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Circular economy indicators for the food system

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Summary

This report is part of the ongoing research at the Policy Research Centre for Circular Economy to create a monitor to guide the transition to a circular economy in Flanders. This report presents a guiding framework specifically for circular economy in the food system and provides a first set of indicators to monitor the food system.

A holistic vision on what circular economy means for the food system is currently missing in (and outside of) Flanders. As this is an essential requirement to assess what to include in a monitor and to evaluate whether the system is evolving towards circularity a guiding framework is created in this report. Through a literature review the available knowledge on (aspects of) CE and food from both academic and policy documents was brought together and supplemented with the insights of stakeholders in Flanders through a participatory Delphi approach. A circular system for food in essence comes down to minimizing the material demand and associated environmental impact of this system, while still ensuring that the nutritional need in Flanders is met for all citizens through a safe, balanced and healthy diet. The created framework has three central themes: (1) the optimization of inputs, (2) the optimization of food products, and (3) the optimization of residual streams. For each of these themes, strategies to minimize the material demand and associated environmental impacts of the food system are discussed**.** The food system is unique within circular economy in a number of ways. Regarding the first theme, input use, a key aspect for this system is that it is difficult to reuse inputs in closed cycle systems, as they re-enter natural biochemical cycles through their use. For the second theme, food products, it is key to account for the inevitable single-use and biological nature of food products. High level circular economy strategies – like reuse and repair - aimed at increasing and extending the use of products cannot be applied to the food system, as after use the product becomes mainly excreta. Instead, the use of biomass in the system should be optimised. The same is true for the third theme, residual streams, as the inevitable organic stream associated with food production and consumption should be optimally valorised. The food system is very complex, crossing multiple policy domains, like agriculture, environment and health. Due to this, current expertise and initiatives on circularity within the food system are spread out among numerous different stakeholders. The framework created in this study can provide a common starting point for the different stakeholders working across policy domains on the different aspects of circular economy for food and can be used to provide guidance for future policy initiatives.

In this report the created framework is used to guide the search for circular economy indicators for the food system in Flanders. The data presented in this report is a first attempt at summarizing the food system in Flanders in terms of circularity. From what was found, it seems that while the food system is intrinsically circular to a certain extent – due to its connection with the biosphere – increasing production and consumption have moved the system away from the underlying natural cycles. Subsequently, today there is a lot of room to optimize the circularity of the system on all three fronts of input use, product use, and use of the residual streams. Input use has to be brought in line with the carrying capacity of natural ecosystems through further reductions in total use, further increases in the share obtained from environmentally sustainable sources, and by halting losses to the environment. The use of food products can be

further optimized by addressing excesses – in the form of overconsumption and food loss – and through shifting diets towards low-impact products. Lastly, the use of residual streams from the food system can be further optimised by increasing selective collection and facilitating more high-level valorisation according to the cascade. In general, transitioning the food system to a circular economy will require a dual focus, by using technological innovation to optimize current cycles, while also focusing on system innovation by questioning the existence and size of current cycles within the limits set by the planetary boundaries.

The high number of indicators discussed throughout this report demonstrates that the food system will not be easily analysed or summarized. The emphasis of circularity strategies differs for the various actors in the food system. The study is focused on the three foremost links in the food chain: primary production, consumption, and waste collection and treatment, and is based on reframing already accessible data, collected for other purposes. Hence, it was not yet possible to work out first-best indicators for all relevant aspects of a circular economy for the food system. Further research is required to address current gaps, like food processing, and finetune the available indicators. Also, while it is clear that current input use bears very high material demands and environmental impacts, it is currently not at all clear which circular targets should be strived for with regard to local and global environmental boundaries. Further research could focus on the development of scenarios for a circular food system, enabling to assess the implications of scenarios and providing input for setting target values for particular indicators. This study fills in the current need for a framework around CE for the food system and provides a first impetus of what is possible with the available data.

Samenvatting

Dit rapport kadert in het lopend onderzoek van het Steunpunt Circulaire Economie om te komen tot een monitor die de transitie naar een circulaire economie in Vlaanderen in goede banen moet leiden. Dit rapport presenteert een richtinggevend kader specifiek voor circulaire economie in het voedselsysteem en geeft een eerste set van indicatoren om het voedselsysteem op te volgen.

Een holistische visie op wat circulaire economie betekent voor het voedselsysteem ontbreekt momenteel in (en buiten) Vlaanderen. Aangezien dit een essentiële vereiste is om te beoordelen wat in een monitor moet worden opgenomen en om te evalueren of het systeem evolueert in de gewenste richting wordt in dit rapport een richtinggevend kader gecreëerd. Via een literatuurstudie werd de beschikbare kennis over (aspecten van) CE en voedsel uit zowel academische als beleidsdocumenten samengebracht en aangevuld met de inzichten van stakeholders in Vlaanderen via een participatieve Delphi-benadering. Een circulair systeem voor voedsel komt in essentie neer op het minimaliseren van de materiaalvraag en de bijbehorende milieu-impact van dit systeem, terwijl er toch voor wordt gezorgd dat de voedingsbehoefte in Vlaanderen voor alle burgers wordt ingevuld via een veilig, evenwichtig en gezond voedingspatroon. Het gecreëerde kader heeft drie centrale thema's: (1) de optimalisatie van de inputs, (2) de optimalisatie van de voedingsproducten, en (3) de optimalisatie van de reststromen. Voor elk van deze thema's worden strategieën besproken om de materiaalvraag en de bijbehorende milieueffecten van het voedselsysteem te minimaliseren. Het voedselsysteem is op een aantal manieren uniek binnen de circulaire economie. Wat betreft het eerste thema, inputgebruik, is een belangrijk aspect voor dit systeem dat het moeilijk is om inputs te hergebruiken in gesloten kringloopsystemen, omdat ze door hun gebruik opnieuw in natuurlijke biochemische cycli terechtkomen. Voor het tweede thema, voedselproducten, is het van essentieel belang rekening te houden met het onvermijdelijke eenmalige en biologische karakter van voedselproducten. Hoogwaardige circulaire-economiestrategieën - zoals hergebruik en reparatie - die erop gericht zijn het gebruik van producten te vergroten en te verlengen, kunnen niet op het voedselsysteem worden toegepast, aangezien het product na gebruik voornamelijk uitwerpselen worden. In plaats daarvan moet het gebruik van biomassa in het systeem worden geoptimaliseerd. Hetzelfde geldt voor het derde thema, reststromen, aangezien de onvermijdelijke organische stroom die met voedselproductie en -consumptie gepaard gaat, optimaal moet worden benut. Het voedselsysteem is zeer complex en doorkruist meerdere beleidsdomeinen, zoals landbouw, milieu en gezondheid. Hierdoor zijn de huidige expertise en initiatieven rond circulariteit binnen het voedselsysteem verspreid over tal van verschillende stakeholders. Het raamwerk dat in deze studie is gecreëerd kan een gemeenschappelijk startpunt bieden voor de verschillende stakeholders die over beleidsdomeinen heen werken aan de verschillende aspecten van de circulaire economie voor voedsel en kan worden gebruikt om richting te geven aan toekomstige beleidsinitiatieven.

