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ABSTRACT

Current urbanization rates concentrate the ever growing demand for food, energy and water (FEW) resources particularly in cities, making them one of the main drivers of greenhouse gas emissions. The FEW nexus integrative approach offers a potential framework for sustainable resource management in cities. However, existing nexus evaluation tools are limited in application and often inadequate. This is primarily due to the FEW nexus intricacy, the tools' operational complexity and/or the need to input comprehensive data that is often unavailable to users. Having outlined these current gaps, this paper introduces the FEWprint, an integrated carbon accounting platform that provides an accessible process for FEW nexus-based evaluations of urban areas. This spreadsheet-based framework is employed to calculate a consumption-based footprint derived from food consumption, thermal/electrical energy use, car fuel demand, water management, and domestic waste processing. A comparative assessment between six different communities reveals significant differences in total annual emissions. The food sector impact shows emissions ranging between 993Kg/cap*yr and 1366Kg/cap*yr in Amsterdam and Tokyo respectively, but is also the least deviating from all considered resource sectors. This holistic carbon footprint and considered food inventory will serve as a baseline for future integrated urban farming strategies and urban design proposals to be tested.

1. Introduction

The world population of approximately 7.5 billion people is anticipated to increase to around 10 billion in 2050 (UN DESA, 2019). With the expected global population growth, the demand for food, energy and water resources continues to grow in parallel. By 2050, food demand is expected to increase by about 60% (FAO, 2017) and fresh water demand by 20–30% (WWAP, 2019) and global energy demand by 40% in 2030 (EIA, 2019). In 2018, 54% of the world's population lived in cities and urbanisation is expected to climb to 68% in 2050 which equals roughly 6.8 billion people (UN DESA, 2019). These figures predict that the demand for the key resources food, energy and water (FEW) will increasingly concentrate in and around cities, making them – under unchanged policy – the main emitter of greenhouse gases globally. In an increasingly urbanised world, with a rising population under the threat of global climate change, the urgency to develop sustainable FEW management solutions at the scale of the city is growing.

The demand for food, energy and water in cities generates emissions of greenhouse gases along the entire life cycle chain of these resources. Greenhouse gases can be expressed in carbon emission equivalents (World Resources Institute, 2014), which are also simply referred to as carbon emissions or CO_2eq throughout this work. Carbon emissions are

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commonly applied to measure the environmental impact of the built environment as they are a key contributor to the global warming effect (IPCC, 2018). Earlier research that applied a carbon accounting framework is the City-zen project, in which an urban energy transition strategy was proposed for the neighbourhood of Gruz in Dubrovnik (Dobbelsteen et al., 2018). Pulselli further developed the applied accounting approach into a generic carbon accounting framework for European cities (Pulselli et al., 2019), which was then demonstrated for a neighbourhood in Seville, Spain (Pulselli et al., 2019) and finally culminated into a stakeholder-engaged consolidated workshop strategy to kick-start the decarbonisation of cities (Pulselli et al., 2021). The aim of this study, the decarbonisation of the urban environment, is similar to the aforementioned studies but it expands the scope with a thorough and context-based consideration of food consumption.

The areas of food, energy and water management are interdependent and share numerous interwoven connections regarding security, environmental impact, quantity and quality (Hoff, 2011). Therefore, policies or physical infrastructure installed to manage resources in one sector, can have knock-on implications in the other sectors. The *FEW nexus* system's theory, introduced at the 2009 World Economic Forum in Germany (Hoff, 2011), appreciates, considers and accounts for this interlinkage when assessing, evaluating or (re)designing a resources system.

Within the academic community, no clear definition of the term *nexus* has yet been developed and it is therefore far from being acknowledged in a uniform way (Endo et al., 2017; Reinhard et al., 2017). In the absence of a commonly agreed definition or conceptual nexus framework, various interpretations of the concept have emerged from a range of organisations and authors. For example Hoff (2011,p.9), main author of the 2011 Bonn conference synopses, states that 'A nexus approach to managing and achieving security in the water, energy, food and environment sectors will support a transition to sustainability by reducing trade-offs […] that outweigh the transaction costs associated with a paradigm shift to stronger integration across sectors.' Endo et al. mention that 'nexus is internationally interpreted as a process to link ideas and actions of different stakeholders from different sectors for achieving sustainable development.' (Endo et al., 2017, p.2). The German GIZ and ICLEI state that '[…] an Urban NEXUS solution integrates two or more systems, services, policy or operational "silos", jurisdictions or social behaviours, in order to achieve multiple urban policy objectives and to deliver greater benefits with equal or less resources.' (GIZ & ICLEI, 2014,p.6). Reinhard et al. (2017, P.6). wrote that 'The water, food and energy nexus is an approach to consider the interactions between water, food and energy, while taking into account the synergies and trade-offs that arise from the management of these three resources, and potential areas of conflict.' Finally, Rees (2013) mentioned that the nexus approach is required to establish a framework of decision making that can identify cross-sectoral impacts and unintended consequences and explore feasible trade-offs.

The cited interpretations of the nexus concept all accentuate a multi-sectoral approach to FEW management in contrast to the *silo-thinking* that has thus far been more prominent, and all interpretations hint towards avoiding (unintended) trade-offs whilst exploiting potential correlations for a synergistic impact on resource security, production efficiency or environmental footprint.

In the past ten years, less than a quarter of the FEW nexus publications focused on the urban scale (Zhang et al., 2019). The scientific community acknowledges this gap and researchers call for a downscaling of nexus research to urban resources production and management (Yan and Roggema, 2019). Rees (2013) and Leck et al. (2015) both point out that we have marginal research-based evidence on how to implement the ambitious FEW Nexus attitude in the physical realm and build real-world solutions across various scales or provide guidance to decision makers. Terrapon-Pfaff et al. (2018) state that the past and contemporary focus of FEW nexus discussions and applications has mainly been on national or global levels, discussing macro-level drivers, material stocks and flows and large infrastructure developments. This is acknowledged by Leung Pah Hang et al. (2017) and Martinez-Hernandez et al. (2017), who point out that most of the existing work addresses larger global, national or regional scales and there have only been a few studies analysing the FEW Nexus at the local scale. However, it is at the micro scale -meaning building to neighbourhood level- where policies and strategies inform physical interventions (Leung Pah Hang et al., 2017; Martinez-Hernandez et al., 2017).

Several assessment tools have been developed that help to comprehend the complexity of the FEW nexus, for example: WEAP (SEI, 2020), LEAP (Heaps, 2020), MuSIASM (Giampietro and Mayumi, 2000) and CLEWS (Howells et al., 2013). Despite the considerable array of developed evaluation tools, most of them provide a perspective at the (supra) national or at best regional scale and only give a primitive consideration of the effects at the local scale (Hake et al., 2016). Contemporary FEW nexus assessment or modelling tools, such as the aforementioned examples, have been extensively reviewed in the past years by various studies. The recurring issues and challenges within the array of tools include limitations due to data availability and standardisation, comparability of results, short-term analysis, level of integration, specific entry point, user accessibility, stakeholder involvement, perception of complex synergies posed by various urban systems and defining the system scale/boundary (Brouwer et al., 2018; Dargin et al., 2019; FAO, 2014; IRENA, 2015; Kaddoura and El Khatib, 2017).

The overarching challenge is the extensive amount of data input required to build models, run simulations or perform evaluations. Simplification of the assessed interconnectivity of resources can partly overcome the problem of data constraints; however, this could compromise output accuracy (Kaddoura and El Khatib, 2017). Public databases like FOASTAT, EuroStat, UNSD or national statistics bureaus provide readily available data for national or transnational nexus assessments. However, granular data is often not collected and stored by a particular centralised agency and/or data management tends to be sectorally organised. Furthermore, the data needed to assess a neighbourhood, is collected at varying scales defined by the geographical, ecological, jurisdictional, and operational extents of the city. This will be made evident in the case studies, elaborated later in this article. Finally, complications with paywalls or data sensitivity obstruct researchers from retrieving important data (McGrane et al., 2018). A tool and framework is lacking that operates at the neighbourhood scale, requiring minimal public data input. In addition, tool output should be expressed in units that are relatable and relevant to urban policy makers, designers and/or researchers.

Community farms and urban food production have gained the interest of the general public, urban planners, architects, students and researchers in the past decade. A farm can be considered a materialization of the food, energy and water nexus concept: food, energy, water, nutrients and topsoil (space) are assimilated and processed into food or feed, various forms of waste products and greenhouse gases. On a higher scale-level of consideration, a neighbourhood or city is another example of a nexus: resources enter the city-system as inputs and waste and greenhouse gases are disposed of as outputs. But what is considered a waste product for one entity can be considered a valuable resource for the other through principles of circularity. Further, new connections could be established when the two systems are in close proximity to each other (Leung Pah Hang et al., 2017). As such, a synergetic assimilation of food producing systems within the urban resources systems can potentially mitigate the environmental footprint of the farm as well as that of the city (Goldstein et al., 2016).

A nexus-informed urban intervention, like the integration of a food system and a city system, requires a quantified understanding of the comprehensive and thus far under-perceived linkages and interactions between the involved sectors. Only with this new knowledge, can the cross-sectoral resource implications of urban food production (UFP) systems be quantified and urban (re)design proposals be holistically evaluated.

This work introduces the Food, Energy and Water integrated carbon footprint accounting tool, or *FEWprint*. The FEWprint is a three-pronged urban food production (UFP) evaluation platform that consists of an 1) *evaluation,* 2) *shift* and 3) *design* component. The *evaluation* component is further elaborated in the *Method & Materials* section and applied in this work. Briefly, it offers the framework to rapidly calculate a carbon footprint profile of urban communities on the aspects of food, energy and water (FEW) demand and waste processing by using publicly available data. This is demonstrated by calculating and comparing the business-as-usual (BAU) or baseline carbon profiles for six urban neighbourhoods that differentiate in terms of scale, context, population and societal factors. The case studies are: Amsterdam (Kattenburg), Belfast (Inner-East), Detroit (Oakland Avenue Farming Community), Doha (Qatar University Campus), Tokyo (Tamaplaza) and Sydney (West Sydney).

2. Methods

This chapter discusses the approach and scope of the urban community carbon accounting framework and platform and introduces the six case studies used in this work. Special attention is given to the assessment of food consumption.

2.1. General purpose and operation

The platform operates as a scenario comparison tool. This means that after establishing a baseline scenario, alternative solutions to urban resource management can be tested by redefining the quantity, sources or management practices of the consumed resources, which establishes the *new* scenario, see Fig. 1. The spreadsheet based tool is divided into several themed tabs where average end-user consumption data is inserted: (1) Food, (2) Energy, (3) Water, (4) Waste and (5) Mobility. General information about the context (e.g. demographics) is inserted in the *info* tab. Each time resource input is changed into a (renewable) alternative, the FEWprint tool responds by recalculating the carbon footprint. This process should be iteratively repeated for all relevant resource demands to gradually reduce the community footprint until desired targets are met. The FEWprint does not auto-generate solutions according to user-defined emission targets or policies, but rather facilitates a *trial-and-error* work flow to assess options. A step-by-step explanation is added to each of the aforementioned tabs to guide the user through the platform.

To account in the comparative analysis for projected long-term demographic changes (population change), grid mix changes (a transition to renewable energy resources) and non-situational developments surrounding mobility, the FEWprint tool offers three timestamps to which the expected development can be anchored. The long-term development of these three externalities is different for each context and most likely will remain speculative when taken into consideration. Therefore, the platform does not provide default data for future scenarios and requires the user to define such future projections. In order to assess the effect of urban FEW management changes without including these long-term developments, a *present* option is offered in which the before mentioned factors remain similar to the baseline scenario.

2.2. Carbon accounting approach

This study applies the consumption based accounting approach, or CBA (Mi et al., 2019). CBA allocates resource use related emissions to the consumers, subsequently making carbon emission mitigation an effort of user behaviour changes and resource demand reduction at the end-user level. A (residential) urban environment, like the case studies considered in this work, often import their throughput resources from outside the geographic boundaries, sometimes across nations or even continents, subsequently outsourcing the production related emissions to these other locations (Bai, 2007). Consumption-based indicators include the entire supply chain emissions in infrastructure and non-infrastructure goods but excludes chain emissions related to the urban production and export of (excess) resources to outside the boundary (Chen et al., 2020).

A workable protocol for organising community carbon accounting boundaries of territorial and exo-urban emissions is the *Global protocol for Community-Scale Greenhouse Gas Emission Inventories*, that distinguishes urban-driven emissions into three scopes in order to prevent double counting (World Resources Institute, 2014). Scope 1 accounts for emissions coming from fuel combustion from within the urban boundary. Scope 2 addresses cross-boundary emissions occurring consequentially to the urban demand for grid-supplied electricity and district heating and/or cooling. Scope 3 notes all other greenhouse gas emissions outside the urban boundary as a result of activities and resource demands from within the city boundary. Limiting the carbon inventory to territorial emissions (scope 1), leads to a deficient depiction of the community's contribution to the global warming effect (Feng et al., 2020; Fry et al.,

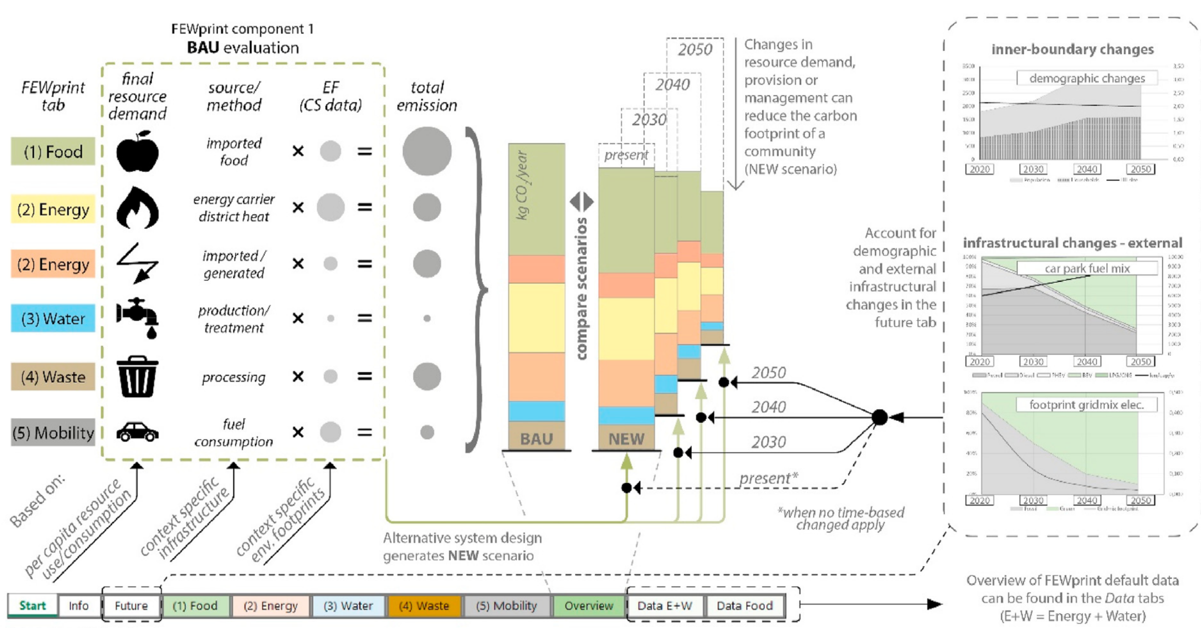

Fig. 1. Schematic representation of the FEWprint's evaluation component. NEW scenarios can be tested for three different future time stamps. The default years are 2030, 2040 and 2050, but any year can be entered to define timelines.

2018). The CBA indicator therefore considers scope 1–3 emissions driven by final resource consumption at the level of the individual user. Fig. 3 is an adaptation of the WRI framework to better fit the intended application scale of the FEWprint platform.

The FEWprint platform assesses the carbon footprint of a community, defined by their shared geographic area and extents. The interpretation and conditions of a *community within its neighbourhood* can differ across nations and various stakeholder discourses. For this reason, this research adheres to the following definition: the community considered is a multiplication of *n* users in an urban context, that represent the average consumption of routinely used throughput resources specific to that urban context. This definition excludes (heavy) industry or other urban functions where the resource consumption of one urban entity (for example a swimming pool) does not reflect the every-day consumption patterns and behaviour of the individual. Simultaneously, the assessment is not limited to urban dwellers, but for example also allows for application to student-communities within university campuses. The intended scale of application is the *neighbourhood*; however, application is possible from building scale to city scale.

2.3. Carbon assessment scope

The resource assessment scope of the FEWprint covers the provision and management of throughput resources that are commonly identifiable in an urban community. These are: food, electrical energy, thermal energy (energy carriers), fuel for mobility, drinking water, the management of waste- and rainwater and the processing of domestically produced waste.

