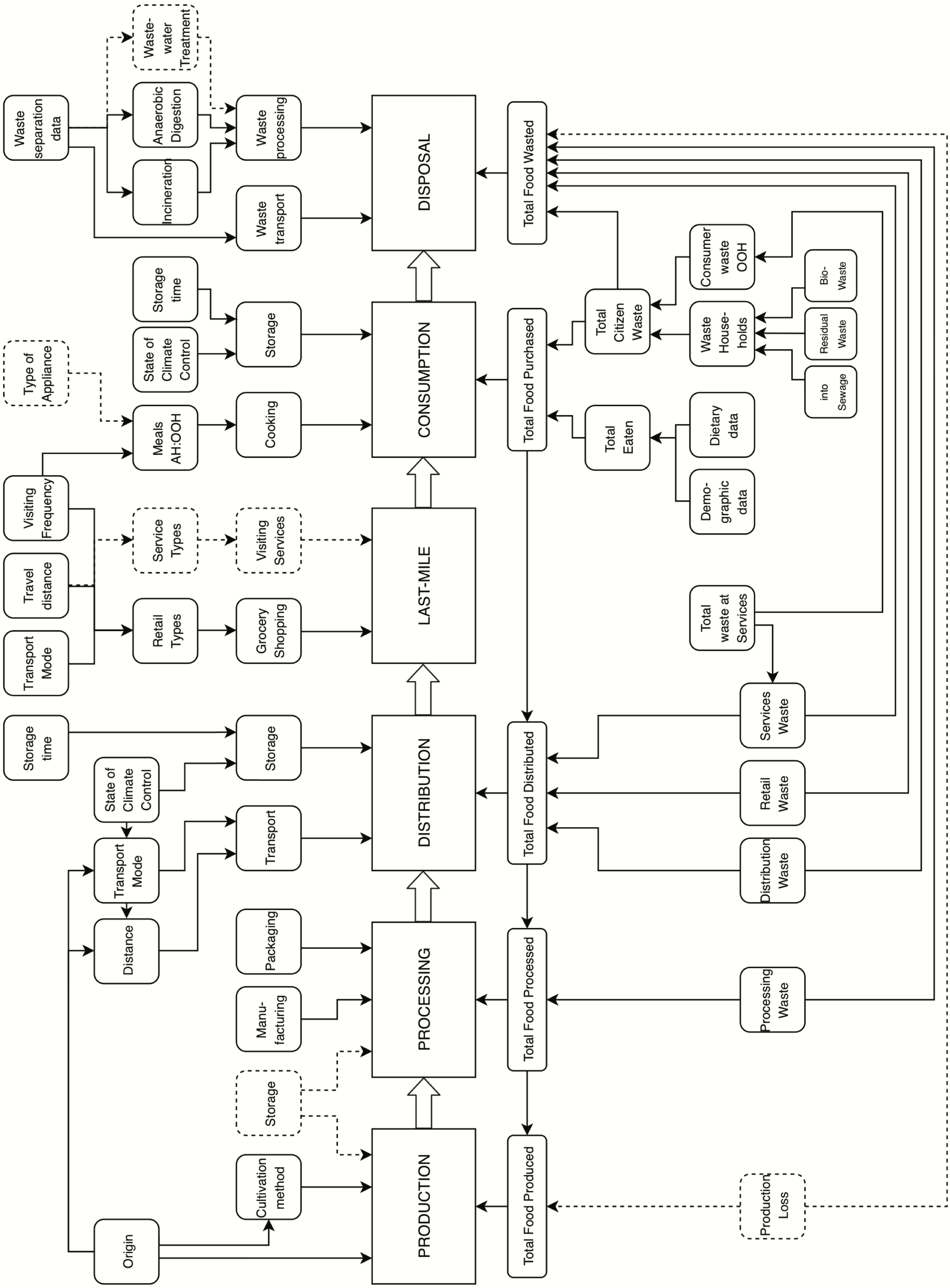

Figure 34. A roadmap for bottom-up modelling of urban food-systems.

CONCLUSIONS & RECOMMENDATIONS

8.

This study demonstrates that bottom-up modelling to evaluate urban food-systems and their environmental impacts is extensive. Also, data gathering for bottom-up modelling is challenging due to the numerous interconnected elements within food-systems that arguably require equally many data inputs. The life-cycle phases production, processing, distribution, last-mile, consumption and disposal formed the major components within the food-system model of Almere. Initial modelling started from the consumption phase, therefore dietary data was an essential element as it formed the basis to model the food-consumption of the city.