In dit rapport wordt het gecreëerde kader gebruikt om richting te geven aan de zoektocht naar circulaire economie indicatoren voor het voedselsysteem in Vlaanderen. De gegevens die in dit rapport worden gepresenteerd zijn een eerste poging om het voedselsysteem in Vlaanderen samen te vatten in termen van circulariteit. Uit wat werd gevonden, blijkt dat hoewel het voedselsysteem tot op zekere hoogte intrinsiek circulair is - door de verbinding met de biosfeer

- de toenemende productie en consumptie het systeem hebben weggeduwd van de onderliggende natuurlijke cycli. Vervolgens is er vandaag veel ruimte om de circulariteit van het systeem te optimaliseren op alle drie de fronten van inputgebruik, productgebruik, en gebruik van de reststromen. Het gebruik van inputs moet in overeenstemming worden gebracht met de draagkracht van de natuurlijke ecosystemen door een verdere vermindering van het totale gebruik, een verdere toename van het aandeel dat wordt verkregen uit hernieuwbare bronnen, en door de verliezen naar het milieu een halt toe te roepen. Het gebruik van voedingsmiddelen kan verder worden geoptimaliseerd door excessen - in de vorm van overconsumptie en voedselverlies - aan te pakken en door de voedingsgewoonten te verschuiven naar producten met een gering milieueffect. Ten slotte kan het gebruik van reststromen uit het voedselsysteem verder worden geoptimaliseerd door de selectieve inzameling te vergroten en meer valorisatie op hoog niveau volgens de cascade mogelijk te maken. In het algemeen zal de transitie van het voedselsysteem naar een circulaire economie een tweeledige focus vereisen, door technologische innovatie te gebruiken om de huidige cycli te optimaliseren, en tegelijkertijd te focussen op systeeminnovatie door het bestaan en de omvang van de huidige cycli ter discussie te stellen binnen de grenzen die door de planetaire grenzen worden gesteld.

Het grote aantal indicatoren dat in dit hele rapport wordt besproken, laat zien dat het voedselsysteem niet gemakkelijk te analyseren of samen te vatten is. De nadruk van circulariteitsstrategieën verschilt voor de verschillende actoren in het voedselsysteem. De studie richt zich op de drie belangrijkste schakels in de voedselketen: primaire productie, consumptie, en afvalinzameling en -verwerking, en is gebaseerd op het herkaderen van reeds toegankelijke gegevens, verzameld voor andere doeleinden. Het was dan ook nog niet mogelijk om voor alle relevante aspecten van een circulaire economie voor het voedselsysteem de best mogelijke indicatoren uit te werken. Verder onderzoek is nodig om de huidige hiaten, zoals voedselverwerking, aan te pakken en de beschikbare indicatoren te verfijnen. Ook is het duidelijk dat het huidige inputgebruik zeer hoge materiaaleisen en milieueffecten met zich meebrengt, maar is het momenteel helemaal niet duidelijk welke circulaire doelen moeten worden nagestreefd met betrekking tot lokale en mondiale milieugrenzen. Verder onderzoek zou zich kunnen richten op het ontwikkelen van scenario's voor een circulair voedselsysteem, waardoor de implicaties van scenario's kunnen worden beoordeeld en input kan worden geleverd voor het vaststellen van streefwaarden voor bepaalde indicatoren. Deze studie voorziet in de huidige behoefte aan een kader rond CE voor het voedselsysteem en geeft een eerste aanzet van wat mogelijk is met de beschikbare gegevens.

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List of Abbreviations

BWS	Best-Worst Scaling
CE	Circular Economy
CF	Carbon Footprint
COICOP	Classification of Individual Consumption by Purpose
CO_2-eq	CO_2 equivalent
VFG	Vegetable, fruit and garden waste
GHG	Greenhouse gas
MF	Material Footprint
MSW	Municipal Solid Waste
N	Nitrogen
LULUCF	Land-use, land-use change and forestry
P	Phosphorus
PPP	Plant Protection Products
RDA	Recommended Daily Amount

Circular economy indicators for the food system

1 Introduction

The region of Flanders has put forth the ambition to have a circular economy by 2050 (Vlaamse Regering, 2016b). To help achieve this, the Policy Research Centre for Circular Economy was given the task to create a monitor for the circular economy in Flanders by 2021. The aim of this monitor is to provide indicators to help guide the transition to a circular economy and give feedback to policy makers. The theoretical framework developed to underpin this monitor has been described in Alaerts et al., 2019a, where it was decided to focus on 4 particular systems: 'mobility', 'housing', 'consumer goods', and 'food'.

This study implements the developed framework for the **food system**. The study aims to define what a CE for food entails and how this can be measured, whereafter the available data is discussed. First, a reference framework on CE for the food system is created. After which, the available data is reframed within this framework. The focus for the data gathering aspect of this study lays on the primary production, consumption and end-of-life stage in Flanders. The monitoring of food processing, distribution, as well as biomass production for non-food purposes are considered outside of the scope of this study and left for further research.

Previous work already applied the framework described in Alaerts et al., 2019a to **the system of mobility** and **the system of consumer goods**, resulting in two sets of indicators that showcase the current state of these systems with regard to the transition towards circular economy in Flanders (Alaerts et al., 2020; Vermeyen et al., 2021). These studies helped to make the theoretical framework more tangible and provided practical insights into the challenges and bottlenecks of applying the developed concept.

2 Materials and methods

This section first discusses the framework behind the monitor and how it was applied to the food system. This is followed by a brief description of the literature study. Next, the methodology behind the Delphi study conducted to supplement the literature study is described. The section finishes with listing the sources used for the data gathering process, with a brief description of the different actors from whom data was used.

2.1 Framework for CE monitor

The work on creating a CE monitor for Flanders started in 2017 with the development of a conceptual framework to underpin the monitor. The focus of the resulting framework is on so-called '**systems that fulfil societal needs**' (Alaerts et al., 2019a, 2019b), which were inspired by the major consumption domains of households, i.e.: mobility, housing, food and consumer goods[1]. As is shown in figure 1, households take up the largest share of the material and carbon footprint, with the four chosen consumption domains together representing about 90% of household consumption in Flanders (Raes et al., 2020; Vercalsteren et al., 2017). The reasoning behind this framework is that the economy is a system which fulfils needs through offering products and services. A transition to a circular economy will involve major modifications in those products and services. By creating a better understanding of these, the associated material requirements and impacts, as well as the potential progress towards a more circular economy can be monitored.