Resource demand that pertains to the working place or to the public domain, i.e. any other domain than the considered urban context, are not accounted for in this assessment. As such, it should be noted that the outcomes of this work do not outline the broader impact of an individual person, but rather of a dweller/user in the community domain. In addition, this scope does not contain the full range of emissions that can be ascribed to the urban dweller and certain omissions apply. The use of public transportation services are not accounted for. Embodied emissions of building construction materials or other urban infrastructure in the public domain are excluded. Emissions occurring during the manufacturing, transportation and end-of-life of procurement are not accounted for (e.g. cars, household inventory, delivery services or other utensils). Finally, carbon sequestration by existing biomass in the considered context is left out of the scope.

These omissions could constitute a significant portion of the total emissions of a person. However, aside from the complexity of embodied carbon assessment and its integration in a user-friendly platform, we believe that insight in the omitted carbon sources would not contribute to the umbrella purpose of the FEWprint platform: the appraisal of urban food strategies during the conceptual stage of the design process.

2.4. Carbon accounting of food

To clarify methodological decisions of food consumption carbon accounting, the overall purpose of the FEWprint platform needs to be briefly explained. The key function of the platform is to support designers during the design of urban food producing systems, which will be further discussed in the discussion chapter. To accomplish this function, the FEWprint is divided into three integrated components: *evaluation, shift* and *design.* This article only discusses the *evaluation* component. The development of a three-pronged platform involved finding a functional balance between inter-component integration and achieving a comprehensive scope while securing simplicity and user-friendliness. In this conceptual triangle of platform values, prioritising one inherently diminishes the other(s). By setting certain limitations for the considered food inventory, inter-component integration is enhanced and food system design remains intelligible; however, this goes at the expense of food consumption carbon assessment comprehensiveness.

2.4.1. Food inventory

The FEWprint combines consumption data for 18 food groups to compose a representative diet profile for a community (Table 1). All groups represent staple foods, meaning that the food is eaten routinely and in such quantities that it constitutes a dominant portion of a standard diet of a community. The food inventory is limited to unprocessed or semi-processed food only and liquids are excluded. The exceptions of these are cheese and milk: processed food groups that generally have considerable carbon footprints and are consumed in high amounts in certain cultures. The exclusion of processed food and beverages is done for two purposes. First, it increases comparability between the results as data on processed items becomes increasingly difficult to interpret, process and assign to a food group, especially when six case studies need to be aligned. Second, the food production chain of processed items is difficult to grasp and requires an industry that is not easily conceivable in an (inner) urban context as part of an urban food production strategy

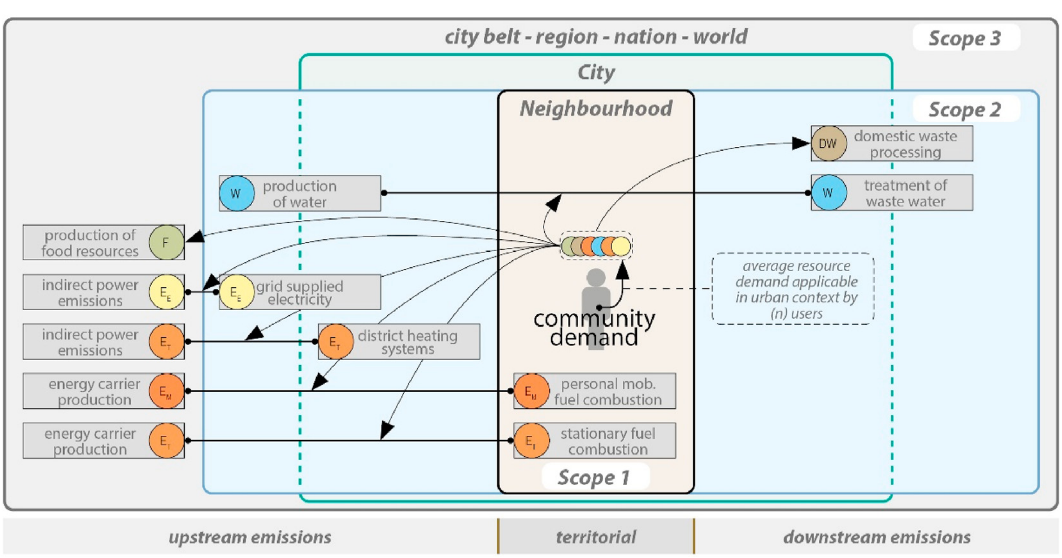

Fig. 2. Adaptation of the WRI carbon accounting scopes framework that addresses the neighbourhood as the smallest area of consideration, as opposed to the city-level in the WRI framework.

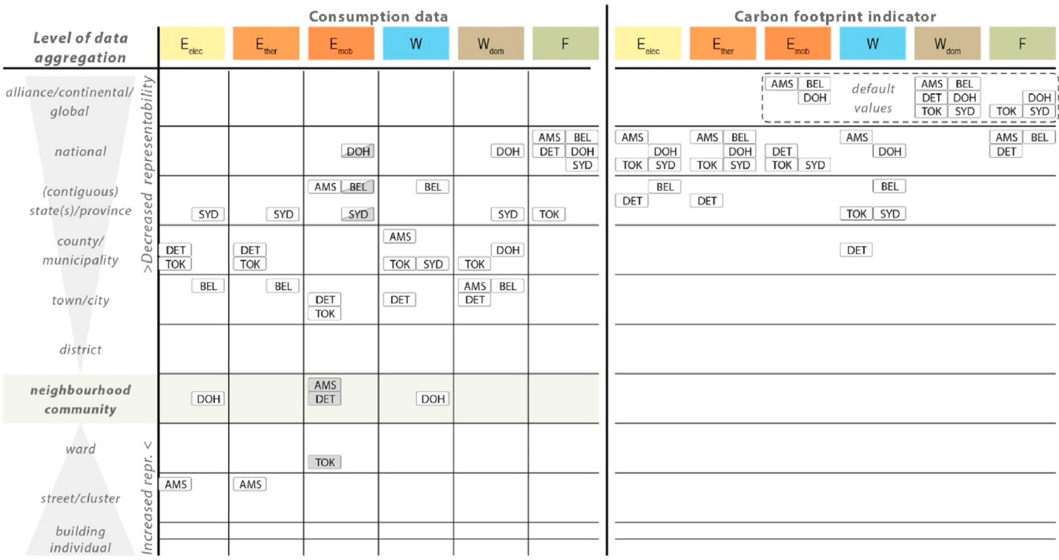

Fig. 3. Data aggregation levels of end-user resource consumption data for the 6 case studies. Mobility labels represent the average distance driven per year (white hatch) and car ownership (dark hatch). The position of the carbon footprint labels (right) indicates the scale of operation/service of the assessed resource infrastructure.

2.4.2. Food footprint data

This study's assessment makes use of categorical carbon footprint indicators that are either provided as such by the data source or are formed by grouping footprints of individual products. This method is much less time consuming in terms of gathering, interpretation and data insertion of the required figures and data gaps of individual products are easily overcome by applying the food group figure. However, the method is a compromise to outcome accuracy as it is less of a reflection of reality, which is further discussed and assessed in a sensitivity analysis in section 4.4.

In this paper, country-specific Life Cycle Inventory assessment of food carbon footprints are gathered and used for the case studies, where available. Per case study, the taxonomy of the source's dataset has been analysed and aligned as much as possible with the categorisation used in this work in order to acquire a group carbon footprint that contains as many sub-products as possible. Situational carbon footprint data are not available in Sydney, Tokyo and Qatar, for which global average indicators calculated by Poore & Nemecek is used as a substitute (2018).

Finally we want to underline that, even though carbon equivalent emissions encompasses various greenhouse gas emissions that are responsible for climate change implications world-wide, resource demand or agricultural practises can also impose destructive and irreversible damage in the local environment. Such climate implications can be equally, if not more pressing to address for a specific context. For example biodiversity destruction, eutrophication, acidification, water- and air pollution or others forms of ecological exhaustion.

2.5. Carbon accounting equation framework

The sum of the sectoral emissions constitutes the FEWprint profile (CF_{tot}) and is composed of the separate sectoral footprints of food consumption (CF_F), electrical energy use (CF_{EE}), thermal energy use (CF_{TE}), the use of car fuel for mobility (CF_{ME}), water production, treatment and rainwater management (CF_W) and the processing of domestically produced waste (CF_{DW}), as shown in equation (1). All sectoral footprints are in [kg/cap* yr] and equation (1) is applicable for both the BAU scenario as well as *new* scenarios. The equation framework and all the sub-components used in the FEWprint are further discussed in detail in Appendix E.

$$CF_{tot} = CF_F + CF_{EE} + CF_{TE} + CF_{ME} + CF_W + CF_{DW} \quad [1]$$

2.6. Case studies

In order to demonstrate the *evaluation* component of the FEWprint platform, six urban communities have been selected for carbon assessment. These communities are located in the cities of Amsterdam (community population = 1721), Belfast (pop. = 32,834), Detroit (pop. = 427), Tokyo (pop. = ~84,850), Doha (student + staff population = ~24,000) and West-Sydney (projected pop. 1,000,000). An extensive description of the cases, demographic data and the resource demand by the community can be found in appendix D.

All of the FEWprint calculations are based on average per capita final resource demands. For the six urban communities assessed in this study, all of the consumption data was retrieved from public databases. Public data registrations generally release average consumption data at different scales of aggregation. The data can either be based on a bottom-up population survey, grouped per geographical area (the average of many individuals) or based on top-down collections at higher levels (measured total consumption divided by the population). The first method cultivates an accurate representation of the community's resource use, whereas the latter approach might produce figures that deviate considerably from local reality. Fig. 3 gives an overview of the aggregation levels of data sources for the case studies used in this study. As the exact definition of an aggregation level can vary between nations, the figure therefore displays a more general stratification of levels. The consumption data of the six case studies and the data sources utilized are further elaborated in appendix D. Bottom-up survey data is used to fill in the food consumption of the 18 groups, listed in Table 1. Appendix C shows the breakdown of the food groups into sub-items for a better understanding of the considered food inventory.

Carbon footprint indicators of resources or services [kg CO_2eq/*unit*] can vary considerably between case studies due to differences in for example management practises, types of primary energy carriers or because system operate at different scales or capacities. To increase the representability of the FEWprint output, it is recommended to apply context specific carbon footprint (CF) values as much as possible. For the assessment of the six case studies, situational carbon indicators have been collected where available and an overview is provided in appendix A. Not all countries release accessible, accurate or unambiguous data for all six sectors that could be used for carbon assessment. In order to overcome these data gaps, the platform offers a set of default data, listed and explained in appendix B.

Table 1
Per Capita consumption (PCC) of the 18 food groups [gram/cap*day] and the associated carbon footprints (CF) [kg CO_2eq/kg food]. The applied contextualisation parameters r_{hal}, r_{car} and r_{add} [%] are explained in Appendix E. Where available, country specific carbon footprints are applied; if unavailable, world average default (D) footprint data is used, provided by Poore & Nemecek (2018). The value between the brackets denotes the number of food products combined within the food group to produce an averaged representative value. n.d. = no data available or not mentioned as an separate food group but logged under other group.

•	Factor	Global mean values	Amsterdam, Kattenburg		Belfast, Inner-East		Tokyo, Tamaplaza		USA, Oakland Av.		Doha, Qatar Uni. Campus		Sydney, Western-Sydney.	
	r_{hal} [%]	*n.a.*	*15%*		*0%*		*0%*		*3%*		*0%*		*0%*	
	r_{car} [%]	*n.a.*	*20%*		*20%*		*0%*		*22%*		*20%*		*0%*	
	r_{add} [%]	*n.a.*	*15%*		*15%*		*0%*		*15%*		*15%*		*0%*	
•	**food group (n)**	**CF [a]**	**PCC [b]**	**CF [c]**	**PCC [d]**	**CF [e]**	**PCC [f]**	**CF [b]**	**PCC [g]**	**CF [h]**	**PCC [i]**	**CF [b]**	**PCC [j]**	**CF [b]**
1	Vegetables	0.40	131.0	1.82 (31)	92	1.77 (3)	283	*as global*	99.7	0.48 (57)	209	*as global*	110.5	*as global*
2	Fruits	0.40	113.8	1.53 (18)	114	0.90 (1)	108	*mean*	77.5	0.57 (32)	187	*mean*	142.3	*mean*
3	Legumes & pulses	0.90	4.5	2.53 (3)	3	3.40 (2)	63		11.6	0.80 (18)	41		8.8	
4	Grains	1.40	138.3	1.32 (12)	106	1.00 (2)	103		150.8	0.46 (14)	211		131.9	
5	Rice	4.00	0.0	1.71 (2)	15	3.90 (1)	291		n.d.	1.73 (4)	184		32.2	
6	Starchy roots	0.60	72.2	0.92 (1)	93	0.40 (1)	46		57.7	0.25 (3)	59		61.1	
7	Beef (& veal)	60.0	12.6	30.82 (6)	21	68.8 (1)	14		51.8	32.85 (1)	7		18.9	
8	Pork	7.00	13.0	13.73 (4)	31	7.90 (1)	45		39.4	5.56 (1)	n.d.		6.0	
9	Sheep/Goat	24.0	0.6	24.0 (D)	5	64.2 (1)	-		0.7	34.75 (1)	53		7.2	
10	Poultry	6.00	16.6	12.21 (2)	36	5.40 (1)	32		75.1	3.20 (3)	119		25.6	
11	Fish	3.00	12.9	8.61 (19)	22	5.40 (1)	66		8.2	7.70 (6)	46		29.9	
12	Cheese	4.50	32.6	11.28 (5)	18	4.50 (1)	4		34.2	9.97 (1)	n.d.		11.4	
13	Dairy & Milk	21.0	254.3	2.31 (11)	262	1.90 (2)	130		138.6	1.33 (2)	232		209.4	
14	Eggs	3.00	12.7	4.32 (1)	15	4.90 (1)	38		27.3	3.75 (1)	32		6.6	
15	Pasta (durum)	n.d.	47.1	1.52 (1)	14	1.00 (1)	12		n.d.	n.d.	n.d.		16.2	
16	Nuts & Seeds	0.30	6.3	4.16 (8)	5	2.00 (1)	n.d.		13.9	1.89 (13)	n.d.		6.5	
17	Meat replacements	2.00	1.5	2.00 (D)	n.d.	2.00 (D)	n.d.		n.d.	2.00 (D)	n.d.		1.2	
18	Dairy replacements	0.90	8.4	0.76 (1)	n.d.	0.90 (D)	n.d.		n.d.	0.53 (2)	n.d.		7.9	
	total [gram/cap*day]		**878**	-	**852**	-	**1235**	-	**786**	-	**1380**	-	**833**	-

[a] (Poore & Nemecek, 2018),
[b] (RIVM, 2017),
[c] (RIVM, 2020b),
[d] (DEFRA, 2020a),
[e] (Scarborough et al., 2014),
[f] (MHLW, 2018),
[g] (USDA ERS, 2017),
[h] (Heller et al., 2018),
[i] (MME Qatar, 2020),
[j] (ABS, 2014)

3. Results

Fig. 4 depicts the annual sectoral carbon emissions per capita [kg/cap*yr] for each of the six case studies. The communal carbon footprint of Kattenburg, Amsterdam (AMS) and Inner-East, Belfast (BEL) are in the same order of magnitude and show a comparable percentile distribution. The Qatar University campus, Doha (DOH), West-Sydney, Sydney (SYD) and Tamaplaza, Tokyo (TOK) present considerably higher emissions mainly due to more emissions associated with water management, mobility and domestic energy use. The CO_2eq emissions of the Oakland Avenue community (DET) exceed the other communities by far, predominantly due the combined effect of high demand for energy resources and high carbon footprint indicator values.

Table 3 provides an overview of the sectoral emissions and lists some of the important situational factors that determine the carbon footprint of a sector. This table is used for inter-city comparison and supports the interpretation of the outcomes, which is briefly discussed in section 3.1.

3.1. Emissions analysis

Energy. Doha relies completely on electrical energy for the indoor temperature control of dwellings; hence no emissions are noted under thermal energy. In Belfast, Amsterdam, Tokyo and Sydney, natural gas is mainly used for domestic heating. In Detroit, both electricity and natural gas are used for space heating. The combination of an elevated energy demand and a high CF for grid mix electricity amounts to a considerable impact in the energy sector in Detroit. This is coupled with a legacy of a poorly performing housing stock, making the residents of the Oakland Avenue community the largest emitters among the assessed case studies.

Water. Doha relies on electricity intense desalination methods to produce potable water. Combined with a large household demand for drinking water, this sector constitutes a significant part of the total emissions for the Doha community. In Amsterdam, Doha and Sydney, rainwater is not processed and is immediately directed out of the neighbourhood and/or city. In Tokyo, Belfast and Detroit, captured rainwater from non-permeable surfaces is pre-treated centrally by means of conventional sewage treatment before it is disposed of in natural water flows. However, it is only in Detroit where this pre-treatment leads to considerable additional emissions.