The urban metabolism (UM) of the city of Almere is estimated at 156 k tons of food per year. This includes food that is eaten and wasted by retail, food-services and households. Before the food reaches the city, additional food-waste is generated by processors and distributors. In this way, total production of 167.1 k tons of food is required to be produced in order to feed the population of Almere an entire year.

The environmental impacts were calculated based on the food-system model, in terms of Global Warming Potential (GWP), Freshwater Eutrophication Potential (FEP) and Agricultural Land Occupation (ALO). The GWP is estimated between 351 - 411 k tons CO_2 eq. emissions per year. The FEP is estimated between 153 - 169 tons P eq. deposition and the ALO between 174 - 189 km^2 per year. However, further research is recommended for both the FEP and ALO because the FEP requires validation and the ALO is likely to be an underestimation.

Nevertheless, a robust model was developed for Almere that provides reliable insights and potential focal points for sustainability strategies. The results show the advantage of the bottom-up approach through the detail that the model contains. Especially the details provided by the survey results illustrate the importance of gathering bottom-up data. Various elements within the food-system model play a different part in the environmental impacts. Based on the main elements of the model, the following recommendations have been developed for Almere.

Urban diets are at the core of urban food consumption and have a significant impact on the food-system and the environment. The current average diet of an Almere citizen is not in line with the recommendations for a healthy diet. Meat consumption is on average too high; around 1.5-2 times the recommended intake. Contrarily, vegetable consumption is on average too low; about half the recommended intake. A healthy diet does not include consumption of sodas and alcoholic beverages. Thereby, the intake of these beverages is automatically too high. Nevertheless, it is striking that beverages form one-third of all the food consumed, while tap-water is excluded from the model. The majority of the environmental impact for each indicator is generated by the production and processing of the food. The food categories meat, dairy and beverages have the highest impact shares. Significant reductions in environmental impacts are achieved by reducing the consumption of these foods. In accordance with previous research, dietary shifting is recommended both from a sustainability and health perspective.

The majority of food (tons) is transported by trucks from within Europe or even the Netherlands. The largest share of freight (tkm) is by ships because of the long travel distances. However, the impacts of air freight are significantly higher than any other transport mode. Therefore, minimizing air freight in the food supply results in significant impact reductions. It could be interesting for Almere to explore the possibility to avoid or deny food that is distributed by air freight trough policy. This connects well to the ambition to increase the share of regional production.

Currently, more than 70% of households purchase their potatoes, vegetables and fruits in supermarkets. Only a small share of fresh produce (3.7%) is purchased through a short supply chain, directly at the farmers in Flevoland. This amounts to only 0.85% of the total food consumption. Further research is needed to determine the flows of regional production through other retail channels. However, it is likely that currently far from the ambitioned share of 20% is regionally produced. As the majority of fresh produce is purchased in supermarkets, it is recommended to first explore the flows and opportunities to increase the share of regional production there. Also because the short supply chain is not necessarily more environmentally friendly, as it depends on the mode of transport used for the last-mile.

The average household in Almere visits food retailers 226 times a year for grocery shopping. The majority of the last mile is travelled by private motorized modes (68%), mainly cars. The total motorized distance travelled of the entire population of Almere is equal to roughly 1500 trips around the planet every year. Consequently, the impact of the last-mile forms a considerable share (5.3%) of the GWP of the entire food-system of Almere. It is recommended to reduce the amount of motorized travel for the last-mile as this would reduce the environmental impact substantially. This can be achieved by developing strategies to lower the visiting frequency by car and encourage a shift to active modes such as walking and biking.

In total, approximately 16% of the initial food inputs into Almere are wasted each year. Citizens in the role of consumers are responsible for the majority of the waste (82%). About 12 tons of the 20 tons of annual food-waste by consumers are considered avoidable. This food has been produced and distributed to Almere. Therefore, it is responsible for a considerable share of the total GWP (7.1%), FEP (7.5%) and ALO (8.7%). Avoiding this food-waste would considerably reduce the environmental impacts. The reduction of food-waste is significantly more impactful than diverting food-waste from residual to bio-waste. While separation efforts should continue it is recommended to primarily focus on the reduction of food-waste.

Besides recommendations for Almere, this study provides learnings for bottom-up modelling in general. It is relevant to explore the opportunities to receive consumption data from retailers, as dietary data is considered an essential element in bottom-up modelling of urban food-systems. Based on the case-study, a roadmap has been designed that can be used as a starting point for future modelling projects. In addition, the roadmap as well as the results can be used in the debate on the suitable modelling approach.
While there are many aspects that require further research, there are also multiple confident recommendations for Almere and cities in general to start working on. Therefore, there is no need to wait and cities can start with the development and implementation of sustainability strategies. Moreover, the transformation towards sustainable urban food-systems *cannot* wait and should start today.

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