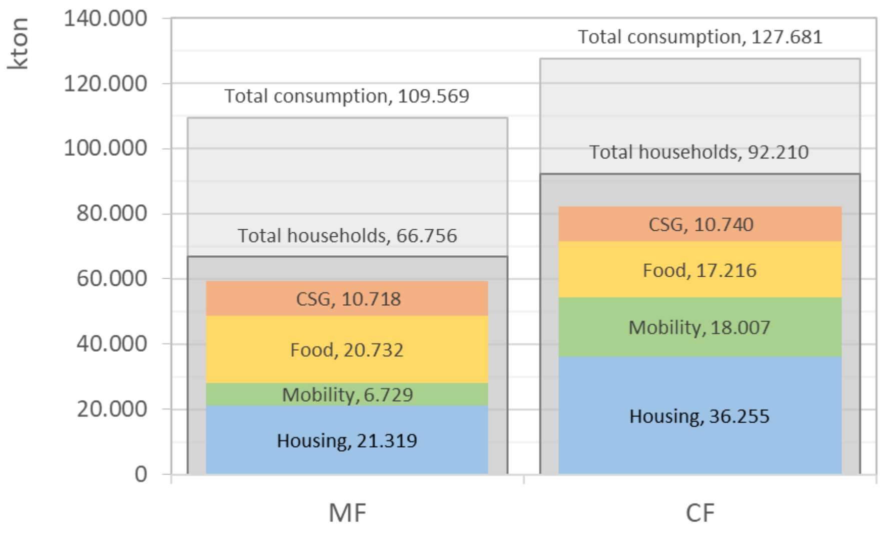

Figure 1 – yearly material- and carbon footprint (resp. MF and CF) of consumption in kton, Flanders, 2010 (source: Christis et al., 2019; Vercalsteren et al., 2017)

It should be noted that while the fulfilment of societal needs lays at the basis of this monitor, it is not the aim of the monitor to make a judgement on the need itself, but to show how the societal need can be fulfilled in a more circular way. The aim is to create a set of indicators for

[1] The first three domains (mobility, housing and food) are each individually established final demand categories in COICOP (1999), while the last domain (consumer goods) was added to encompass the remaining large categories.

each system, which reveals its underlying processes. The material and carbon footprint of consumption were used as a guide to determine which systems to include in the CE monitor for Flanders. Whereafter, the monitor takes a lifecycle perspective, including all lifecycle phases from extraction and design to End-Of-Life. This way a bridge is forged between production and consumption. Through a range of indicators, from the society-wide level of macro indicators to micro level product indicators, the monitor aims to display the material demand and associated impacts of these systems (Figure 2), with the meso-level highlighting relevant trends in each of the four major consumption domains of households. This combination of indicators should then offer more direct feedback at different levels to policymakers.

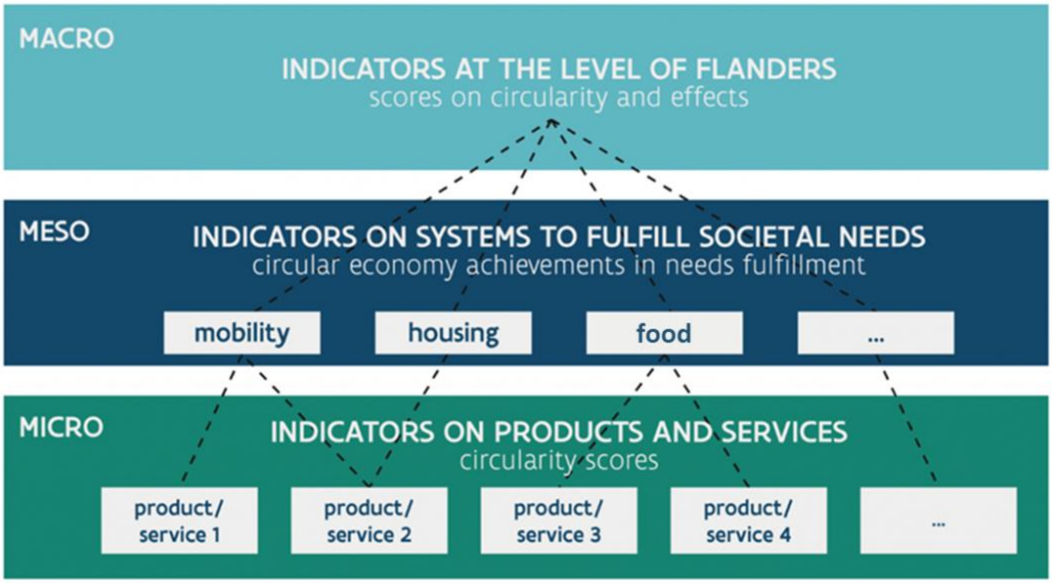

Figure 2 – Overview of the monitoring framework for circular economy in Flanders
(source: Alaerts et al., 2019a)

This study applies the developed framework to the food system. It is a first attempt to show how the food system in Flanders is evolving in terms of circularity. In order to better understand such a monitor, the terms circular economy, food system, and life cycle perspective are explained below.

In general, the key idea of **circular economy** (CE) is to keep products and materials functional as long as possible at the highest possible application level, while minimizing total material-related environmental impacts (Alaerts et al., 2019b). This can then be roughly translated into two high-level objectives:

- To minimize our material footprint, with the aim that our global consumption of materials should be minimized – as such respecting the planetary boundaries (Alaerts et al. 2019b).
- To minimize our carbon footprint, with respect to reducing the environmental impact our consumption has, most notably the CO2-eq emissions given the context of climate change.

The **food system** comprises of all processes required to provide the food and drinks necessary to meet the human demand for nutrition. This system is closely intertwined with the demand for biomass in general and hence the bio-economy. This study looks specifically at the food system but acknowledges the bridge to the bio-economy where residues and waste streams of this system can be best valorised for non-food purposes. Further, the food system is highly globalised, but as the aim of the monitor is to aid the transition to a CE in Flanders, this report focuses specifically on opportunities within Flanders.

Lastly, the framework looks at circularity from a **lifecycle perspective**, meaning that not only the use phase is considered but also all preceding and subsequent steps. By taking this perspective it becomes possible to look at both the role of consumption and production. To create a truly circular system for food it is necessary to look at all steps in a product's lifecycle, whether they occur in Flanders or abroad. Due to the size and complexity of the food system it was not achievable to integrate all steps in the food system into the monitor created in this study. The focus of the monitor is currently on the primary production, consumption, and waste collection and treatment stage. Further work should be done to integrate steps such as 'processing' and 'distribution' into the monitor, as the developed framework on CE and food allows for this.

In general, based on the definitions above, a circular system for food in essence comes down to minimizing the material demand and associated environmental impact of the products in this system throughout their lifecycle, while still ensuring that the nutritional need in Flanders is met for all citizens. This lays the basis of the CE monitor for the food system.

2.2 Literature review

To gain insight into the established work on 'CE and food' a literature review was conducted on both academic and policy documents. Relevant policy documents were located using generic search engines (e.g., google), while for academic literature search terms in scientific databases were used (e.g., google scholar). Subsequently, interesting references in the read articles led to additional literature. Reports from established organisations like OECD, the EU, or PBL provided insights on food systems and CE at different levels. Further, as there is not yet a broadly accepted framework that outlines circular food (Moraga et al., 2019; Pauliuk, 2018), different search queries were used to gain insights on specific aspects, for example, on global biochemical cycles, the impact of diets or food waste.