Mobility. The sectoral impact of mobility is affected by the combination of five parameters: car ownership, car typology based on fuel input, annual driving distance, fuel footprints and car fuel use efficiency. The efficiency is assumed similarly for all cases in this study (see Table 3) and car fuel carbon footprint values show minor differences between the cities. Amsterdam, Belfast and Doha apply the default values (=European average). In Amsterdam, the low private car ownership combined with a limited annual driving distance result in the lowest relative and total emissions for mobility between the six case studies. Qatar University campus emissions exceed the other communities by far. The combination of high car use and high car ownership for the students and staff makes mobility related emissions account for a third of the total (33%).

Waste. Similar carbon footprint indicators for domestic waste processing are applied across all the case studies. The sectoral impact is therefore based on the three remaining factors: the amount of domestic

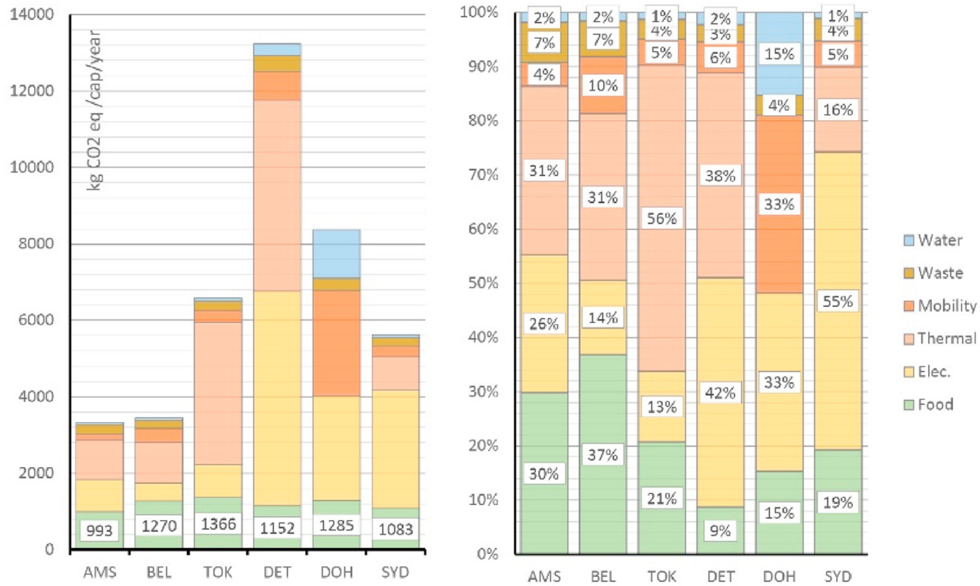

Fig. 4. a: (left) Sectoral emissions of the six case studies, total [kg/cap*yr] and Fig. 4b: (right) percentile distribution [%].

waste produced annually, the applied recycling fraction and the prevailing waste processing method used. For inter-city comparability, the aforementioned factors are combined into one carbon footprint indicator, expressed per kg of domestic waste (see Table 3). This indicator reveals that Tokyo has the best performing waste management, whereas Doha shows the highest carbon impact per kg of waste produced. This is mainly due to landfilling being the prevailing method of waste management.

Food. Food related emissions are discussed in section 4.1.

4. Discussion

The first section discusses the food sector emissions calculated in this work. Section 4.2 explains the link between food consumption assessment and urban food production design within the FEWprint platform. Sections 4.3, 4.4 and 4.5 discuss the applied method and outcomes.

4.1. Food emissions

The total carbon impact of food consumption is found in the range of 993 kg/cap*yr (Amsterdam) to 1366 kg/cap*yr (Tokyo) and the relative consumption starts from 9% (Detroit) up to 37% of the total (Belfast). Where the data was available, country-specific consumption data was combined with country-specific carbon footprint indicators. Based solely on the comparative assessment of this study, an unambiguous correlation cannot be measured between the food intake composition and the resulting food sector emissions as it uses a combination of variable data entries.

Substantial sectoral and total carbon emission differences are observed between the case studies. However, food consumption related emissions show the least differences between the cases. The coefficient of variation, i.e. relative standard deviation (c_v), between the cases' food sector emissions is the lowest of all sectors: 11%. The other sectors are $c_v(waste.) = 28\%$, $c_v(elec) = 99\%$, $c_v(therm) = 170\%$, $c_v(mob) = 270\%$ ϵ and most deviated $c_v(water) = 573\%$. These differences are also visually recognisable in Fig. 4a (left). This insinuates that the relative role of food consumption emissions within a community [%] is, in this assessment, mainly determined by the carbon performance of the other five sectors.

The BAU scenario assessment provides an estimative figure on the contribution of food consumption to a FEWprint. In cities where the relative carbon impact of food consumption is lower, such as Detroit (9%), more emphasis could initially be put on improving thermal energy management (38%) rather than directing the focus to local food production. In Amsterdam and Belfast, where food constitutes respectively 30% and 37% of the emissions, (low-hanging fruit) strategies in the food sector, either in the form of diet changes or in the form of local production, could potentially lead to significant reductions in the total impact of these communities. However, this assessment does merely address the *numerical space* for improvement. Further contextual analysis, local goals and local ambitions should incite continued investigations into urban food production.

4.2. Design of urban food production

An implemented UFP system is considered as an integrated part of the neighbourhood, not only spatially but also in terms of its environmental footprint. The tenor is that carbon impact of UFP -provided it serves the local community-cannot be holistically estimated without accounting for its fundamental output: food. As such, the UFP's resource input scope and carbon assessment scope is matched with the neighbourhood's resource input and carbon assessment scope. Consequently, the aggregated CO_2eq footprints produced in this work, referred to as the *FEWprints*, can serve as the initial conditions from which to begin and test integrated UFP measures towards a decarbonised built environment.

Urban food system design is a multi-faceted challenge. Urban farming can materialise in different forms (low tech - high tech) at different scales and by means of varying food production techniques (e.g. soil-based, hydroponic, aquaponics, DFT, NFT, aeroponic, stacked farming). In addition, UFP will perform differently in various climates, similar to conventional farming. Finally, UFP is claimed to offer benefits on various environmental aspects compared to our conventional food systems (Rothwell et al., 2016). Urban agriculture can position itself as the nexus within urban resource flows to foster circular or synergistic solutions (Goldstein et al., 2016). The diversity and inherent complexity of (urban) food production makes it difficult for non-experts to provide holistic evaluations, especially during the exploratory phase of design when performance assessment needs to keep up with rapid trial-and-error based decision-making.

When viewed through a carbon impact lens, the aim of UFP is to reduce the community's emissions by substituting imported food with local alternatives, potentially avoiding part of the emissions associated with conventional food production, like *land use/land use change* and *food*

Table 2
Overview of the resource demand/use for the six case studies and other relevant data to complete a carbon assessment with the FEWprint platform. More information about the end-use consumptions and references are provided in Appendix D. Terms (equation) refer to the equation framework in Appendix E.

Sector	Component	term	Product/Activity/Note	demand	Unit
Kattenburg, Amsterdam (population: 1721, household size 2.2)					
Food	Various	CF_F	Selection food groups (specified in detail in Table 1)	~321	kg/cap*yr
Energy	Electrical	CF_{EE}	grid mix electricity	1614	kWh_e/cap*yr
	Thermal	CF_{TE}	natural gas, centrally provided	549	m^3/cap*yr
	Mobility	CF_{ME}	Car ownership/distance driven per year	313/5800	#/1000hh, km
			petrol (80%), assumed efficiency: 1:15[a]	44,0	L/cap*yr
			diesel (15%), assumed efficiency: 1:18[a]	6.9	L/cap*yr
			electric (5%), assumed efficiency: 1:15[a]	2.8	kWh/cap*yr
Water	Domestic use	CF_{pw}	centralised production (110L/cap*day, ext: surface water)	40	m^3/cap*yr
	Waste water prod.	CF_{ww}	centralised treatment (110L/cap*day, ext.: conv. sewage treatm.)	40	m^3/cap*yr
	Rainwater management	CF_{rw}	Annual rainfall specific to region	871	mm/m^2*yr
			Surface area: permeable/non-permeable	8.0/3.0	ha
			Pre-treatment of rainwater before disposal?	No	–
Waste	Processing	CF_{DW}	total domestic waste produced	377	kg/cap*yr
			Waste-to-Recycle	0	%
			Waste-to-energy/Waste-to-Landfill/Waste-to-Compost.	100/0/0	%
Inner-East, Belfast (population: 32,834, household size 2.15)					
Food	Various	CF_F	Selection food groups (Table 1)	~311	kg/cap*yr
Energy	Electrical	CF_{EE}	grid mix electricity	1395	kWh_e/cap*yr
	Thermal	CF_{TE}	natural gas, centrally provided	524	m^3/cap*yr
	Mobility	CF_{ME}	Car ownership/distance driven per year	667/6368	#/1000hh, km
			petrol (57%), assumed efficiency: 1:15	75.1	L/cap*yr
			diesel (42%), assumed efficiency: 1:18	46.1	L/cap*yr
			electric (1%), assumed efficiency: 1:15	1.3	kWh/cap*yr
Water	Domestic use	CF_{pw}	centralised production (145 L/cap*yr, ext: surface water)	53	m^3/cap*yr
	Domestic prod	CF_{ww}	centralised treatment (145L/cap*yr, ext.: conv. sewage treatm.)	53	m^3/cap*yr
	Rainwater management	CF_{rw}	Annual rainfall specific to region	930	mm/m^2*yr
			Surface area: permeable/non-permeable	1000/322	ha
			Pre-treatment of rainwater before disposal?	Yes	–
Waste	Processing	CF_{DW}	total domestic waste produced	416	kg/cap*yr
			Waste-to-Recycle	24	%
			Waste-to-energy/Waste-to-Landfill/Waste-to-Compost.	26/52/22	%
Tamaplaza, Tokyo (population: 84,850, household size 2.43)					
Food	Various	CF_F	Selection food groups (Table 1)	~451	kg/cap*yr
Energy	Electrical	CF_{EE}	grid mix electricity	1954	kWh_e/cap*yr
	Thermal	CF_{TE}	City Gas (=natural gas)	1387	m^3/cap*yr
	Thermal	CF_{TE}	Light oil products	173	L/cap/yr
	Thermal	CF_{TE}	LPG	381	L/cap*yr
	Mobility	CF_{ME}	Car ownership/distance driven per year	704/7231	#/1000hh, km
			petrol (80%), assumed efficiency: 1:15	111.7	L/cap*yr
			diesel (17%), assumed efficiency: 1:18	19.8	L/cap*yr
			electric (3%), assumed efficiency: 1:15	4.2	kWh/cap*yr
Water	Domestic use	CF_{pw}	centralised production (220L/cap*day, ext: surface water)	80	m^3/cap*yr
	Waste water prod.	CF_{ww}	centralised treatment (220L/cap*day, ext.: conv. sewage treatm.)	80	m^3/cap*yr
	Rainwater management	CF_{rw}	Annual rainfall specific to region	1688	mm/m^2*yr
			Surface area: permeable/non-permeable	125/707	ha
			Pre-treatment of rainwater before disposal?	yes	–
Waste	Processing	CF_{DW}	total domestic waste produced	312	kg/cap*yr
			Waste-to-Recycle	23	%
			Waste-to-energy/Waste-to-Landfill/Waste-to-Compost.	77/1/22	%
Oakland Av. Urban Farms, Detroit (population: 427, household size 2.2)					
Food	Various	CF_F	Selection food groups (Table 1)	~287	kg/cap*yr
Energy	Electrical	CF_{EE}	grid mix electricity	6301	kWh_e/cap*yr
	Thermal	CF_{TE}	Propane (thermal)	1565	m^3/cap*yr
	Thermal	CF_{TE}	Natural gas (thermal)	1206	m^3/cap*yr
	Mobility	CF_{ME}	Car ownership/distance driven per year	753/14.2K	#/1000hh, km
			petrol (96.7%), assumed efficiency: 1:15	313.7	L/cap*yr
			diesel (2.9%), assumed efficiency: 1:18	7.7	L/cap*yr
			LPG (0.35%), assumed efficiency: 1:7	1,9	L/cap*yr
			electric (0.04%), assumed efficiency: 1:15	0.1	kWh/cap*yr
Water	Domestic use	CF_{pw}	centralised production (219.5L/cap*day, ext: surface water)	80.1	m^3/cap*yr
	Waste water prod.	CF_{ww}	centralised treatment (219,5 L/cap*day, ext.: conv. sewage treatm.)	80.1	m^3/cap*yr
	Rainwater management	CF_{rw}	Annual rainfall specific to region	787	mm/m^2*yr
			Surface area: permeable/non-permeable	19.7/17.0	ha
			Pre-treatment of rainwater before disposal?	yes	–
Waste	Processing	CF_{DW}	total domestic waste produced	432	kg/cap*yr
			Waste-to-Recycle	1	%
			Waste-to-energy/Waste-to-Landfill/Waste-to-Compost.	71/23/5	%
Qatar University Campus, Doha (population: 24.000, household size n.a.)					
Food	Various	CF_F	Selection food groups (Table 1)	~504	kg/cap*yr
Energy	Electrical	CF_{EE}	grid mix electricity	4612	kWh_e/cap*yr

(continued on next page)

Table 2 (*continued*)

Sector	Component	term	Product/Activity/Note	demand	Unit
	Mobility	CF_{ME}	Car ownership/distance driven per year (also see appendix D)	n.a./22K	#/1000hh, km
			petrol (80%), assumed efficiency: 1:15	102.6	L/cap*yr
			diesel (19%), assumed efficiency: 1:18	20.3	L/cap*yr
			electric (1%), assumed efficiency: 1:15	1.3	kWh/cap*yr
Water	Domestic use	CF_{pw}	centralised production (249L/cap*day, multi Stage flash meth.)	91	m^3/cap*yr
	Waste water prod.	CF_{ww}	centralised treatment (249L/cap*day, ext.: conv. sewage treatm.)	91	m^3/cap*yr
	Rainwater management	CF_{rw}	Annual rainfall specific to region	76	mm/m^2*yr
			Surface area: permeable/non-permeable		
			Pre-treatment of rainwater before disposal?		
Waste	Processing	CF_{DW}	total domestic waste produced	514	kg/cap*yr
			Waste-to-Recycle	8	%
			Waste-to-energy/Waste-to-Landfill/Waste-to-Compost.	4/91/5	%
Wester Sydney, Sydney (population: 1.000.000), household size 2.6)					
Food	Various	CF_F	Selection food groups (Table 1)	~304 kg	kg/cap*yr
Energy	Electrical	CF_{EE}	grid mix electricity (appliances & other)	3818	kWh_e/cap*yr
	Thermal	CF_{TE}	Jemena gas (=natural gas)	455	m^3/cap*yr
	Mobility	CF_{ME}	Car ownership/distance driven per year	536/8700	#/1000hh, km
			petrol (72,7%), assumed efficiency: 1:15	86.9	L/cap*yr
			diesel (25,6%), assumed efficiency: 1:18	25.5	L/cap*yr
			LPG (1,7%), assumed efficiency: 1:7	3.0	L/cap*yr
Water	Domestic use	CF_{pw}	centralised production (301 L/cap*day, ext: surface water)	110	m^3/cap*yr
	Waste water prod.	CF_{ww}	centralised treatment (301 L/cap*day, ext.: conv. sewage treatm.)	110	m^3/cap*yr
	Rainwater management	CF_{rw}	Annual rainfall specific to region	1213	mm/m^2*yr
			Surface area: permeable/non-permeable	323K/485K	ha
			Pre-treatment of rainwater before disposal?	No	–
Waste	Processing	CF_{DW}	total domestic waste produced	550	kg/cap*yr
			Waste-to-Recycle	22	%
			Waste-to-energy/Waste-to-Landfill/Waste-to-Compost.	0/73/27	%

[a] A similar value for fuel efficiency (also called fuel economy) is used for all cases. E.g. 1:15 implies that is takes 1 unit of fuel to move the vehicle 15 km. Applied values are assumptions and fuel economy can be different between nations due to differences in car fleet.

transport (Poore and Nemecek, 2018). Ideally, local production should be managed through the optimal use of renewable resources and/or resource circulation in order to achieve mutual benefits between the farm and the community and subsequently maintain a sustainable system with minimal remaining emissions. In addition, the resource demand imposed on a community by the new UFP system should be proportionate to the existing community resource demand. In other words: the goal should justify the *means*. These *means*, or food system design, co-depend on the availability of suitable farming spaces, as this could be determinative for the chosen food production forms and products. The *UFP component* of the platform provides the framework to streamline this nexus-challenge between space, method, product, resources and impact and translates UFP implementations into performance indicators relevant to urban designers and planners.

The platform has been developed for the evaluation of urban food production strategies, for which three key purposes are formulated, displayed in Fig. 5. First, it provides a user-friendly framework for the calculation of the carbon footprint profiles of communities, which is demonstrated in this paper. Second, the tool can be employed to assess the implications of community-wide dietary changes on the total carbon footprint, which is discussed in Caat et al. (2022). Third, it offers the exploratory design component that can deliver an indication of the agricultural output of a self-composed UFP system and calculates the required FEW resources, plus corresponding carbon impacts, for preliminary evaluation of an urban food strategy. All three components are interconnected with each other and are therefore not completed in a linear fashion, but rather facilitate an iterative process of design and assessment. This also includes design modifications of non-food related infrastructure, like local energy production, building stock improvements, mobility systems, water recovery and processing and waste reuse and diversion.

4.3. Practical implications and contribution

Carbon footprints are a useful index to quantify a community's contribution to climate change and to monitor the progress towards the carbon emission goals. The FEWprint offers an user-friendly digital interface to produce the carbon profile of a community and, afterward, to ex-ante estimate the impact on this profile after alternative resource management solutions and/or local food production implementations.

The platform is developed to provide a strategy and framework for non-agriculturist (e.g. urban planners and designers) and to support the UFP design process through the lens of the FEW nexus. It does so by reducing UFP complexity to a handful of elementary building blocks. The platform serves an informative role in the conceptual stage of the design process by rapidly delivering preliminary feedback on resources implications of design choices. With the FEWprint, urban design strategies that contain elements of food production -whether they are radical concepts or more subtle proposals that fill in a pre-existing long term vision-can be better substantiated with holistically assessed estimations on carbon impact reductions and the overall potential can therefore be better evaluated. The design and evaluation of UFP strategies is discussed and demonstrated in future disseminations.

To encourage accessibility, the platform has been developed with Microsoft Office Excel software (Professional Plus 2016 version) and is open for download, free of registration or costs, from the research project website or by contacting the corresponding author. Step-by-step information is provided within the various tabs of the platform to inform about its functioning and the required data. The platform does not require specific technical knowledge to operate and carbon footprint assessments could be performed with the provided default data in case context-specific data is unavailable.

4.4. Sensitivity analysis

The assessed food inventory of this study has been limited to semi-unprocessed food items and excludes drinks. In addition, food impact is assessed with food category indicators instead of product-level values to make the data acquisition phase less time consuming for a platform user. Categorical indicators combine all the known product-level

Table 3
Sectoral annual carbon footprints per capita [kg/cap*yr] of the baseline assessment. The determinative factors of resource demand and carbon footprint indicators are listed in *italic*.

FEW Sector	AMS K'burg	BEL Inner-East	DET OAF	TOK T'plaza	DOH Campus	SYD Syd-West	unit
Food (LCA assessment)	**993**	**1270**	**1152**	**1366**	**1285**	**1083**	kg_{CO2eq}
Total food consumption	321	311	287	451	504	304	kg/cap*yr
Energy, electricity	**849**	**473**	**5608**	**864**	**2749**	**3093**	*kWh$_e$/cap*yr*
electricity demand	*1614*	*1395*	*6301*	*1954*	*4612*	*3818*	*kWh$_e$/cap*yr]*
carbon footprint	*0.526*	*0.339*	*0.890*	*0.442*	*0.596*	*0.810*	kg_{CO2eq}/kWh_e
Energy, thermal	**1034**	**1060**	**5003**	**3719**	**0**	**874**	kg_{CO2eq}
gas demand	*549*	*524*	*1062*	*1387*	*0*	*455*	*m^3/cap*yr*
carbon footprint	*1.89*	*2.02*	*1.91*	*2.23*	*0*	*1.92*	kg_{CO2eq}/m^3
Energy, car mobility	**147**	**360**	**750**	**312**	**2747**	**274**	kg_{CO2eq}
annual distance driven	*5800*	*6400*	*14.200*	*7200*	*22.000*	*8700*	*km/cap*yr*
car ownership	*0.313*	*0.667*	*0.753*	*0.704*	*n.a.*[2]	*0.536*	*# cars/household*
Water, production & distrib.	**15**	**7**	**40**	**22**	**1021**	**23**	kg_{CO2eq}
Water, wastewater treatment	**46**	**23**	**77**	**32**	**255**	**42**	kg_{CO2eq}
Water, rainwater treatment	**n.a.**	**25**	**187**	**35**	**n.a.**	**n.a.**	kg_{CO2eq}
Water use	*40*	*53*	*80*	*80*	*91*	*101*	*m^3/cap*yr*
Rainwater runoff pre-treated?	*No*	*Yes*	*Yes*	*Yes*	*No*	*No*	-
Waste processing	**246**	**227**	**420**	**239**	**312**	**232**	kg_{CO2eq}
Domestic waste produced	*492*	*416*	*492*	*312*	*514*	*550*	*kg/cap*yr*
Inc../Land./Comp.[3]	*100/0/0*	*26/52/22*	*71/23/5*	*77/1/22*	*4/91/5*	*0/73/27*	*%*
Carbon footprint waste procc.	*0.65*	*0.65*	*0.73*	*0.45*	*1.02*	*0.39*	kg_{CO2eq}/kg_{waste}
Total emissions	**3330**	**3445**	**13237**	**6589**	**5961**	**5619**	kg_{CO2eq}

[1] Own assessment.*impact waste* $[kg_{CO2}/kg_{waste}] = ((PCP_{dw} * r_{rec}) * \sum(r(n)_{waste} * ef(n))/PCP_{dw}$
[2] Assumptions apply to estimate car ownership, see appendix D.
[3] Domestic waste centralised processing method [% of total]. Incineration (Inc.)/Landfilling (Land.)/Composting (Comp.).

footprint indicators within that food category into one average figure. This is a simple and quick method to overcome missing data for certain food items when a detailed figure on these specific items is not important. However, as food items tend to not be consumed in equal proportion to each other, applying an average indicator could result in footprints that deviate from reality.

The two limitations resulted in a deficient representation of the food sector emissions. Previous research showed for the entire USA, the food related emissions of self-reported diets to be 4.70 kg CO_2eq per capita per day, or 1715 kg/year (including food losses), 563 kg more than calculated in this work (Heller et al., 2018). A study in The Netherlands calculated the greenhouse gas emissions derived from the Dutch National Food Consumption Survey 2012–2016 and found a daily impact of 4.96 kg CO_2eq per day for the total population (age 1–79, n = 4313), or 1810 kg CO_2eq per year (Vellinga et al., 2019). This is 817 kg more than the emissions calculated in this study.

For the Kattenburg (Amsterdam) community, the effect of the two limitations has been calculated by performing three alternative assessments: a limited scope assessment with product-level indicators for the carbon footprint of food items (column II in Fig. 6), a full-scope assessment with category indicators (III) and a full scope assessment with product-level indicators (FSPI) (IV). The latter alternative assessment produces the most representative reflection of reality as it is most comprehensive and uses detailed data. Only Kattenburg is analysed in such detail as extensive food consumption data was readily available from the same source as for the limited scope assessment.

As expected, the analysis quantified an emission deficit due to the limited food inventory used in this study. First, a full scope assessment more than doubles the food sector emissions compared to this study. This is mainly because the meat intake is doubled with the inclusion of processed meat products and due to the added impact of soda, coffee, tea and alcoholic drinks. Second, the analysis points out that the food sector emissions significantly drop when product-specific footprints are used. It should be noted that in column III, the large emission portion of drinks is mainly caused by the erroneous accounting of tap water drinking (high in consumption, nearly zero impact in reality) with the categorical indicator of 0.64 kg CO_2/kg.

The FSPI assessment (column IV, Fig. 6) shows similar results to the study by Vellinga et al. (2019), which was based on the same food consumption survey data and LCA impact data. If the food sector outcomes of this work are substituted with the comprehensive and detailed FSPI assessment, the total carbon footprint of Kattenburg (Amsterdam) will increase to 4248 kg/cap*yr (+22%) and the food sector emissions will increase from 30% to 45% in the total. A detailed overview of the analysis results is provided in detail in Appendix F.

4.5. Study limitations

Care and consideration are taken in this study to synchronise the inventory of assessed food items between the six case studies in order to increase the inter-comparability. However, there are differences between national data registrations on the aspects of food categorisation, taxonomy, grouping of food items, data availability and consumption data gathering methods. This inevitably leads to discrepancies between the total daily food intake among countries (787–1380 g/cap*day). The question arises whether the cause of this observed consumption difference can be assigned to data collection and interpretation or to actual differences in food consumption in reality. Without systematic gathering of survey-based data on food intake in each of the six urban areas, this remains a recurring uncertainty in carbon accounting of food with secondary data.

Per capita food consumption data, commonly released at the national level (Fig. 2), may not always be representative of local diets. This applies especially to larger countries like USA and UK as many factors including geographic, social, economic, climatic, and cultural factors define community diets. Contextualising the national diet to the neighbourhood level diet can be done to a limited extent with the *halal* (removes pork) and *carnivorous* fractions (explained in Appendix E), but further contextualisation might be necessary by a considerable customisation of the national diet into a local diet when doing a more thorough assessment.

Finally, the carbon footprint values for food groups/items are not available at national level in Tokyo, Doha and Sydney. Therefore, the sectoral impact is based on global mean data provided by the UN Food and Agricultural Organisation. This study could produce a more accurate

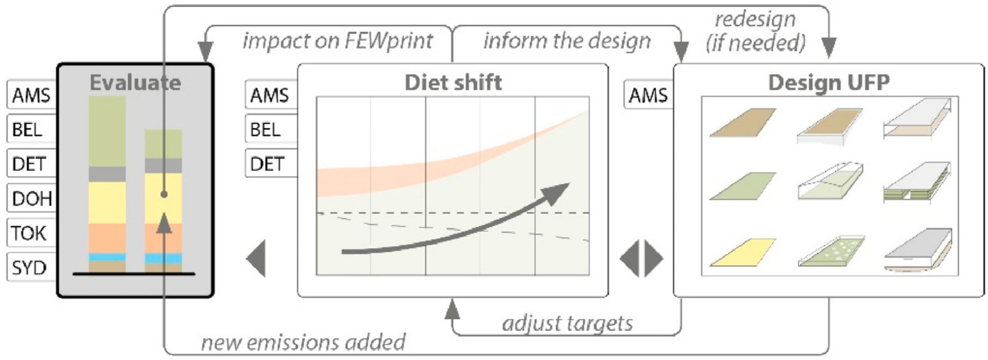

Fig. 5. The FEWprint consist of 3 components, corresponding with the 3 key purposes of the platform: carbon emissions assessment, diet shift assessment and UFP design.

carbon accounting of these contexts if these values were available at the time of writing this paper.

5. Conclusion and future directions

This work introduces the FEWprint, acronym for Food, Energy and Water carbon footprint assessment platform and provides a user-friendly framework for the assessment of urban carbon emission equivalents. Under the umbrella-theme of urban food production, this research contributes to the downscaling and substantialising of the FEW nexus discourse by consideration of the resource nexus at the local scale. The *evaluation* component of the FEWprint is discussed in this work and produces the consumption-based carbon equivalent footprint of urban communities derived from food consumption, thermal and electrical energy use, car fuel demand, potable water management and domestic waste processing. This application is demonstrated in this paper for six urban communities in six global cities: Amsterdam, Belfast, Detroit, Doha, Tokyo and Sydney. Per capita emission equivalents fall in the range of 3329 kg/yr for a community in Amsterdam up to 13,237 kg/year in Detroit. The results show that in terms of total emissions, the sectoral impact of food consumption falls in the range of 993 kg/cap*yr (Amsterdam) to 1366 kg/cap*year (Tokyo). In terms of relative impact, the food sector emissions constitute between 9% (Detroit) and 37% (Belfast) of the total carbon impact of a community. The FEWprint carbon profiles give a preliminary indication of the carbon mitigation potential of a dietary transition or local food production and serves as the initial condition to start from and test holistically assessed urban farming strategies towards community carbon neutrality, which will be further elaborated in follow-up disseminations.

This work introduced the FEWprint's *evaluation* component for the integrated carbon assessment of urban communities. Part two, *Diet Shift*, explores the impact on a community's carbon footprint when transitioning away from animal-sourced food towards plant-based alternatives (Caat et al., 2022). The third part, *UFP Design*, describes the *design* component of the platform and its applicability to explore food production solutions for urban communities with the aim of mitigating carbon emissions through a FEW nexus lens.

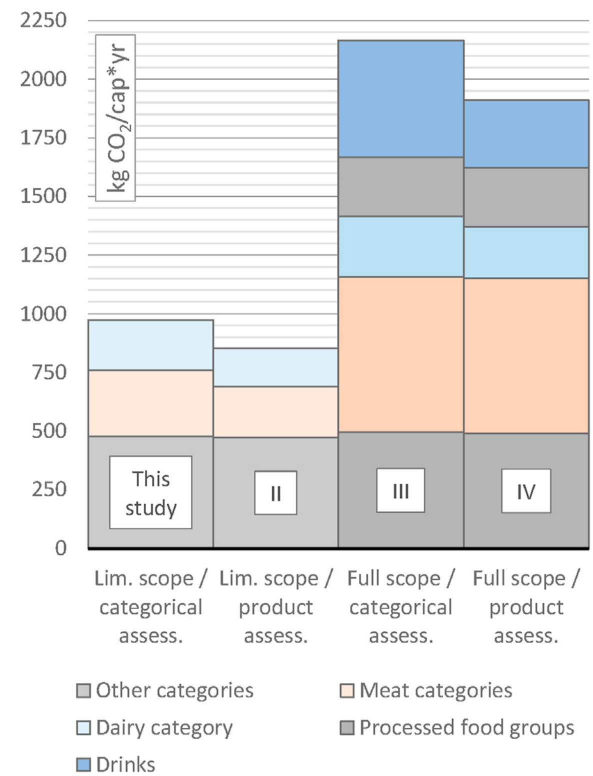

Fig. 6. Results of the sensitivity analysis. This work = 973 kg/cap*yr; LSPI = 854kg/cap*yr; FSCI = 2165 kg/cap*yr; FSPI = 1911 kg/cap*yr.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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APPENDIX A. Carbon footprint values - 6 case studies

Table A1
Inventory of carbon footprint (CF) indicators relevant to this study,grouped per urban case. Food CF are specified in Table 1. Default data is noted with (D) and is listed in appendix B. Where CO_2 is written, CO_2eq is meant.