2.3 Delphi study

From a preliminary literature study and stakeholder interactions at the beginning of this study it became clear that a definition of CE for the food system is currently missing from both policy documents and in literature. While an extensive literature review did reveal useful insights, it was judged to be opportune to conduct an additional stakeholder survey to further focus on the specific situation in Flanders. The Delphi method was applied to assess consensus among a group of experts (Dalkey & Helmer, 1962). The Delphi method follows an iterative process, allowing anonymous interaction between experts by gathering opinions and creating follow-up rounds based on these opinions (Okoli & Pawlowski, 2004). It is an interesting format to give all stakeholders an equal opportunity to be heard.

To gather insight on what circularity for the food system in Flanders should entail, a two-round Delphi study was constructed consisting of (1) a brainstorm round and (2) a ranking of indicator-themes. In the first round, open-ended questions were asked, which allowed for unlimited response and wide-ranging answers. The answers of the first round were analysed using open coding, which is a qualitative data technique using ‘keywords’ to identify important themes. In the second round, closed questions were constructed to rank a list of identified indicator-themes based on their perceived relevance to monitor a circular economy of the food system in Flanders. The best-worst scaling (BWS) technique was used, which is a choice modelling technique asking respondents for the ‘best’ (i.e., most relevant) and ‘worst’ (i.e., least relevant) option in a subset of options. The BWS results reveal the relative importance stakeholders give to the identified indicator-themes. The results of the Delphi study are briefly discussed in section 3.1.B, while more detailed information on the design and analysis of both rounds is available in a background report, which can be provided upon request.

2.4 Data sources

To create the CE indicators in this report, an extensive data collection process was implemented through a snowballing method. To start, an extensive literature review was conducted to find potentially relevant data sources. The stakeholders which manage these data sources were then contacted to provide further insights into their data and asked for any additional data sources. This way new contacts were found. The following organizations provided data which was analysed for the first run of the monitor:

- Bodemkundige dienst van België is a non-profit which provides research and advice on the quality of soils in Belgium. There data was used to look at the state of agricultural soils.
- The Department of Agriculture and Fisheries (Departement Landbouw en visserij) is tasked with, amongst others, collecting and reporting data on the agricultural sector in Flanders. The main source of data used in this report is from the LMN, which stands for ‘landbouw monitoring netwerk’ , translating to ‘agricultural monitoring network’. Through a yearly survey the LMN collects data about a representative sample of farmers in Flanders, which can then be extrapolated to the sector as a whole, as well as to each specific agricultural sector.
- The Department of Environment and Spatial Development (Departement Omgeving) is tasked, amongst others, with monitoring various aspects of the living environment in Flanders. They provided data on the spatial divide in Flanders, as well as on food loss in households.
- Fost Plus is the extended producer responsibility organisation for consumer packaging in Belgium. They coordinate for their members the collection and recycling of consumer packaging put-on-market in Belgium, as well as handle the reporting to the Interregional Packaging Commission (IVC). The data from their yearly reports was used to assess the prevalence of food packaging.
- MIRA is the unit, within the Department of Environment and Spatial Development, responsible for the State of the Environment Report (SOER) in Flanders. MIRA provided the data on the material and carbon footprints of the Flemish consumption.
- OVAM is the ‘Public Waste Agency of Flanders’ which is, amongst others, responsible for monitoring waste collection and treatment in Flanders. OVAM provided data on municipal solid waste, like the amount of waste, the types of waste and the treatment of waste.

- Sciensano is a federally recognised research institution. This study used their data from the yearly ‘Health Survey’ and the 10-yearly ‘Food Consumption Survey’ to gain insight into the consumption patterns in Flanders.

- Gezond Leven or ‘Flanders institute for healthy living’ is a non-profit organisation which provides information and strategies to promote healthy and sustainable diets and other health-related topics to citizens in Flanders, mainly at the request of the Flemish government. Their reports were used to gain insight into what a balanced diet should look like.

- Vlaams Ketenplatform Voedselverlies (VKV) is a platform which united the Flemish government and 8 key stakeholders[2] to work on reducing food waste in Flanders between 2015 and 2020. As part of this exertion a specific effort was made to map and monitor current food waste in Flanders. The resulting data from this monitoring program was used in this report.

- Vlaco is a non-profit organisation which unites the different companies that process organic waste in Flanders. Hence, they provided the data on composting and fermentation of the organic waste stream, as well as home composting.

- VLAM or ‘Vlaams Centrum voor Agro- en Visserijmarketing’ is a cooperation between the Flemish government and the private sector (from primary production to food processing) meant to promote local food both inside and outside of Flanders. To do this, the VLAM collects data on the consumption patterns of households in Flanders. This data was used to gain insight into consumption patterns.

- VLM or ‘Vlaamse Landmaatschappij’ is the governmental agency responsible for, amongst others, collecting data and reporting on the use of manure in Flanders. The data from their yearly report on manure was used to discuss the nitrogen and phosphorus flows in Flanders.

- VMM or ‘Vlaamse Milieumaatschapij’ is Flanders Environmental agency which is, amongst others, responsible for reporting on water, air and the state of the environment. Hence, they provided the data on these topics, like the amount and type of emissions to air.

[2] Consisting of: Boerenbond - FEVIA Vlaanderen - Comeos Vlaanderen - Unie Belgische Catering - Horeca Vlaanderen – UNIZO - Buurtsuper.be - OIVO

3 Results

The first section of the results outlines the creation of a reference framework for CE and food through a review of the existing literature and Delphi study. The second section covers the available data to monitor CE and food, discussing trends and providing detail into the origin and quality of the data. The final section puts forth the key indicators from this study, resulting in a first version of the CE monitor for the food system.

3.1 CE for food

To create a relevant monitor, it was required to first define what a circular food system entails. This was necessary to determine which indicators could be part of a monitor for circular food. Currently, there is no official guideline to follow, as there is not yet a broadly accepted framework that outlines circular food (Moraga et al., 2019; Pauliuk, 2018). This section attempts to address this gap with the aim of creating a reference framework for CE and food in Flanders. In part A the findings from a literature review bring together the available knowledge on (aspects of) CE and food. In part B the insights of stakeholders in Flanders are added to the reference framework through a participatory Delphi approach. The combination of these two approaches allows for indicator selection (Mascarenhas et al., 2015). Finally, the key principles of a CE for food are visually summarized in part C.

A. Findings from the literature review

Food systems today face a triple challenge of needing to provide sufficient food while ensuring fair livelihoods and contributing to environmental sustainability (OECD, 2021). The intensification within the food system has led to large productivity gains. However, current production and consumption patterns come at an increasing material demand and contribute to numerous adverse environmental impacts. The current overexploitation of natural resources, land-use change, and waste generation are adversely affecting the very natural biogeochemical cycles the food system depends upon (OECD, 2021; Willett et al., 2019). Disruptions in these cycles, like changing weather patterns or pollution, adversely affect production and are subsequently felt throughout the value chain, threatening food security in the long run. Of the nine planetary boundaries defined by Steffen et al., (2015) as necessary to maintain a save operating space for humanity, the current food production system puts particular pressure on five boundaries: biodiversity loss, the biogeochemical cycle of nitrogen and phosphorus, fresh water use, land use change, and climate change (Willett et al., 2019). If the system remains unchanged, the pressure it exerts on the environment will only further increase due to the growing global population and changing consumption patterns. As a consequence, the food system has come under increasing scrutiny, resulting in concrete initiatives being implemented to create a more sustainable food system, both in Flanders and internationally. At a global level the sustainable development goals (SDGs) touch upon sustainable food systems by working towards, amongst others, food security (SDG 2), global resource efficiency (SDG 8.4) and sustainable production and consumption systems (SDG 12, 14, and 15). The EU's 'green deal' and 'farm to fork' strategy both address food systems and Flanders is currently working out their own regional food strategy (Departement Landbouw & Visserij, 2020).

A sustainable diet should take care not to overburden the carrying capacity of local ecosystems (Rubens et al., 2021), while still ensuring that the nutritional need in Flanders is met for all its citizens through a safe, balanced and healthy diet (Vlaamse Regering, 2016b). Moving to a circular economy for the food system is proposed as a tool to address several of the environmental challenges due to the strong emphasis of CE on optimizing material flows. Section 2.1 already stated that a circular system for food in Flanders comes down to minimizing the material need and associated environmental impacts of this system, while still ensuring that the nutritional need in Flanders is met for all citizens. The CE aims to achieve this through optimally valorising all inputs and products (Rood et al., 2016). A large share of the inputs and products in the food system consist of biological materials, which are obtained and disposed of through biogeochemical processes (Ellen MacArthur Foundation, 2017). This sets this system apart within the CE as the materials, unlike with abiotic materials, cannot be kept in the economy indefinitely through reuse, repair or recycling. According to Rood et al., (2016) obtaining a CE for food comes down to optimising the valorisation of (1) inputs, (2) food, and (3) residual streams. Figure 3 applies the EEA's DPSIR framework to the food system, using the planetary boundaries framework by Steffen et al., (2015) and drawing from Rood et al., (2016) to summarize and visualise the aims of implementing a CE for food.

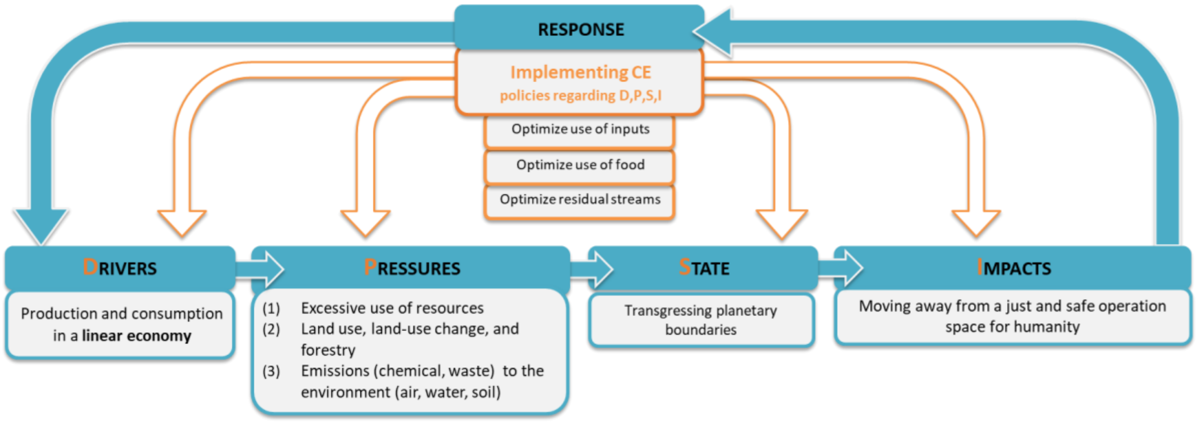

Figure 3 – The DPSIR model applied to circular economy and the food system
(source: own creation based upon the EEA, Steffen et al., (2015)*, and Rood et al., (2016))*

Defining a CE for food is complex because the system crosses various policy boundaries, like agricultural, environmental, health or economic policy. Further, a CE for food will need to cross sectoral and scale boundaries, as the food system is characterized by global chains and inevitably entangled with the wider system of the bio-economy. This means looking for opportunities at multiple levels: within companies, in the companies' surroundings, in cross-sectoral chains, and internationally. For this study the focus is on the food system in Flanders, the bio-economy is only discussed when (by-)products from the food system are used for a non-food purpose. Further research should cover this gap.

Optimizing the use and management of inputs

In general, the amount of products produced in the food system is determined by three factors, with varying environmental implications: (1) total land use, (2) total use of other inputs, and (3) efficiency in the use of inputs (OECD, 2021). A CE for food would see each of these factors optimised, while still ensuring food security. Further increases in the first two strategies are undesirable, as excessive use and bad management of land/inputs can lead to resource depletion and can have adverse effects on the surrounding environment, disrupting natural cycles and ecosystems. The third strategy however follows the CE's principle of optimizing the use and management of the inputs needed throughout the system. Input use can be optimized during production through innovative products and manufacturing processes that decrease the total amount of required inputs and increase the efficiency of the used inputs. Most of the inputs used in the food system are renewable inputs, drawn from the natural capital present in the area, like soils, water or pollinators. Aside from this, also man-made inputs are added, like synthetic fertilizers or packaging.

Production in the food system is impossible without renewable inputs like water. Even if there would be no unwanted losses to the environment, inputs still need to be replenished as they leave in the produced products. It can thus be noted that while the aim is to reduce the total extraction of renewable inputs as much as possible, this can never become zero. Instead, to ensure the continued availability of renewable inputs, 4 key strategies need to be considered: (1) sustainable sourcing, (2) optimal use through cascading, (3) closing cycles, and (4) minimizing the impact of resource extraction (Navare et al., 2020). When it comes to closing cycles, the question is on what scale to close cycles. The answer to this differs for each input. The Netherlands put forth the following guiding principle 'as small as possible, but as large as required to be efficient', taking into account aspects like logistics, cost-efficiency, governance and transparency (Rijksoverheid, 2018).