Sector	Component	Product/Activity	CF	Unit	Note (source)
Kattenburg, Amsterdam (AMS)					
Energy	Electrical	grid mix	0.526	kg CO_2/kWh$_e$	Country specific value. (Otten and Afman, 2015)
	Thermal	natural gas	1.884	kg CO_2/m^3	Zijlema (2018)
Water	Domestic demand	centralised production	0.360	kg CO_2q/m^3	(STOWA, 2008) Country specific value
		centralised treatment	1.140	kg CO_2/m^3	(STOWA, 2008) Country specific value
Waste[1]	Unrecycled fraction	waste-to-energy	0.652 (D)	kg CO_2/kg	Based on IPCC Waste model (Pulselli et al., 2019)
		waste-to-landfill	1.160 (D)	kg CO_2/kg	Based on IPCC Waste model (Pulselli et al., 2019)
		waste-to-compost	0.091 (D)	kg CO_2/kg	Based on IPCC Waste model (Pulselli et al., 2019)
Mobility	Personal mobility	petrol (gasoline, E95)	2.800 (D)	kg CO_2/L	European value. Assumed $\eta_{fuel} = 15$. (NEN-EN, 2012)
		diesel	3.240 (D)	kg CO_2/L	European value. Assumed $\eta_{fuel} = 18$. (NEN-EN, 2012)
		electric	0.526	kg CO_2/kWh$_e$	Assume CS grid mix electricity. Assumed $\eta_{fuel} = 15$
Food	Various	Various	Varies	kg CO_2/kg	See Table 1
Inner-East, Belfast (BEL)					
Energy	Electrical	grid mix	0.339	kg CO_2/kWh$_e$	Country specific value. (DAERA, 2020)
	Thermal	natural gas	2.023	kg CO_2/m^3	DEFRA (2020b)
Water	Domestic demand	centralised production	0.139	kg CO_2/m^3	(N.I. Water, 2019)
		centralised treatment	0.433	kg CO_2/m^3	(N.I. Water, 2019)
Mobility	Personal mobility	petrol (gasoline, E95)	2.800(D)	kg CO_2/L	European value. Assumed $\eta_{fuel} = 15$. (NEN-EN, 2012)
		diesel	3.240 (D)	kg CO_2/L	European value. Assumed $\eta_{fuel} = 18$. (NEN-EN, 2012)
		LPG	1.900 (D)	kg CO_2/L	European value. Assumed $\eta_{fuel} = 10$. (NEN-EN, 2012)
		electric	0.339	kg CO_2/kWh$_e$	Assume CS grid mix electricity. Assumed $\eta_{fuel} = 15$
Food	Various	various	varies	kg CO_2/kg	See Table 1
Tamaplaza, Tokyo (TOK)					
Energy	Electrical	grid mix	0.442	kg CO_2/kWh$_e$	Country specific value. (TEPCO, n.d.)
	Thermal	City gas (natural gas)	2.230	kg CO_2/m^3	(Japan LP Gas association, 2020)
	Thermal	Light oil products	0.247	kg CO_2/L	(Japan LP Gas association, 2020)
	Thermal	LPG	1.530	kg CO_2/L	(MoE Japan, 2017)
Water	Domestic demand	centralised production	0.270	kg CO_2/m^3	Bureau of Waterworks Tokyo (2020)
		centralised treatment	0.397	kg CO_2/m^3	Sano et al. (2012)
Mobility	Personal mobility	petrol (gasoline, E95)	2.320	kg CO_2/L	(MoE Japan, 2017)
		diesel	2.580	kg CO_2/L	(MoE Japan, 2017)
		LPG	1.530	kg CO_2/L	(MoE Japan, 2017)
		electric	0.442	kg CO_2/kWh$_e$	Assume CS grid mix electricity. Assumed $\eta_{fuel} = 15$
Food	Various	various	varies	kg CO_2/kg	See Table 1.
Oakland Avenue Farms, Detroit (DET)					
Energy	Electrical	grid mix (comp. elec.)	0.890	kg CO_2/kWh$_e$	(Carlson et al., 2014) Includes T&D losses
	Thermal	Natural gas	1.910	kg CO_2/m^3	(Carlson et al., 2014),
Water	Domestic demand	centralised production	0.510	kg CO_2/m^3	Based on peak time emission (Jin et al., 2015)
		centralised treatment	0.960	kg CO_2/m^3	Base case WWT Plant (Cashman et al., 2014)
Mobility	Personal mobility	petrol (gasoline, E95)	2.316	kg CO_2/L	US EPA (2020)
		diesel	2.693	kg CO_2/L	US EPA (2020)
		LPG	1.499	kg CO_2/L	US EPA (2020)
		electric	0.890	kg CO_2/kWh$_e$	Assume CS grid mix electricity. Assumed $\eta_{fuel} = 15$
Food	Various	various	varies	kg CO_2/kg	See Table 1
Qatar University Campus, Doha (DOH)					
Energy	Electrical	grid mix	0.596	kg CO_2/kWh$_e$	Country specific value. (Ecometrica, 2011)
Water	Domestic demand	centralised production	11.23	kg CO_2/m^3	Multi Stage Flash desal. (Darwish and Mohtar, 2012)
		centralised treatment	2.810	kg CO_2/m^3	SWRO (Darwish and Mohtar, 2012)
Mobility	Personal mobility	petrol (gasoline, E95)	2.900 (D)	kg CO_2/L	European value. Assumed $\eta_{fuel} = 15$. (NEN-EN, 2012)
		diesel	3.240 (D)	kg CO_2/L	European value. Assumed $\eta_{fuel} = 18$. (NEN-EN, 2012)
		electric	0.596	kg CO_2/kWh$_e$	Assume CS grid mix electricity. Assumed $\eta_{fuel} = 15$
Food	Various	various	varies	kg CO_2/kg	See Table 1
Western Sydney, Sydney (SYD)					
Energy	Electrical	grid mix	0.810	kg CO_2/kWh$_e$	Country specific value. (DISER, 2020)

(continued on next column)

Table A1 (*continued*)

Sector	Component	Product/Activity	CF	Unit	Note (source)
	Thermal	Jemena gas (nat. gas)	1.930	kg CO_2/m^3	Own assessment[2]
Water	Domestic demand	centralised production	0.210	kg CO_2/m^3	Sydney Water (2019)
		centralised treatment	0.380	kg CO_2/m^3	(Sydney Water, 20s19)
Mobility	Personal mobility	petrol (gasoline, E95)	2.305	kg CO_2/L	DISER (2020)
		diesel	2.698	kg CO_2/L	DISER (2020)
		LPG	1.577	kg CO_2/L	DISER (2020)
Food	Various	various	varies	kg CO_2/kg	See Table 1

[1] Mean carbon emissions indicators are applied similarly for all case studies but are only tabulated for the Amsterdam case.
[2] Source reports only emissions from activities (i.e. chain related emissions, or Well-to-tank), which is 1.77 ton CO_2/TJ (Jemena, 2020). Based on assuming 1 GJ = 26.14 GJ, we can estimate the scope 3 emissions to be around 0.067 kg/m^3. To account for territorial emissions, we assume that 1 m^3 of natural gas produces 42.3 mol CO_2, or 1.86 kg. Combined gives 1.86 + 0.067 = 1.93 kg CO_2eq/m^3.

APPENDIX B. List of Default values provided in FEWprint

Not all countries release accessible, accurate or available data that could be used for carbon assessment and in order to overcome these data gaps, the platform offers a set of default data. All values specified below can be adjusted by the user on the platform and new methods can be added. The platform offers a selection of common fuels for car mobility (listed in table B1, item 1–8), energy carriers for home heating (item 9–18), district heating methods (item 19–23) and electricity sources, both renewable, fossil and nuclear (item 24–35). CF data on energy provision describe either European averages or represent generic indicators from literature. The processing of domestically produced waste through the three key methods of incineration, landfilling or composting (item 36–39) can be expressed in carbon emission equivalents. This study adapts the values applied by Pulselli et al. (2019) and are based on the IPCC Waste Model mean global values. The carbon footprint of drinking water infrastructure denotes only process related (scope 3) emissions (or scope 2 emissions should water management takes place within the system borders) and various methods of water production and treatment are possible. Water infrastructure is strongly contextual and most of the default values are estimates. The CF is split up in upstream (provision + distribution, item 40–53) and downstream indicators (collection + treatment, item 54–60). Finally, the FEWprint provides default food CF data for a selection of countries plus the global average, based on the United Nations FAO database (Table 1).

Table B1
List of default carbon footprints provided in the FEWprint tool. Where possible, global/European averages are used. CS = Country Specific, i.e. no default values apply. Carbon assessment is done with the full-scope footprint (scope 1 + 2+3), to which the $ef(n)$ terms mentioned in appendix E refer to. Values/methods can be changed, added or replaced at any time within the platform. The carbon impact factors of food categories are listed in Table 1.
Estimations for greenhouse gas emissions associated with water management (item 40–60) are based on an grid mix carbon footprint of 0.500 kg/kWh$_e$

•	Product/Activity	Scope 1	Scope 2	Scope 3	Unit	Note (Source)
	Energy - Personal mobility (commonly found fuels)					
1	Petrol (gasoline, E95)	2.30	–	0.50	kg CO_2/L	European value, E95 type. Assumed η_{fuel} = 15. (NEN-EN, 2012)
2	Diesel	2.67	–	0.57	kg CO_2/L	European value. Assumed η_{fuel} = 18. (NEN-EN, 2012)
3	LPG (Liquefied Petroleum Gas)	1.70	–	0.20	kg CO_2/L	European value. Assumed η_{fuel} = 10. (NEN-EN, 2012)
4	CNG (Compressed Natural Gas)	2.68	–	0.39	kg CO_2/kg	European value. Assumed η_{fuel} = 7. (NEN-EN, 2012)
5	Biofuel (Diesel)	0.00	–	1.92	kg CO_2/L	Assumed η_{fuel} = 18. (NEN-EN, 2012)
6	Biogas (CNG, green gas based))	0.03	–	0.35	kg CO_2/m^3	Estimation for the Netherlands. Assumed η_{fuel} = 7. Adapted from (CE Delft, 2015)
7	Electricity (full/hybrid)	CS	CS	CS	kg CO_2/kWh	Assume CS grid mix electricity. Assumed η_fuel = 15
8	Hydrogen (green based)	0.00	–	0.64	kg CO_2/m^3	Estimation for the Netherlands Assumed η_{fuel} = 7. Adapted from (CE Delft, 2015)
	Energy - Primary energy for heating + energy carriers.					
9	Natural gas/CNG/LNG	1.79	–	n.d.	kg CO_2/m^3	Dutch reference value (Zijlema, 2020)
10	Propane (for home heating)	1.53	–	0.20	kg CO_2/L	[add source]
11	Wood combustion, dry wood	0.01	–	0.05	kg CO_2/kg	Average value of various wood forms. (AVIH, 2018)
12	Cokes coal	2.69	–	n.d.	kg CO_2/kg	Dutch reference value (Zijlema, 2020)
14	Charcoal (bricks)	3.36	–	n.d.	kg CO_2/kg	Dutch reference value (Zijlema, 2020)
15	Residential fuel oil	3.19	–	n.d.	kg CO_2/L	Dutch reference value (Zijlema, 2020)
16	LPG	3.02	–	n.d.	kg CO_2/L	Dutch reference value (Zijlema, 2020)
17	Biogas (conventional digester)	0.00	–	0.74	kg CO_2/m^3	Dutch reference value. Based on 23,4 kg CO2eq/GJ and a caloric value of 31,65 MJ/m3. Input material: domestic organic waste (CE Delft, 2019)
18	Lignite	2.02	–	n.d.	kg CO_2/kg	Not very common anymore. (Zijlema, 2020)
19	District heating - CCGT	–	32.50	3.40	kg CO_2/GJ	Combined Cycle gas Turbine power plant. (CE Delft, 2016)
20	District heating - Industry residual heat	–	20.60	0.90	kg CO_2/GJ	No co-firing. (CE Delft, 2016)
21	District heating - Waste Incineration	–	23.10	3.40	kg CO_2/GJ	(CE Delft, 2016)
22	District heating - Geothermal	–	23.40	1.60	kg CO_2/GJ	(CE Delft, 2016)
23	District heating - Biomass	–	15.30	10.50	kg CO_2/GJ	Based on imported pellets. (CE Delft, 2016)
	Energy - Electricity					
24	Grid mix - National grid mix	CS	CS	CS	kg CO_2/kWh	Country specific value, based on grid mix composition.
25	Grid mix - European average	–	0.38	?	kg CO_2/kWh	European electricity grid mix - 2015 values (Pulselli et al., 2019)
26	thermoelectricity - GAS based	–	0.44	?	kg CO_2/kWh	Various combined cycle turbines (Sovacool, 2008)
27	thermoelectricity - PETROL based	–	0.78	?	kg CO_2/kWh	Various generator and turbine types (Sovacool, 2008)
28	thermoelectricity - COAL based	–	1.05	?	kg CO_2/kWh	Various generator types with scrubbing (Sovacool, 2008)
29	Nuclear electricity	–	0.07	?	kg CO_2/kWh	Mean value (Sovacool, 2008)
30	renewable - photovoltaic	–	–	0.03	kg CO_2/kWh	Polycrystalline silicone based. (Pehnt, 2006)

(continued on next column)

Table B1 (*continued*)

•	Product/Activity	Scope 1	Scope 2	Scope 3	Unit	Note (Source)
31	renewable - wind energy	–	–	0.01	kg CO_2/kWh	2.5 MW turbine offshore. (Pehnt, 2006)
32	renewable - hydroelectric energy	–	–	0.01	kg CO_2/kWh	Reservoir based.(Pehnt, 2006)
33	renewable - geothermal energy	–	–	0.04	kg CO_2/kWh	80 MW capacity. (Pehnt, 2006)
34	renewable - biomass incineration	–	–	0.04	kg CO_2/kWh	Short rotation forestry, reciprocating engine(Pehnt, 2006)
35	renewable - biogas combustion	–	–	0.01	kg CO_2/kWh	Anaerobic Digestion. (Pehnt, 2006)
	Waste - Domestic waste processing					
36	Waste-to-recycling	–	–	0.00	kg CO_2/kg	No emissions accounted for recycled fraction.
37	Waste-to-incineration	–	–	0.65	kg CO_2/kg	For the production of energy. (Pulselli et al., 2019)
38	Waste-to-landfill	–	–	1.16	kg CO_2/kg	Pulselli et al. (2019)
39	Waste-to-compost	–	–	0.09	kg CO_2/kg	Organic fraction (Pulselli et al., 2019)
	Water - Production & distribution					
	Production method/source	**kg CO_2eq/m^3**	**kWh/m^3**		**Note (ref. carbon footprint)/Note (ref. embodied energy)**	
40	ext.: desalination - reverse osmosis	2.20	4.30		Range 0.08–4.3, ± 2.2 (Cornejo et al., 2014)/Range 4.0–4.5, ± 4.3 (Cornejo et al., 2014)	
41	ext.: desalination - multi stage flash	17.70	18.50		Range 0.3–34.7, ± 17.7 (Cornejo et al., 2014)/Range 13.5–23.5, ± 18.5 (Cornejo et al., 2014)	
42	ext.: desalination - multi-effect distillation	13.60	8.00		Range 0.3–26.9, ± 13.6 (Cornejo et al., 2014)/Range 6.0–10.0, ± 8.0 (Cornejo et al., 2014)	
43	ext.: desalination - other	5.00	10.00		Range n.a., estimation/Range n.a., estimation	
44	ext.: underground aquifer	1.00	2.00		Estimation/Estimation for pumping energy	
45	ext.: surface water (basin/lake)	0.36	0.72		Dutch reference value - LCA study, upstream emissions (STOWA, 2008)/Estimation	
46	ext.: unknown	0.25	0.50		Estimation/Estimation for pumping energy	
47	local: recirc. waste water (filtered & treated)	2.50	5.00		Estimation/Estimation for pumping and processing energy	
48	local: surface water (untreated)	0.25	0.50		Estimation/Estimation for pumping energy	
49	local: surface water (filtered)	0.50	1.00		Estimation/Estimation for pumping energy + filtration energy	
50	local: ground water (untreated)	0.38	0.75		Estimation/Estimation for pumping energy	
51	local: ground water (filtered)	0.63	1.25		Estimation/Estimation for pumping energy + filtration energy	
52	local: rainwater (untreated)	0.13	0.25		Estimation/Estimation for pumping energy	
53	local: rainwater (filtered)	0.38	0.75		Estimation/Estimation for pumping energy + filtration energy	
	Water - Collection and treatment					
54	External: conventional sewage treatment	1.14	2.20		Dutch reference value - LCA study, downstream emissions (STOWA, 2008)/Estimation	
55	External: no treatment (to surface water)	0.25	0.50		Estimation/Estimation for pumping energy	
56	External: constructed wetlands	0.25	0.50		Estimation/Estimation for pumping energy	
57	External: unknown	0.25	0.50		Estimation/Estimation for pumping energy	
58	local: recirc. waste water (filtered & treated)	2.50	5.00		Estimation/Estimation for pumping and processing energy	
59	Local: constructed wetlands	0.13	0.25		Estimation/Estimation for pumping energy	
60	Local: storage basin (untreated)	0.05	0.10		Estimation/Estimation for pumping energy	

APPENDIX C. Subdivision of food groups - 6 case studies

Table C1

Subdivision of food groups into seperate poducts (when applicable) The diet profile applied in this study does not reflect the complete dietary intake of a consumer and only food groups and/or subgroups/products are used that are semi-unprocessed.

Additional remarks: frozen products are included. Milk & yoghurt are pasteurised (i.e. semi-processed) and are accounted for. Cheese is a semi-processed product and is also included to the assessment.