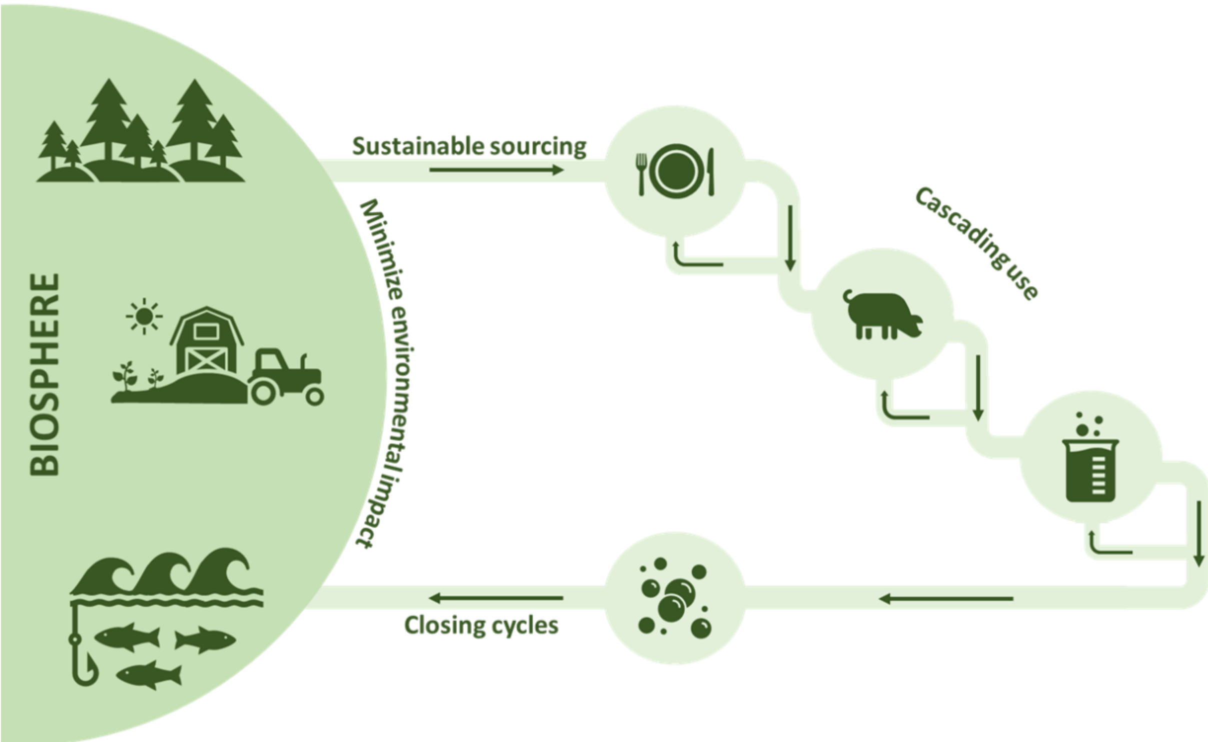

Figure 4 – Sustainable use of biological inputs in a CE
(source: adaptation from Navare et al., (2020)*)*

In general, inputs can be optimized by examining what products are produced and how they are produced. 'What is produced' comes down to the choice of product (and amount), while 'how it is produced' comes down to the choice of production method. Initial insights can be gained from understanding how different products(categories) and production processes relate to each other with regard to their material requirements and associated environmental impacts. At a macro-level, the material and carbon footprint can provide a first understanding of this, as well as into the geographic distribution. However, the impact of the food system goes beyond greenhouse gas (GHG) emissions, requiring other relevant environmental impact categories to be included. For example, the use of fertilizers in agriculture is a major contributor to the disruption in the biogeochemical cycles of nitrogen and phosphorus, for which the safe operating space set in the planetary boundary framework has already been surpassed (Steffen et al., 2015). Additional footprints, like a nitrogen footprint, could provide further insight. Also, footprints use a top-down approach, providing little detail at product level. Alternatively, life Cycle assessments[3] (LCA) are an established bottom-up method, which can be used to compare different products over multiple impact categories, if sufficient data is available.

When considering **'What to produce'**, the aim of CE is to fulfil the nutritional need with those products which require the fewest inputs and the smallest associated environmental impact. One aspect which emerges throughout the literature, is the relative large material need and environmental impact of producing animal-based products compared to that of plant-based products (Castellani et al., 2017; De Krom et al., 2020). This is because animal-based products come from livestock which requires additional inputs, like feed from plant-based products. On average, the additional production step reduces the overall efficiency of the production process (Rood et al., 2016; Rubens et al., 2021). Further, the current size of animal-based production contributes to the pressure on multiple planetary boundaries (Buckwell & Nadeu, 2018). This however does not mean there is no place for animal-based products in a circular food system. The University of Wageningen suggests to tailor the size of animal production to what is optimal to sustain plant production, where animals are fed mainly with the residues from plant-based food products and in turn provide the animal manure needed to sustain plant production (De Boer & Van Ittersum, 2018). This requires a circular food system to find the right balance between plant-based and animal-based production (Van Zanten et al., 2019).

The material needs and associated environmental impacts also varies strongly among plant-based products. Replacing high-input crops with low-input crops is put forth as another pathway to increase circularity. For example, legumes require less fertilizers, as they fix nitrogen in soils, making it also available to the next crop in rotation. Crops can also be made more input efficient through genetic selection, e.g., for drought resistance. It can be noted that the choice of what to produce was historically between plant-based or animal-based production. This is starting to change with novel cultivations, like insects or seaweeds, increasingly being put forth as more input-efficient, as they are for example not soil bound. The main disadvantage of most novel cultivations is a high energy requirement, which should be met through renewable energy sources (Van Zanten et al., 2019). The processing industry is developing novel products based on novel cultivations. Through smart food design, in the form of ingredient selection and sourcing, the impact of products can be reduced (Ellen MacArthur Foundation, 2021). Lastly, it can be noted that the material needs and associated environmental impact of processed foods is higher, because additional steps are needed to come to the final product.

[3] An full LCA looks at ecosystem impacts (climate change, acidification, eutrophication, land-use change, solid waste, toxicity), human impacts (ozone depletion, smog, particulate matter, carcinogens, toxicity) and resource depletion (fossil fuel, freshwater, soil, forest, grassland, minerals) of a product over its entire lifecycle.

Further, **‘How to produce’** strongly influences the material need and associated impact of a particular product, as there are different methods to produce the same final product. For example, the reduction of N and P in animal manure through the use of low-nutrient feeds (VLM, 2021). With regard to primary production, production can be sorted into three different types with regard to their interaction with natural habitats: (1) agriculture can be organised intensively, with a strong focus on efficiency and maximizing output per unit, (2) agriculture can be organised in such a way as to maximally co-exist with natural habitats, attempting to minimize any adverse effects on the surrounding ecosystem, accepting sub-optimal yields, and (3) agriculture can be used in nature management, where the focus is not on yields but on maintaining a certain nature type. All three types have their merits and thus a place in a circular economy. Primary production in Flanders should be organised in such a way as that the type of production in an area makes sense for that specific area, so that the carrying capacity of our natural capital is not overburdened, while still allowing the sector space to operate. This could for example mean that when agricultural production is close to valuable nature reserves the focus is on more extensive agriculture to not overburden the surrounding area. This reasoning is already implemented for nitrogen deposition from livestock farms in Flanders. Under the nitrogen policy plan (PAS), the renewal of the license of holdings close to valuable nature is depended on their nitrogen emissions. The holdings found ineligible for renewal are offered the possibility to shift, move or discontinue production (Vlaamse Regering, 2016a). In other areas more intensive forms of agriculture can exist to ensure sufficient food production. Here, technological innovation - like precision agriculture - offer interesting opportunities to optimize and reduce the use of critical inputs like land and water. Cooperation between agricultural holdings – or the wider industry – can offer interesting opportunities for optimizing the use of residual streams, like water or heat, and machinery.

There are different CE strategies required to ensure optimal use of inputs during primary production. For mechanical inputs, like tractors, circular strategies to increase the number of uses per product are possible. Several ‘machine sharing’ initiatives already exist within Flanders. For the natural resources used during production the focus should be on sustainable sourcing. As inputs inevitably leave the system in either the produced products or as emissions to the environment they need to be continually replenished. For renewable inputs like water, carbon and nitrogen input use should be tailored to what can be sustainably sourced from natural cycles. The use of non-renewable inputs should be reduced as much as feasible and where possible inputs should come from recovered sources - like for phosphorus.

As crops prefer certain growing conditions, the time and place of production are also significant factors influencing the impact of production (De Boer & Van Ittersum, 2018). It is not necessarily beneficial to focus solely on local production, as the impact of transport is in general small compared to that of the production method (De Boer & Van Ittersum, 2018; OECD, 2021; Van Zanten et al., 2019). Further, the environmental impact of transportation is determined more by the transport method, with cooled transport and transport by air being associated with high environmental impacts, than by the total distance travelled (Rubens et al., 2021; Van Passel, 2013). Production location for livestock is more flexible then for crops, as it is less depended on specific seasonal circumstances. As the impact of production is case dependent, LCAs can provide insight into which production method is most opportune where and when. Lastly, it should be kept in mind that the size of a production system ultimately determines its final impact. When considering options, the potential impacts from LCAs studies are often compared per functional unit. However, a highly efficient production method can still cause excessive adverse effects due to the size of production. Thus, apart from deciding what and how to produce, attention also needs to be paid to how much is produced in a certain region. The size of production should be tailored to what the (local) carrying capacity of ecosystems can handle.

During food processing, the focus should be on using the best available techniques for minimizing the total input requirement and reusing inputs. For example, reusing process water, using renewable energy, novel resources and valorisation of any waste streams. Here both opportunities within the company and between companies should be considered (industrial symbiosis). Food processing results in large amounts of uniform organic residual streams, which can become inputs for other processes. This provides much more opportunities for high-level valorisation than the mixed organic residual stream originating from households. The possibilities for residual streams from food processing should already be considered from the start through eco-design.

To monitor the circularity of input use in Flanders the evolutions in total input use, sourcing of inputs, the state of our natural capital and the associated environmental impacts of input use could be mapped. This can reveal where policies are needed to improve upon the monitored aspects and where additional data is needed.

Optimizing the use of food products

The products within the food system are unique within CE in the sense that they can only be consumed once. Because of this, typical CE strategies which aim at increasing the number of uses per product – like sharing and repair - are unavailable. Further, the use of the products in this system needs to occur within a limited timeframe, before it spoils. Strategies to extend the lifetime of products - like food processing, smart packaging, and proper storage - help to reduce food waste, but cannot increase the number of uses per product. Once consumed the product seizes to exist as such, mainly becoming excreta (Rood et al., 2016). To optimize the use of food products, the CE looks for ways to more efficiently fulfil the nutritional demand of consumers. By doing this the same nutritional need can be fulfilled with less production, hence reducing the material need and associated impacts. This can be achieved through two main strategies: avoiding excesses, and choosing low-impact products, as shown in figure 5.

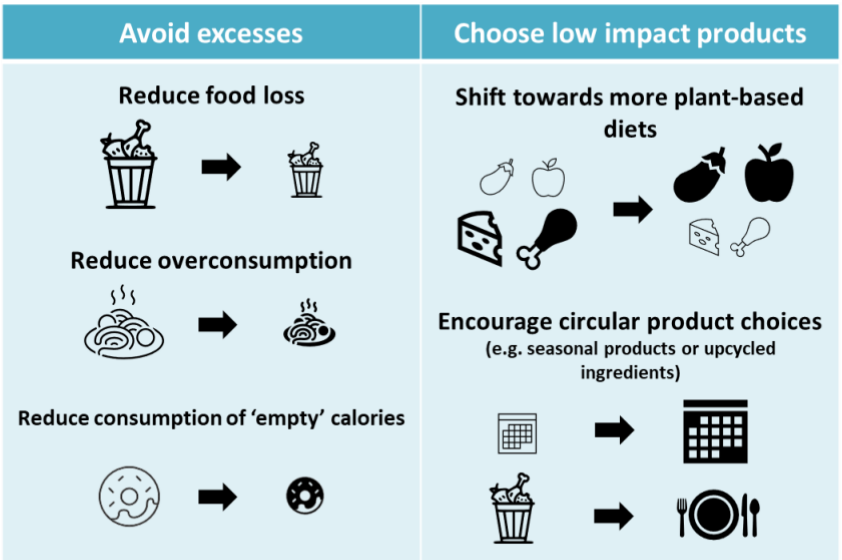

Figure 5 – Main strategies to increase the circularity of consumption

This reveals that consumer choices have a central role to play in making the food system more circular. While the material needs and associated environmental impact of a food product may be determined by the 'what' and 'how' of production (as discussed), the impact of consumption is ultimately determined by the choices consumers make with regard to the available food products. For example, if food products are wasted, this is included in the final impact of consumption. **The material needs and associated environmental impact of food consumption is determined by 'what we eat' and 'how we eat'. 'What we eat' comes down to choices consumers make regarding which products (and how much of them) they choose to consume, while 'how we eat' deals with the way in which consumers handle the chosen food products.** As with production, the material and carbon footprint can provide a first understanding on how different product categories and consumption patterns relate to each other at a macro level. But more detail is required, on multiple impact categories, to make a correct assessment.

Consumers make daily choices on **'what to consume'**. A first aspect that comes into scope here is eliminating excess consumption, as this reduces the total amount of production required and consequently also the total material need and associated impact. Flanders has a typical western diet, high in calories, saturated fats, sugar, and salt (Neven & Versele, 2017). To increase circularity, total consumption should decrease in such a way as to bring it in line with dietary recommendations, especially through shifting away from products which are high in calories but have low nutritional value ('empty calories'). Food waste is also an excess but is discussed under 'how to consume'.

Secondly, material and environmental gains can be obtained by shifting diets towards low-impact products. Like with production, LCAs are increasingly being used to gain insight into the impact of different food products. For example, the EU's Joint Research Centre (JRC) used LCAs to calculate the impact of food consumption in Europe for a Basket-of-Products (Castellani et al., 2017). They assessed 19 different food products on 15 environmental impact categories, revealing where hotspots emerged. LCAs may reveal trade-offs between impact categories. For example, a study in the Netherlands found that shifting to more healthy diets would have lower GHG emissions but would increase blue water use (Vellinga et al., 2019). Thus while further research can provide additional data and insights to support policy makers, it will ultimately fall to policymakers to set clear priorities (OECD, 2021). LCA studies on national diets have been conducted in the UK (Kramer et al., 2017), the Netherlands (Vellinga et al., 2019), France (ECO2 and WWF, 2017), and recently also for Belgium (te Pas et al., 2021). In general, there is a reoccurring finding that the production of animal-based products has a significantly higher impact than plant-based products (Castellani et al., 2017; De Krom et al., 2020; Rubens et al., 2021; te Pas et al., 2021). As the current consumption of animal-based products is above recommended levels (Rubens et al., 2021), an absolute reduction in the consumption of animal-based products is desirable to reduce the material need and associated environmental impacts of consumption. Currently, animal-based products are the main source of protein in the Flemish diet. Additional material and environmental gains can be obtained by shifting consumption towards plant-based protein, allowing for an even greater reduction in the consumption of animal-based products while still meeting the human body's need for protein. Here care should be given that the protein mix still contains all essential amino acids in sufficient amounts.