Kattenburg, Amsterdam			
●	Food group	gr/day	Subgroups/products
1	Vegetables	131.0	All vegetable types, including: unclassified + mixed vegetables/salads (11.8), leek, onion, garlic (11.8), mushrooms (2.9),cabbages (19.4), root veg. (12.3), fruiting veg. (48.4), leafy veg. (19.2), grain- & pod veg. (2.5) and stalk vegetables (2.6). *Excluding: vegetable juices, tomato sauces.*
2	Fruits	113.8	Fruits (113.4), unclassified mixed fruits and others (0.4). *Excluding: fruit juices, jams & jelly, marmalade.*
3	Pulses & legumes	4.5	Legumes (4.5).
4	Grains (bread)	138.3	Bread (125.6), Crispbread-rusks (5.3), Breakfast cereals (7.4). *Excluding: dough & pastry and flour, starches, flakes, semolina.*
5	Rice	0.0	No sub-specification available, rice included in group 15.
6	Starchy roots	72.2	Potatoes (71.6), Unspecified tubers (0.5).
7	Beef (+veal)	12.6	Beef (12.2), Calf (0.4). *Excluding hot- & cold processed beef, offal, game.*
8	Pork	13.0	Pork (13). *Excluding: hot- & cold processed pork.*
9	Mutton (+lamb & goat)	0.6	Mutton/Lamb (0.6). *Excluding: hot- & cold processed mutton*
10	Poultry (+turkey)	16.6	Chicken, hen (15.9), Turkey, young turkey (0.4), Duck (0.3) *Excluding: hot- & cold processed poultry*
11	Fish (incl. sea food)	12.9	Fish (11.5), Crustaceans & molluscs (1.4). *Excluding: unspecified fish and combined fish products, amphibians and reptiles, fish in crumbs.*

(*continued on next column*)

Table C1 (*continued*)

●	Food group	gr/day	Subgroups/products
Kattenburg, Amsterdam			
12	Cheese	32.6	Cheeses - including spread cheeses (32.6).
13	Dairy (milk & yoghurt)	254.3	Milk-fermented (200.6), Yoghurt (53.7). Excluding creams, sorbets, ice creams, non-dairy products, Fromage blancs.
14	Eggs	12.7	Eggs (12.7).
15	Pasta (Durum wheat)	47.1	Pasta, rice and other grain (47.1).
16	Nuts and Seeds (+olives)	6.3	Nuts, Peanuts & Seeds (5.7), Olives (0.6). *Excluding: spreads,* e.g. *peanut butter.*
17	Meat replacements	1.5	Meat substitutes (1.5).
18	Dairy replacements	8.4	Milk substitutes and substituting products (8.4).
	total	**878.4**	
general note Kattenburg, Amsterdam: Data retrieved from the Dutch National Food Survey 2012–2016 (RIVM, 2020a). Data constitutes the average values for female + male food consumption in the age group 1–79.			
Inner-East, Belfast, U.K.			
1	Vegetables	92.0	All vegetable types, including: unclassified + mixed vegetables/salads (48.5), onions, leeks & shallots (15.4), cucumbers (7.3), mushrooms (5.1), tomatoes (11.9). *Excluding vegetable juices, tomato sauces.*
2	Fruits	114.0	Fruits (114). *Excluding: fruit juices, jams & jelly, marmalade, dried fruit.*
3	Pulses & legumes	3.0	Legumes (3).
4	Grains (bread)	106.0	Bread (84.3), Oatmeal and oat products (3.86), Breakfast cereals (17.5). *Excluding: dough & pastry and flour, starches, flakes, semolina.*
5	Rice	15.0	Rice (15).
6	Starchy roots	93.0	Potatoes (60.2), carrots (14.5), turnips (1.66) and other root vegetables (7.61).
7	Beef (+veal)	21.0	Beef (21), *Excluding hot and cold processed beef, offal, game.*
8	Pork	31.0	Pork (31). *Including joints, chops, steaks, bacon and sausages.*
9	Mutton (+lamb & goat)	5.0	Mutton/Lamb (5). *Including joints and chops.*
10	Poultry (+turkey)	36.0	Chicken – whole or pieces (36). *Including hot and cold when purchased.*
11	Fish (incl. sea food)	22.0	Fish (22). *Including white fish, blue fish, shellfish, tinned fish, ready meals and takeaway fish products.*
12	Cheese	18.0	Cheeses (18). *Including spread cheeses.*
13	Dairy (milk & yoghurt)	262.0	Liquid wholemilk (42.4), skimmed milk (151), condensed milk (2.36), infant milks (7.38), yoghurt (26.9), cream (3.75) and other milks and dairy desserts (20.4).
14	Eggs	15.0	Eggs (15).
15	Pasta (Durum wheat)	14.0	Pasta (14).
16	Nuts and Seeds (+olives)	5.0	Nuts, edible seeds and peanut butter (5).
17	Meat replacements	n.d.	n.a.
18	Dairy replacements	n.d.	n.a.
	total	**852.0**	
general note Inner-East, Belfast: Data retrieved from *Family food statistics* survey by Department for Environment, Food and Rural Affairs (DEFRA, 2020a). Data consists of three-year U.K. average for quantities of food and drink purchased.			
Tamaplaza, Tokyo			
1	Vegetables	283.0	Tomato(21.2), Carrot(18.5), Spinach(11.6), Green Pepper(3.6), Other Green and Yellow Vegetables(35.6), Cabbage(30.0), Cucumber(9.9), Radish(22.0), Onion(31.6), Chinese Cabbage(19.8), Other Pale Vegetables(50.0), *Including: Fruit Juice(17.8)*
2	Fruits	108.0	Strawberry(0.1), Orange(20.7), Banana(17.0), Apple(17.6), *Including: fruit juices, jams*
3	Pulses & legumes	63.0	Soy(61.6)
4	Grains (bread)	103.0	Bread(35.2), Muffin and Doughnut(4.7), Udon and Soba(a kind of noodles) (47.0), Wheat(3.5)
5	Rice	291.0	Rice(291.0)
6	Starchy roots	46.0	Sweet Potato(5.5), Potato(24.8), Other Potatoes(15.7), *Including: Starch*
7	Beef (+veal)	14.0	Beef(13.9) *Excluding hot and cold processed beef*
8	Pork	45.0	Pork(45.4) *Excluding: Sausage*
9	Mutton (+lamb & goat)	n.d.	n.a.
10	Poultry (+turkey)	32.0	Poultry(32.1)
11	Fish (incl. sea food)	66.0	Fish (66). *Including raw fish, ready meals and takeaway fish products.*
12	Cheese	4.0	Cheese(4.1)
13	Dairy (milk & yoghurt)	130.0	Milk(81.1), Other Dairy(48.5)
14	Eggs	38.0	Eggs(38.0)
15	Pasta (Durum wheat)	12.0	Pasta(11.9)
16	Nuts and Seeds (+olives)	n.d.	n.a.
17	Meat replacements	n.d.	n.a.
18	Dairy replacements	n.d.	n.a.
	total	**1235.0**	
general note Tamaplaza, Tokyo: National Health and Nutrition Survey. Retrieved from (MHLW, 2018).			

(*continued on next column*)

Table C1 (*continued*)

Kattenburg, Amsterdam			
●	Food group	gr/day	Subgroups/products
Oakland Avenue Farms, Detroit			
1	Vegetables	99.7	All vegetable types- fresh and frozen including: artichokes(0.43), asparagus(0.73), bell peppers(5.77), broccoli (5.90), brussels sprouts(0.72), cabbage (4.03), cauliflower (1.12), celery (2.72), collard (0.24), sweet corn (3.61), cucumber (3.70), eggplant (0.47), escarole (0.07), garlic(1.41),kale (0.31), lettuce (18.67), lima beans (0.17), mushroom (2.19), mustard green (0.18), okra (0.26), onion (14.05), pumpkin (1.28), snap beans (2.38), spinach (1.47); squash (3.04); tomatoes (15.39); turnip (0.06); carrot (5.86); radish (0.24); green peas (1.06); other (2.17) *Excluding: vegetable juices, tomato sauces, dehydrated, and canned vegetables.*
2	Fruits	77.5	Fresh Fruits (73.6), Frozen Fruits (3.9). *Excluding: dried fruits, canned fruits, fruit juices, jams & jelly, marmalade.*
3	Pulses & legumes	11.6	Legumes (11.6).
4	Grains (bread)	150.8	Total wheat flour- white and whole wheat flour and durum flour (115.3), Rye flour (0.46), Total corn products- corn flour and meal, hominy and grits, and starch (30.8), Barley products(0.67), Oat products (3.61)
5	Rice	n.d	No sub-specification available
6	Starchy roots	57.7	Potatoes Fresh (32.3), Potatoes Frozen (25.42)
7	Beef (+veal)	51.8	Beef (51.7), Calf (0.1). *Accounts for edible weights adjusted for loss.*
8	Pork	39.4	Pork (39.4). *Accounts for edible weights adjusted for loss*
9	Mutton (+lamb & goat)	0.7	Lamb (0.7). *Accounts for edible weights adjusted for loss*
10	Poultry (+turkey)	75.1	Chicken, hen (65.0), Turkey (10.1). *Accounts for edible weights adjusted for loss*
11	Fish (incl. sea food)	8.1	Fresh and Frozen Fish (4.2), Fresh and Frozen Shellfish (3.9). *Excluding: Canned and Cured fish.*
12	Cheese	34.2	Cheeses – all types of processed cheese (29.8), cottage cheese (1.9) Cream cheese (2.5)
13	Dairy (milk & yoghurt)	138.6	Total fluid milk - Beverage milk and refrigerated yogurt (138.6). *Excluding: Butter, Frozen dairy products- ice cream, evaporated and condensed milk, dry milk products, half and half cream, eggnog*
14	Eggs	27.3	Eggs (27.3).
15	Pasta (Durum wheat)	n.d.	Included in grains
16	Nuts and Seeds (+olives)	13.9	Peanuts (8.2), Almonds (2.1), Hazelnuts (0.1), Pecans (0.5), Walnuts (0.5), Macadamia nuts (0.1), Pistachio nuts (0.4), Other tree nut (1.1), Coconut (0.9)
17	Meat replacements	n.d	n.a.
18	Dairy replacements	n.d	n.a.
	total	**786.5**	
general note Oakland Avenue Farms, Detroit: Data retrieved from Food Availability (Per Capita) Data System-Loss Adjusted food availability (USDA ERS, 2017). The data is not specific for Oakland Avenue, Detroit but a USA per capita consumption estimate.			
Qatar University Campus, Doha			
1	Vegetables	209.0	Tomato (48.2), cucumber (19.5), pepper (13.5), squash (7.2), cabbage (8.9), cauliflower (9.9), onions (84.7), lettuce (6.7), eggplant (10.2)
2	Fruits	187.0	Banana (40.3), apples (29.7), citrus (60.5), (water)melon (24.4), dates (32.4)
3	Pulses & legumes	41.0	Legumes (41)
4	Grains (bread)	211.0	Wheat (211)
5	Rice	184.0	Rice (184)
6	Starchy roots	59.0	Potato (59)
7	Beef (+veal)	7.0	Beef (7)
8	Pork	n.d.	n.d.
9	Mutton (+lamb & goat)	53.0	Sheep meat (53)
10	Poultry (+turkey)	119.0	Fresh poultry (22.1), frozen poultry (96.9)
11	Fish (incl. sea food)	46.0	Seawater fish (40.8), other seafood (5.3)
12	Cheese	n.d.	n.d.
13	Dairy (milk & yoghurt)	232.0	Milk (232)
14	Eggs	32.0	Eggs (32)
15	Pasta (Durum wheat)	n.d.	n.a.
16	Nuts and Seeds (+olives)	n.d.	n.a.
17	Meat replacements	n.d.	n.a.
18	Dairy replacements	n.d.	n.a.
	total	**1380.0**	
general note Qatar University Campus, Doha: Data retrieved from the Qatar National Food Security Strategy 2018–2023. Ministry of Municipality and Environment (MME) - Food Security Department (MME Qatar, 2020). Data are commodity-based.			
West-Sydney, Sydney			
1	Vegetables	110.5	Cabbage, cauliflower and similar brassica vegetables (9.9), Leaf and stalk vegetables (7), Peas and beans (7.1), Tomato and tomato products (14.4), Other fruiting vegetables (20), Other vegetables and vegetable combinations (16.9), Dishes where vegetable is the major component (35.2)
2	Fruits	142.3	Pome fruit (46), Berry fruit (4), Citrus fruit (20.9), Stone fruit (17.1), Tropical and subtropical fruit (28.1), Other fruit (15.4), Mixtures of two or more groups of fruit (6.8), Dried fruit, preserved fruit (3), Mixed dishes where fruit is the major component (0.8)
3	Pulses & legumes	8.8	Mature legumes and pulses (2.5), Mature legume and pulse products and dishes (6.2)
4	Grains (bread)	131.9	Grains (bread) 131.9
5	Rice	32.2	Rice (32.2)
6	Starchy roots	61.1	Potatoes (46.3), Carrot and similar root vegetables (14.7)
7	Beef (+veal)	18.9	Beef (18.7, Veal (0.2)
8	Pork	6.0	Pork (6)
9	Mutton (+lamb & goat)	7.2	Lamb and mutton (7.2)
10	Poultry (+turkey)	25.6	Chicken (24.3), Other poultry (1.3)
11	Fish (incl. sea food)	29.9	

(*continued on next column*)

Table C1 (*continued*)

Kattenburg, Amsterdam			
●	Food group	gr/day	Subgroups/products
			Finfish (excluding commercially sterile) (7.6), Crustacea and molluscs (excluding commercially sterile) (1.3), Other sea and freshwater foods (0.5), Packed (commercially sterile) fish and seafood (5.5), Fish and seafood products (homemade and takeaway) (8.6), Mixed dishes with fish or seafood as the major component (6.1)
12	Cheese	11.4	Cheese (11.4)
13	Dairy (milk & yoghurt)	209.4	Dairy milk (cow, sheep and goat) (139.1), Yoghurt (23.5), Cream (1.8), Frozen milk products (14.6), Custards (2.5), Other dishes where milk or a milk product is the major component (3.3), Flavoured milks and milkshakes (24.7)
14	Eggs	8.6	Eggs (8.6)
15	Pasta (Durum wheat)	16.2	Pasta and pasta products (without sauce) (16.2)
16	Nuts and Seeds (+olives)	6.5	Seeds and seed products (0.5), Nuts and nut products (6)
17	Meat replacements	1.2	Meat substitutes (1.2)
18	Dairy replacements	8.3	Dairy milk substitutes, unflavoured (7.8), Dairy milk substitutes, flavoured (0.1), Cheese substitute (0.1), Soy-based ice confection (0.2), Soy-based yoghurts (0.1)
	total	**836.0**	

general note West-Sydney, Sydney: Food consumption is retrieved from ABS (2014).

APPENDIX D. Description of case studies

The six sections below describe the data sources addressed to determine the per capita consumption of various FEW resources. All data comes from (online) publicly accessible sources. Table 1 (food) and Table 2 (energy, electricity, mobility, water resources and waste flows) provide an overview of all the consumption data used in the calculation of the FEWprint carbon profiles.

(1) Amsterdam, Kattenburg (population = 1721)

The residential neighbourhood of Kattenburg is located on an artificial island adjacent to Amsterdam's city centre. Throughout history, the neighbourhood has provided housing for workers in the shipbuilding industry and naval activities. In the 1970s, the original dwellings were demolished and replaced with large residential complexes, including gallery flats and tenement buildings that have not been changed since then. As of 2020, the Kattenburg community counts 1720 residents divided over 989 households. City statistical data note that the community is aging (20.9% = 65+), income levels are at city-average (€34,400 cap/yr) and the percentage of the population with a non-Western background (23,6%) is lower than in the rest of the city (OIS Amsterdam, 2020). In this study, a Halal fraction of 15% and a Carnivorous fraction of 20% are assumed for Kattenburg.

The consumption data used to contextualise the Kattenburg community are either from national (The Netherlands), province (Zuid-Holland), regional (Amsterdam + belt), municipality (Amsterdam), city (Amsterdam), neighbourhood (Kattenburg) or street-level registrations. All the Kattenburg consumption data used in this study is retrieved from online public sources. The average food consumption per person is retrieved from census data provided by the Dutch National Institute for Public Health and the Environment (RIVM, 2017). Data on electricity and gas consumption is provided at the address level (anonymised) by the network manager Liander (2019). Car ownership data is released at the neighbourhood level and the average distance driven per year is at the province level: 300 vehicles per 1000 household (CBS, 2016) and 11,700 km/yr (CBS, 2017) respectively, of which the latter is reduced by 50% to account for the inner city location where cars are less used in general. Data on car type based on fuel use is available at the national level. In a car fleet 80% uses petrol, 15% uses diesel and about 5% uses electric (CBS, 2019). Water consumption data is published by the local water provider (Waternet, 2016). The study assumes that water used/consumed is equal to the water treated afterward. Data on domestic waste production is provided at the municipal level, which is similar to the city level in the case of Amsterdam. Amsterdam residents produce 377 kg annually, which includes fine and bulky waste (CBS, 2018). Official data on waste recycling is lacking (recycle fraction = 0%) and to the extent of our knowledge, all waste is incinerated. The platform offers default data for waste composition (organic, paper, plastic, glass, metal & other [%]) based on income level (low, lower-middle, upper-middle, high) as determined by the World Bank (2012). For Kattenburg, the *High income* level is used.

(2) Belfast, Inner-East district (population = 32.000)

Situated on the eastern bank of the Lagan River, Inner East Belfast was historically important in providing housing for workers of the shipyards, to the north and Sirocco works, to the west. Today, Inner East Belfast is a low-density neighbourhood with a wide variety of housing typologies, from mid-twentieth century terrace housing to detached bungalow housing from the 1990s. Consisting of six administrative wards of Ballymacarrett, Woodstock, The Mount, Bloomfield, Island and Sydenham, it has a population of 32.834 residents divided over 15.246 households. The total site area considered for this study spans 1322 ha, of which 322 ha is non-permeable area. The neighbourhood consists of a large percentage of one-person households (41.5%). A Halal fraction of 0% and Carnivorous fraction of 20% is applied to the diet of residents compared to the average GB diet.

The consumption information of residents is sourced from government data sources. Further, the consumption data used to contextualise Inner-East Belfast are either from national (United Kingdom), province (Northern-Ireland), county (Antrim and Down), city (Belfast), or neighbourhood (Inner-East) level. The average food consumption is drawn from the Family food statistics survey by Department for Environment, Food and Rural Affairs (DEFRA, 2020a). While food data is available at a regional level for N.I., the data used in this study is a U.K. average. Data on electricity generation and associated environmental factors are taken at provincial level with the electricity generation producing carbon at 0.339 kgCO_2e/kWh in 2018, demonstrating the high percentage of contribution from renewables in Northern Ireland (DAERA, 2020). The emissions factors for other fuel types are drawn from a national, U.K., level (BEIS, 2020). Electricity consumption and gas consumption are measured at a city level (DfE, 2020). Car ownership – 667 per 1000 people over the age of 17 – is high in Northern Ireland compared to the U.K., while the average person travels 6369 km/yr (DfI, 2017). The fuel used for cars is 57% petrol, 42% diesel and 1% electric or hybrid (NISRA, 2016). Average water consumption data (53 m^3/cap/year) is published by N.I. Water alongside the environmental factor of water treatment (0.139 kg CO_2e/m^3) and wastewater treatment (0.433 kg CO_2e/m^3) (N.I. Water, 2019). Waste is monitored at the Local Council Area level with the average resident in Belfast producing 416 kg of waste annually. Official data states the Belfast recycling and reuse rate is approximately 25% while as much as 40% is sent to landfill (DAERA, 2019). The income level is set to *high*.

(3) Detroit, Oakland Avenue Urban Farm (OAUF) (population = 427)

Situated in the North End of Detroit, Michigan, the OAUF neighbourhood is centred around a 2.4 ha urban farm. The farm serves as a community hub for social activities, education, and outreach concerning food sovereignty and justice while providing fresh food access to neighbouring communities. Currently, the farm consists of a series of garden plots and apple orchards, a farmer's market, community public art projects, a performance area, a community house, and a farm store. Historically, the North End neighbourhood was an automobile industry in the 1920–30s, and the Oakland Avenue corridor was recognized for its jazz and entertainment. Since the mid-1950s, the neighbourhood has witnessed a gradual decrease in population and increased vacancy, due to the loss of manufacturing jobs, suburbanization, disinvestment, and closure of small businesses. Within the one-block radius of the farm, 5–10min walking distance, an estimated population of 427 divided over 197 households live within an urban footprint of 36.7 ha, of which 17 ha is non-permeable. The neighbourhood is predominantly comprised of single-detached homes. The median income of the census tract (5114) falls in the *low-income* bracket ($20,362) (USCB, 2018). The majority of the population in the census tract (19.8%) is between the age of 55–64 years (USCB, 2018). Considering that 3% of the population in the Detroit Metro area are Muslim, the study assumes a Halal percentage of 3% as well (Pew Research Centre, 2020). Further, based on the studies by the Centres for Disease Control and Prevention (CDC), 18.5% of adults (aged 18+) and 42.4% of children (between age 12–18 years) consume vegetables less than one time daily in Michigan, thus the study applies a cumulative carnivorous fraction of 21.75% (CDC, 2020).

The consumption data used to contextualise OAUF neighbourhood are either from national (USA), state (Michigan), regional (Midwest or South East Michigan), county (Wayne), city (Detroit), or census tract (5114) datasets, retrieved primarily from public online sources. The estimated per capita food consumption is drawn from the national Food availability (per capita) data system using the Loss-adjusted food availability data for 2017 (USDA ERS, 2017). The Environmental Factors for the US diet is based on the Database of food impacts on the Environment for Linking to Diets (Heller et al., 2018). The energy consumption data per household member is generated from the regional data-annual household site consumption and expenditure in the Midwest, from the 2015 Residential Energy Consumption Survey: Energy Consumption and Expenditures (US EIA, 2015). The carbon footprints for electricity and natural gas are based on the report, City of Detroit Greenhouse Gas Inventory (Carlson et al., 2014). The annual vehicular distance travelled per capita within Detroit is 14215 km (USDOT, 2015). Within census tract-5114, there is an estimate of 752.6 vehicles per 1000 households (USCB, 2018). The fuel types used for light-duty vehicles, including passenger cars and light-duty trucks in the U.S., are 96.7% petrol, 2.9% diesel, 0.35% propane, and 0.04% electric (Davis and Boundy, 2020; EIA, 2017). The Great Lakes water authority (GLWA) is a regional system managing water supply and wastewater systems in seven Southeast Michigan counties, including Wayne County. The environmental factor applied for the water supply and wastewater treatment are proxy values from U.S. based studies due to limited data availability for GLWA (Cashman et al., 2014; Jin et al., 2015) The daily water consumption per person in Detroit is 219.5 L (CDM Smith, 2015). The study assumes that all the water used for domestic consumption becomes wastewater in the calculation. Waste estimates for the City of Detroit are from the Wayne County Municipality Report 2015. Each Detroit resident produces 432 Kg of waste per year, out of which 1% is recycled, 71% is incinerated, 6% is composted, and 23% is sent to landfill (Wayne Country, 2015).

(4) Doha, Qatar University Campus (QU) (population = 24.00)

Qatar University is a public university, north of Doha and 2 km from the Gulf shore, situated on an elevated site. In 2019 the university accommodated more than 23,000 students and 1000 staff members within a campus area of 80.9 ha, of which 7.2 ha is considered non-permeable surface. The student population consists mostly of Qatari citizens: 66% (Qatar University Publications, 2020). The campus is composed of residential and commercial buildings, a central library, a science centre, a park, as well as numerous colleges and student centres. Additional social and commercial activities take place in retail facilities including mini markets, shops, food outlets, health centres as well as recreation and athletic facilities. Qatar is among the richest countries globally with a GDP of 146.37 billion USD in 2020 (The World Bank, 2021), thus the national income level is classified as high and therefore the income level is set to *high*. Qatar being an Islamic country with approximately 67.7% of the population Muslims (World Population Review, 2021), the Halal fraction is set to zero as the national data represents this specific diet. Further, the study assumes a Carnivorous fraction of 20%, since Qatari diet is high in meat products (Al-Thani et al., 2017).

The consumption data used to contextualise the Qatar University Campus are either from the national (Qatar), or neighbourhood level (QU campus). The Qatar University campus consumption data used in this study are retrieved from public online sources, in collaboration with the Facilities & General Services Department (FGSD) at QU. The average food consumption per person is collected by the Food Security Department, Ministry of Municipality and Environment in Qatar (MME Qatar, 2020). For this assessment demonstration, this study assumes that all staff and students live on campus and that 100% of the staff, 75% of the Qatari student and staff and 50% of the international students own a car, resulting in a total of 16,295 cars on campus. This number is manually inserted to the platform. The average vehicular distance travelled is approximately 22,000 km per year (Cihat et al., 2019). Data on electricity and water consumption were provided by the FGSD. Data on domestic waste production are given at a national level from the Planning and Statistics Authority in Qatar. In 2019, the domestic waste produced amounted to 1.41 kg per capita per day (Planning and Statistics Authority Qatar, 2019).

(5) Tokyo, Tamaplaza (population = 84.850)

The Japanese population made a significant transformation from rural areas to large cities in the 1960s and 1970s due to labour demand in urban areas. To meet the enormous demand for housing, a policy of ownership with a focus on own-construction was promoted so that suburban areas were rapidly converted to residential areas by the private sector (Ishabashi and Taniguchi, 2005). Examples in Tokyo include Tama New Town and Tama Garden City, Tamaplaza is a part of these housing complexes. The Tamaplaza neighbourhood has a population of 84850 divided over 34918 households, residing within an urban footprint of 832 ha, of which 707 ha is non-permeable surface. Although there are no official statistics, the number of people following a Halal diet is considered to be extremely low. The study assumes an overall Halal fraction and Carnivore fraction of 0%. The income level is set to *high*.

The consumption data used to contextualise Tamaplaza are either from national (Japan), province (Kanto), regional (Tokyo Metropolitan Area), municipality (Kanagawa), city (Yokohama) or neighbourhood (Tamaplaza). Carbon footprints for electricity, gas and water are specified by law and from reports of the Water Department. For electricity and gas, the law stipulates a system for calculating, reporting, and announcing greenhouse gas emissions, and this study applies the prescribed coefficients in the calculations (ME Japan, 2020). Although water supply is managed at the prefectural level, the data for Kanagawa Prefecture(where Tamaplaza is located) remains inaccessible. Therefore, the study applies data collected by Tokyo Metropolitan Waterworks Bureau and results from other academic publications (Bureau of Waterworks Tokyo, 2019; Sano et al., 2012).

The resident consumption data are based on government and business data sources. Average food consumption is obtained at the regional level from the National Health and Nutrition Survey of the Ministry of Health, Labour and Welfare (MHLW, 2018). Data on per capita consumption of electricity, gas and water are prepared at the county level (ANRE, 2019; Bureau of Waterworks Tokyo, 2015). According to data generated at the ward level and published by the City of Yokohama, there are 704 cars per 1000 households (Yokoma City, 2020). The average distance travelled by cars is 7231 km, calculated at the city level (Yokohama City, 2010). The number of vehicles by fuel type is estimated using data provided by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT, 2010, 2018). Waste data is sourced from a report by the City of Yokohama, which informs that the annual per capita household waste generated is 222 kg (Yokohama City, 2019). In addition, the recycling rate of waste is 33.1% (YCRMB, 2017).

(6) Sydney, Western Parkland City (population = 1000000)

The Sydney case study is a futuristic project, for which the applied values are estimates. As part of the Greater Sydney Region Plan Metropolis of Three Cities (GSC, 2018a), Sydney will transform into three distinct but interconnected cities: the Eastern Harbour City, the Central River City, and the Western Parkland City. The city will be established on the strength of the new international Western Sydney Airport and Badgerys Creek Aerotropolis. Western Parkland City is the subject of the M-NEX Sydney Living Lab as it is currently sparsely populated and environmentally degraded. Previously the site was primarily used for grazing, hobby farming and industrial activities. The scale of the proposed development is unprecedented. The population of Western Parkland City is projected to grow from 740,000 in 2016 to 1,1 million by 2036, and over 1,5 million by 2056 (GSC, 2018b). The study assumes a population 1,000,000, divided over 384,615 households residing within an urban footprint of 808,661 ha, of which 485,196 ha is non-permeable. The income level of this future city is set to *high*. The study assumes an overall Halal fraction and Carnivore fraction of 0%.

The consumption data used to contextualise Western Parkland City are either from national (Australia), State (New South Wales), regional (Greater Sydney), city (Sydney), or neighbourhood (Western Sydney) level. The Western Sydney consumption data used in this study is retrieved from public online sources. The average food consumption per person is retrieved from the Australian Bureau of Statistics (ABS, 2014). Data on electricity and gas consumption is provided at the State level from the NSW Environmental Protection Agency's State of the Environment Report (US EPA, 2015). Car ownership data and average distance travelled per year are released at the state level: 536 vehicles per 1000 households (ABS, 2021) and 8700 km/yr (ABS, 2020), of which the latter accounts for the capital city area of operation. Car type based on fuel use is available from the same data set (ABS, 2020) at the State level. In a car fleet 72.7% uses petrol, 25.6% uses diesel, 1.7% uses LPG, and approximately 0.1% uses electric. Water consumption data is provided by the local water provider (Sydney Water, 2019). Data on domestic waste production is given at the state level. NSW residents produce 550 Kg per person annually (US EPA, 2020), 43% is diverted from landfills which comprise 22% recycled and 21% organic. No waste is incinerated and until recently most recycling was sent overseas to China.

APPENDIX E. FEWprint equation framework

This appendix section describes the applied equations used to establish a carbon assessment with the FEWprint platform. The impact of FEW management intervention is measured as the difference in carbon equivalent emissions between the baseline scenario and the designed *new* scenario. As such, this platform operates as a scenario comparison and evaluation tool. Not including any interventions surrounding the production of food, a *new* scenario is composed changing end-user resource demand, resource type or resource infrastructure (see Fig. 1. Therefore, discussed equations in this appendix apply for both the baseline scenario assessment as well as the *new* scenario assessment, where resource demand for new scenario is marked by a notion in the subscript, for example $PCC(n)_{new}$. This particular study does however not discuss any new scenario solutions.

The total carbon footprint of the community (CF_{tot}) is calculated with equation A1, and is composed of the separate sectoral footprints of food consumption (CF_F), electrical energy use (CF_{EE}), thermal energy use (CF_{TE}), the use of car fuel for mobility (CF_{ME}), water production and treatment (CF_W) and the emissions associated with the processing of domestic waste (CF_{DW}). The equations apply [ton/yr] as units, however, note that the results of this study are expressed in [kg/cap/yr] for inter-community comparability purposes.

$$CF_{tot} = CF_F + CF_{EE} + CF_{TE} + CF_{ME} + CF_W + CF_{DW} \quad \text{[A1]}$$

Food

CF_F denotes the summed carbon footprint by the 18 considered food groups consumed in a community and can be calculated with equation (A2). An overview of the considered food inventory is provided in Table 1 and Appendix C.

$$CF_F = N_{tot} * \sum \left(PCC(n)_{ctx} * \frac{365}{1000} * ef\left(n\right)(n)_{kg}\right) \left(\text{apply } PCC(n)_{new} \text{ for a new scenario}\right) \quad \text{[A2]}$$

N_{tot} represents the total number of people in the community. $PCC(n)_{ctx}$ denotes the contextualised daily per capita consumption [g/cap/day]. The contextualisation of the national diet is discussed in the section below. The carbon footprint of a food group is indicated by $ef(n)_{kg}$. Table 1 provides an overview of the country specific values applied in this study as well as a set of mean global default values.

Contextualising food consumption

The carbon assessment of food consumption is based on a selection of food groups and individual food consumption data is extracted from public datasets that usually represent the national average. Through on-site survey data, it is theoretically possible to get an accurate figure on the daily food intake of a considered context. However, data on this granularity is hardly available for a given urban context and it would be resource-intensive to produce. Some datasets connect consumption data with socio-cultural, economical or demographic aspects and present this data through customisable graphs and tables (for example the Dutch RIVM (2020a)). Relevant aspects of the considered community can then be projected on the existing data, yielding a more accurate number on food intake. To narrow the misalignment between data aggregation levels, this work applies a basic method of contextualisation for the more environmentally intensive products: meat.

The FEWprint provides two neighbourhood-specific parameters that can be used attune the national base diet and make it representative for the considered context: the *halal diet* fraction and the *carnivorous* fraction. Even though varying between religions or cultures, halal diets exclude certain food products and prescribe specific procedures surrounding the preparation of meat products. The halal fraction in this study is limited to the reduction of pork meat and the removed amount of pork is for simplicity assumed to be equally substituted by beef, mutton, poultry and fish. The carnivorous fraction describes the number of people in the community that consume more than average amounts of meat. The resulting contextualised diet is denoted by $PCC(n)_{ctx}$ and can be calculated with the equation (A3) for pork consumption and A4 for the other meat categories. The remaining food groups (1–6; 11-18) are not affected by the halal and carnivorous fraction (equation [A5]).

$$PCC(pork\ (8))_{ctx} = PCC(pork(8)) * (1 - r_{hal})*(1 + r_{car} * r_{add}) \quad [A3]$$

$$PCC(7,9,10)_{ctx} = \left(PCC\ (7,9,10) + \frac{PCC(pork)*r_{hal}}{4}\right)*(1 + r_{car} * r_{add}) \quad [A4]$$

$$PCC(n)_{ctx} = PCC(n) \text{ for all remaining food groups.} \quad [A5]$$

PCC(n) is the per capita consumption of food group (n) according to the average national diet [gram/cap/day] and CS food intake data is listed in Table 1 and Appendix C. The community fraction that follows a halal diet is represented by r_{hal}. The group of the community that consume more than average quantities of meat and fish can be accounted for with r_{car}. Their additional meat + fish consumption is included with the factor r_{add} and is set to +15% as a default value, which is roughly corresponding with an extra day of meat consumption per week. All before mentioned parameters can be adjusted while working with the platform. In case the national diet is expected to deviate strongly from the food intake at the community level, inserting a (partly) customised diet is more advisable.

Energy

The carbon footprint of electrical energy use (EF_{EE}) and thermal energy use (EF_{TE}) are calculated with respectively equations A6 and A7 and is based on the per capita use ($PCU(n)$, or $PCU(n)_{new}$) of the various inserted energy sources and/or carriers *n*. The corresponding default footprints of the various energy carriers, electricity sources or district heating systems ($ef(n)_{unit}$) can be found in table B1. The footprints applied in this study can be found in table A1.

$$CF_{EE} = N_{tot} * \sum\left(PCU(n) * ef(n)_{kWh}\right) \left(\text{apply } PCU(n)_{new} \text{ for a new scenario}\right) \quad [A6]$$

$$CF_{TE} = N_{tot} * \sum\left(PCU(n) * ef(n)_{unit}\right) \left(\text{apply } PCU(n)_{new} \text{ for a new scenario}\right) \quad [A7]$$

New energy scenarios can be designed and evaluated by changing the end-user demand and/or changing/decentralising energy provision.

Mobility

The carbon footprint of mobility, i.e. transportation carbon emissions from fuel combustion, is limited to personal transportation only. This limitation allows for a top-down assessment approach where data from local or national registrations are combined to produce a contextual estimation. This educated estimation is based five parameters: (1) community vehicle typology based on fuel input, (2) car efficiency (also called fuel economy), (3) car ownership, (4) annual distance driven and (5) carbon footprint indicators of fuel combustion. The impact of the mobility sector is estimated with equation (A8):

$$CF_{ME} = N_{tot} * \sum\left(PCU(n) * ef(n)\right) \left(\text{apply } PCU(n)_{new} \text{ for a new scenario}\right) \quad [A8]$$

The per capita use of car fuel $PCU(n)$ has to be calculated separately with equation (A9):

$$PCU(n) = \frac{N_{hh} * \frac{c_{car}}{1000} * r(n)_{fuel} * d_{yr}}{\eta(n)_{fuel}} \Big/ N_{tot} \quad [A9]$$

N_{hh} denotes the total number of households in the community and c_{car} represents the car ownership, which should be expressed in number of cars per 1000 household. It is not unlikely that car ownership (c_{car}) is expressed in different terms, like for example per capita, in which case $\left[N_{hh} * \frac{c_{car}}{1000}\right]$ should be exchanged with $[N_{tot} * c_{car}]$ or any other elementary equation that can calculate the total number of car in the community. $r(n)_{fuel}$ notes the fraction of car types based on the fuel input *n*, see item 1–8 in table B1. The car type fractions applied in this study and the average distance driven per capita per year (d_{yr} [km]), are both listed in Table 2. The efficiency of the car, expressed in kilometres driven per 1 unit of fuel, is approximated with $\eta(n)_{fuel}$, of which the applied default values in this study can be found in Table 2 and table B1 in appendix B.

Water

The total carbon footprint of urban water management is composed of the emissions related to the production and distribution of potable water (pw) and the emissions coming from the collection and treatment of wastewater (ww). Also the emissions involved with the treatment of centrally collected rainwater (rw) are accounted for, which may be applicable in cities with mixed rainwater-sewage water pipes. All these processes require electrical energy, hence driving both upstream and downstream carbon emissions. The total carbon emissions occurring in the water sector are calculated with equation (A10):

$$CF_W = CF_{pw} + CF_{ww} + CF_{rw} \quad [A10]$$

The emissions associated with drinking water production are calculated with equation (A11):

$$CF_{pw} = \left(PCU(pw) * \sum\left(E(n_{prod}) * ef(n)_{kWh}\right)\right) * \frac{365}{1000} * N_{tot} \quad [A11]$$

The emissions associated with waste water treatment are calculated with equation (A12):

$$CF_{ww} = \left(PCP(ww) * \sum\left(E(n_{trt}) * ef(n)_{kWh}\right)\right) * \frac{365}{1000} * N_{tot} \quad [A12]$$

The emissions associated with rainwater management are calculated with equation (A13):

$$CF_{rw} = p * \sum A_{imp} * 0.623 * E(n_{trt}) * ef(n)_{kWh} \quad [A13]$$

The per capita use of potable water that is tapped from the regional water provision is noted by PCU_{pw} [L/day] and can be retrieved from public databases or estimated based on resident survey input. The per capita produced wastewater is denoted by PCP_{ww} [L/day]. For simplicity, potable demand and waste water production are assumed to be similar in this work. The embodied electricity per cubic meter of water produced or treated is mentioned by respectively $E(n_{prod})$ and $E(n_{trt})$ [kWh/m^3], and is multiplied with the carbon footprint of the applicable electricity source $ef(n)_{kWh}$. Due to a broadly observed unavailability of embodied energy data on water production and treatment processes, it is also possible to calculate directly with emission footprints [kg CO_2e/m^3].

The emissions related to rainwater management are noted by CF_{rw} and are calculated by multiplying the annual rainfall p [m^3/m^2/yr] with the total amount of impermeable surface A_{imp} [m^2] within the designated urban area. A reduction factor (0.623) is included to account for the rainwater that precipitates in such small quantities that collection and disposal are not required and natural evaporation takes over (Texas A&M, n. d.).

Alternative scenarios can be designed by lowering the water demand, changing and/or decentralising the water provision, changing and/or decentralising water treatment methods and assigning renewable energy sources to the water infrastructure. Alternative rainwater resource management strategies in a new scenario can be assed be increasing the permeable surface area, switching rainwater treatment methods, increase rainwater capture + reuse or allocating renewable energy sources to the treatment systems.

Waste

The carbon equivalent emissions associated with processing domestically produced waste can be estimated with equation (A12):

$$CF_{DW} = N_{tot} * PCP_{dw} * r_{rec} * \sum\left(r(n)_{waste} * ef(n)_{kg}\right) \quad [A12]$$

The per capita waste production PCP_{dw} [kg/yr] is first reduced with the a recycling fraction r_{rec}. No emissions are assigned to the recycled fraction in this study. The remaining waste is sub-divided into the three waste processing methods applicable to the context with $r(n)_{waste}$ and multiplied with the corresponding carbon footprints $ef(n_{38-41})_{kg}$. This study limits to the three main methods of processing: waste-to-energy (incineration), waste-to-landfill and waste-to-compost. The domestic waste management methods can be expressed in carbon emission equivalents, which are adapted from Pulselli et al. (2019) and applied similarly to all case studies. The nature of the waste does not affect the carbon assessment of the baseline scenario in this work. However, the platform offers default data for waste composition (organic, paper, plastic, glass, metal & other [%]) based on income level (low, lower-middle, upper-middle, high) as determined by the World Bank (2012). Subdividing the total waste can be useful when designing a new waste management strategy for the context, since more tailored solutions can be proposed for the different waste streams.

APPENDIX F. Sensitivity Analysis

Detailed overview of the sensitivity analysis' data input and results. Carbon assessment calculations of the Full Scope Categorical Indicator (FSCI), Full Scope Product Indicator (FSPI) and Limited Scope Product Indicator (LSPI) approaches were performed manually.

Table F4
Detailed overview of food consumption [g/cap*day], carbon footprints [kg CO_2eq/kg_{food}] and carbon impacts [kg/yr]. Abbreviations: n.d. = no data; o.s. = Out of Scope.

Food consumption. Limited scope and Full scope.					Footprint	Carbon impact [kg/cap*yr]			
•	Food group	Considered products in limited scope assessment (group based)	Considered products in full scope assessment (product based) (=) is also included in limited scope. (+) is added to scope.	Note on consumed products	Categorical (bold) and product	Lim. scope / Categorical. indicator (LSCI)	Full scope / Categorical. indicator (FSCI)	Full. scope / Product indicator (FSPI)	Lim. scope / Product indicator (LSPI)
1	Vegetables	Total 131.0	**Vegetables total: 131.0**	-	**1.82**	87.0	83.9	87.0	83.9
		- various products	-	-	(n.d.)	-	-	7.8	7.8
		(as full scope column)	= Mixed vegetables (11.8)	Includes spinach & chicory	1.00	-	-	7.0	7.0
					2.47	-	-	43.6	43.6
			=Leafy Greens (19.2)	Tomato. Bell pepper. cucumbers	0.59	-	-	2.6	2.6
			= fruiting vegetables		1.60	-	-	11.3	11.3

(continued on next column)

Table F4 (*continued*)

Food consumption. Limited scope and Full scope.					Footprint	Carbon impact [kg/cap*yr]			
•	Food group	Considered products in limited scope assessment (group based)	Considered products in full scope assessment (product based) (=) is also included in limited scope. (+) is added to scope.	Note on consumed products	Categorical (bold) and product	Lim. scope / Categorical. indicator (LSCI)	Full scope / Categorical. indicator (FSCI)	Full. scope / Product indicator (FSPI)	Lim. scope / Product indicator (LSPI)
			(48.4) = Root vegetables & carrots (12.3) = Cabbages (19.4) = Mushrooms (2.9) = Peas. corn & broad beans (2.5) = Onion. leek. garlic (11.8) = Stalked vegetables & Sprouts (2.6)	Based on carrots Based on kale Based on mushrooms Based on peas, corn & green beans Based on onion (raw & cooked) -	5.21 1.69 0.61 (n.d.)	- - - -	- - - -	5.5 1.5 2.6 1.7	5.5 1.5 2.6 1.7
2	Fruits	Fruits 113.4 - Fruit (113.4)	**Fruits total: 119.5** = Fruit (113.4) + fruit compote (+5.7) + fruit-nut mix (+0.4)	- - - -	**1.53** *(n.d.)* *(n.d.)* *(n.d.)*	63.3 - - -	63.3 - - -	66.7 63.3 3.2 0.2	66.7 63.3 (o.s.) (o.s.)
3	Pul.& Leg.	Pulses & Legumes (4.5)	**Pulses & Legumes total: 4.5**	**-**	**2.53**	4.2	4.2	4.2	4.2
4	Cereals & Grains	138.3 + Bread (125.6) + Knackebrod (5.3) + Breakfast cereals (7.4)	**Cereals & Grains total: 146.9** = Bread (125.6) = Cracker/Knackebrod (5.3) = Breakfast cereals (7.4) + wheat other (8.5)	- - - - -	**1.32** 1.24 (n.d.) 1.38 (n.d.)	66.6 - - - -	70.7 - - - -	- 56.8 2.6 3.7 4.1	- 56.8 2.6 3.7 (o.s.)
5	Rice	n.d.	n.d.	**-**	**1.71**	n.d.	n.d.	n.d.	n.d.
6	Starchy R.	72.1	**Starchy Roots total: 72.1**	**-**	**0.92**	24.2	24.2	24.2	24.2
7	Beef	12..6	**Beef total: 30.5** + Processed mix (18.3)	- Mix of processed meat products (hot/cold)[1]	**30.8** (n.d.)	141.7 -	343 -	343.1 -	141.7 (o.s.)
8	Pork	13.0	**Pork total: 31.3** + Processed mix (18.3)	- Mix of processed meat products (hot/cold)[1]	**13.70** (n.d.)	65 -	157 -	156.9 -	65.1 (o.s.)
9	Mutton	0.6	n.d.	Consumption to low	(n.d.)	n.d.	n.d.	n.d.	n.d.
10	Poultry	16.6	**Poultry total: 34.7** + Processed mix (18.3)	- Mix of processed meat products (hot/cold)[1]	**12.2** (n.d.)	74.0 -	155.0 -	154.6 -	74.0 (o.s.)
11	Fish & Seafood	12.9 - Fish (11.5) - Sea food (1.4)	**Fish & Sea food total: 16.0** = Fish (11.5) = Sea Food (1.4) + Fish products (+3.2)	- - CF based on shrimp -	**8.61** 8.23 15.40 (n.d.)	41.0	51.0	- 34.5 7.9 10.1	- 34.5 7.9 (n.d.);(o.s.)
12	Cheese	32.6	32.6	-	**11.30**	*134.2*	*134.2*	*134.2*	*134.2*
13	Dairy (except cheese)	254.3 - yoghurt (53.7) - fermented (147.4) - unfermented (53.2)	**Dairy total: 310.6** = Yoghurt (53.7) = Milk. fermented (147.4) = Milk. unfermented (53.2) + Other (1.7) + Kwark (11.4) + Vla. porridge. pudding (26.3) + Ice cream (9.8) + Cream. coffee cream (7.1)	- - - - - - - - -	**2.31** *2.26* *1.50* *2.03* (n.d.) *4.72* *2.03* (n.d.) (n.d.)	214.0	262.0	- 44.3 80.7 39.4 1.4 19.6 19.5 8.3 6.0	- 44.3 80.7 39.4 (o.s.) (o.s.) (o.s.) (o.s.) (o.s.)
14	Eggs	12.7	**Eggs total: 12.7**	-	**4.32**	20.0	20.0	20.0	20.0
15	Wheat (P)	47.1	**Wheat (pasta) total: 47.1**	-	**1.52**	26.1	26.1	26.1	26.1
16	Nuts & Seeds	6.3 - Olives (0.6) - Nuts & Seeds (5.7)	**Nuts & Seeds total: 6.3** = Olives (0.6) = Nuts & Seeds (5.7)	- - -	**4.16** (n.d.) (n.d.)	10.0	10.0	- 0.9 8.7	- 0.9 8.7

(*continued on next column*)

Table F4 (*continued*)

Food consumption. Limited scope and Full scope.					Footprint	Carbon impact [kg/cap*yr]			
•	Food group	Considered products in limited scope assessment (group based)	Considered products in full scope assessment (product based) (=) is also included in limited scope. (+) is added to scope.	Note on consumed products	Categorical (bold) and product	Lim. scope / Categorical. indicator (LSCI)	Full scope / Categorical. indicator (FSCI)	Full. scope / Product indicator (FSPI)	Lim. scope / Product indicator (LSPI)
17	Meat rep.	1.5	**Meat replacers total: 1.5**	-	n.d.	0.0	0.0	n.d.	n.d.
18	Dairy rep.	8.4	**Dairy replacements: 8.4**	(soy drink. natural)	**0.76**	2.3	2.3	2.3	2.3
19	Fruits & Nuts	n.a.	**Fruits & Nuts total: 4.0** **Peanut Butter (4.0)**	- -	**8.68**	Out of scope	12.7	- 12.7	Out of scope
20	Fats & Oils	n.a.	**Fats & oils total: 22.0** Fats & Oils. other (1.6) Plant oils (3.5) Butter (2.2) Margarine & prep. fats (14.9)	- Based on category average Based on Sunflower & olive oil Based on Butter. salted + unsalted Margarine	**7.02** (n.d.) 6.09 12.2 4.95	Out of scope	57.0	- 4.1 7.8 9.8 26.9	Out of scope
21	Sugar & Candy	n.a.	**Sugar & Candy total: sum** Sugar & Candy. other (4.7) Sugar (4.7) Marmalade products (5.1) Honey (0.9) Chocolate spread (3.4) Candy. no chocolate (5.8) Dessert sauce (0.7) Chocolate (4.8)	- As average. - Jelly & Apple Sirope - Sprinkles and spread As average. As average. Milk chocolate	**2.54** n.d. 0.84 1.68 1.16 2.56 (n.d.) (n.d.) 6.06	Out of scope	28.0	- 4.4 1.4 3.1 0.4 3.2 5.4 0.6 10.6	Out of scope
22	Cake	n.a.	**Cake & Cookies total: 41.2** Cake. breakfast cake (24.1) Cookie & biscuit (17.1)	- Based on breakfast cake & cakes Based on various products	**3.33** 3.55 3.28	Out of scope	50.0	- 31.2 20.5	Out of scope
23	Non-alcoholic	n.a.	**Non-alcoholic drinks total: 1707.5** Non-alcoholic. other (7.5) Fruit- & vegetable juice (55.4) Lemonades. soda. sirops (349.3) Coffee (392.5) Tea (225.7) Herb- & fruit tea (88.4) Water. bottled water (588.7)	- As average. Various products Cola. Ice tea. lemonades Coffee & Cappuccino -as tea Essentially zero	**0.64** (n.d.) 0.89 0.47 0.90 0.16 0.16 0.01	Out of scope	399.0	- 1.8 18.0 59.9 128.9 13.2 5.2 2.1	Out of scope
24	Alcoholic	n.a.	**Alcoholic Drinks total: 138.8** Wine (38.4) Sherry. Port. Vermouth (1.6) Beer (92.3) Strong spirits. liquor (4.2) Other alcoholic drinks (2.3)	- Wine red. rose and white As average. - Based on Jenever drink As average.	**1.93** 2.15 (n.d.) 0.71 2.49 1.93	Out of scope	98.0	- 30.1 1.1 23.9 3.8 1.6	Out of scope
25	Sauce & seasonings	n.a.	**Sauces & Seasonings total: 35.4** Sauces & Seasonings. other (16.3) Tomato Sauce (6.7) Mayonnaise & dressings (7.9) Bread spread. mayonnaise based (4.5)	- As average (no seasonings included) - - As average	**2.68** 2.68 1.17 5.52 2.68	Out of scope	35.0	- 15.9 2.9 15.9 4.4	Out of scope
26	Bouillon	n.a.	**Bouillon total: 42.6**	**-**	**2.21**	Out of scope	34.4	34.4	Out of scope
27		n.a.				Out of scope	34.3		Out of scope

(*continued on next column*)

Table F4 (*continued*)

Food consumption. Limited scope and Full scope.					Footprint	Carbon impact [kg/cap*yr]			
•	Food group	Considered products in limited scope assessment (group based)	Considered products in full scope assessment (product based) (=) is also included in limited scope. (+) is added to scope.	Note on consumed products	Categorical (bold) and product	Lim. scope / Categorical. indicator (LSCI)	Full scope / Categorical. indicator (FSCI)	Full. scope / Product indicator (FSPI)	Lim. scope / Product indicator (LSPI)
	Savoury Snacks		**Savoury Snacks: 20.6** Salty snacks. crisps. salt cookies (9.4) Snacks. deep-fried. snack breads (11.2)	- Based on crisps and popcorn Based on sausage bread. frikandel and kroket	**4.56** 2.89 6.23			- 9.9 25.5	
Total consumption:		**871 g/cap*day**	**3048 g/cap*day**		**Total impact:**	**2165 kg/cap*yr**	**973 kg/cap*yr**	**1911 kg/cap*yr**	**854 kg/cap*yr**

[1] Mix of (1) Other meat products. (2) Processed meat for warm dinner & (3) Meat products (lunch) = + 18.3.

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