Lastly, also the final product choice between (more or less) the same product influences the final material footprint and associated environmental effects of consumption. For example, vegetables from a hothouse or from a field. Here the production method seems to be the most relevant factor for a product, less so than its origin, as discussed previously in the section on 'how we produce'. Choosing to consume more seasonal products is put forth as a good strategy to lower the material need and environmental impact of diets, as it optimizes both the 'how' and 'where' of production. Further, consuming products made from otherwise lost residual streams improve circularity (upcycling). However, information about the impact of products is not evident for consumers to obtain. Some labels exist informing consumers about production method, but a coherent and clear communication about the impact of products to consumers is currently missing. Here initiatives using LCA data – like the emerging use of eco-scores – are attempting to better inform consumers.

'How to consume' entails how food is obtained, prepared, and consumed. This relates to shopping habits, cooking methods, and location of consumption (in/out of home, on-the go, etc.), which all determine aspects like the amount of food waste and the valorisation possibilities for the residual stream. In first instance the CE aims at preventing food waste. Food waste consists of two fractions: (1) 'food loss' – which is edible food that is not consumed but discarded, and (2) 'residue' – which is the inedible organic fraction that originates from food consumption (e.g., fruit peels). Food loss at the stage of consumption is highly inefficient as it is not only an additional waste stream that needs to be dealt with, but also entails a waste of all material inputs used along the production process. For this reason, minimizing food loss by consumers is a high priority in achieving a CE for the food system. Household practices which determine food management at home – like meal planning or stock management – are key to reduce food loss (Criel & Fleurbaey, 2019) .

In second instance, CE aims at optimal valorisation of all waste streams. An established framework for this is the cascade for value retention (see figure 6), which is further discussed in the section on 'the optimal use of the residual stream'. The organic waste fraction from households is a mixed stream, making high-level valorisation difficult. The generated waste can be used within the household to generate compost, or feed pets and other household animals like chickens. Alternatively, the organic stream should be collected from households separately so that it can be properly processed in industrial composting or fermentation installations. It should be avoided that organic matter ends up in residual waste, which is typically incinerated. A fraction of food waste, as well as excreta from the consumed food, currently leave the food system through sewage water. For a circular food system, nutrient cycles should be closed here through recovery from sewage sludge (Papangelou et al., 2020).

The consumption of food also generates an inorganic waste stream, consisting mainly of packaging meant to ensure food products reach consumers in an optimal condition and to provide information to consumers. Smart use of food packaging can help decrease food loss. However, a trade-off exists between the CE's aim to minimize food loss on the one side and to minimize the production and disposal of (single-use) packaging on the other side (Sarlee et al., 2015). While this can be a difficult balance to make, it is clear that overpackaging should always be avoided. All unavoidable packaging should be collected and brought back into use. Here ecodesign is key, by already considering the whole lifecycle of a product during the design phase. Through ecodesign the reuse and recycling of packaging can be optimally facilitated.

Changing the 'what and how' of consumption is not easy, as consumption habits are often deeply entrenched and have a strong social and cultural context, making it important that any proposed shift in diet accounts for the regionally and culturally embedded context (Jurgilevich et al., 2016). Further, the direct environment in which consumers make choices about what to eat plays an important role (Jurgilevich et al., 2016; Vanoutrive & Cant, 2020). The consumer is influenced by subtle aspects like which products are at eye level in stores or at the top of menus (Departement Omgeving, 2018). Hence, to change consumption patterns, a change in food environments will likely be required. Here other actors in the food systems – like food processing, retail or HORECA – play a key role, as they determine aspects like product composition (e.g., caloric content), portion size or product visibility. Consumption changes resulting from changes made by preceding actors in the food chain are mostly unconscious and are not sustained if the situation is reversed again (Departement Omgeving, 2018). Less subtle methods aim at informing and educating consumers, for example through labels on food products or information campaigns. These methods struggle to have a wide reach, as especially those consumers who are already interested will notice them (Departement Omgeving, 2018). It can be noted that influencing consumption patterns is more effective when food consumption patterns are still forming, for example through education in schools (Departement Omgeving, 2018).

To monitor the circularity of food consumption in Flanders, it should be assessed to what extent the nutritional need of citizens is met with access to sufficient, safe and high-quality food, while avoiding excesses, like food loss and overconsumption. Here it is important to map the actual behaviour of consumers, as this often varies from their stated behaviour (Criel & Fleurbaey, 2019). Regular monitoring of the impact of the average diet in Flanders could be provided through an LCA, revealing where hotspots with regard to different impact factors are. This is quite resource intensive, as it does require regular insight into the actual intake of citizens, as well as an accurate LCA database for food products in Flanders. In absence of this, more specific aspects of the diet can be tracked. Further monitoring of food loss is required to detect and address any avoidable losses. There are already initial monitoring and actions ongoing about food waste in Flanders (OVAM and departement Landbouw en Visserij, 2020).

Optimizing the application of residues and waste products

The products in the food system are unique within CE because of their single-use and biological nature. Typical CE strategies which aim to increase the number of uses per product, like eco-design, repair, sharing and reuse, cannot be applied to this system. **Instead, a CE for food aims to optimize the use of biomass in the system by ensuring that it is used at its highest possible application level. To do this, the cascade of value retention is an established framework in Flanders** (OVAM and departement Landbouw en Visserij, 2020). The cascade shows the preferred application for biomass produced for human consumption (figure 6). Here, first and foremost, food waste should be prevented, meaning that everything consumable by humans should go towards human consumption. If food waste is reduced, less food needs to be produced to fulfil the same demand, requiring less inputs and eliminating any associated adverse environmental impacts. Any remaining food waste should be optimally valorised as animal or insect feed, or go towards composting and fermentation, allowing for nutrients to be cycled back into the biosphere. Alternatively, in bio-refineries valuable materials can be recovered. After this, using biomass to generate biofuels is the most desirable option. Combinations of material reuse and energy generation are possible, for example using the heat from composting. Incineration (with energy recovery) and especially landfilling should be avoided, as the materials are lost. Further, the production and processing of food inevitably results in inedible biomass, for example peels from fruits. These 'residues' should also be optimally valorised in accordance with the cascade but starting with feed. It should be noted that the cascade is meant as a guiding framework, but that certain deviations can be justified due to safety concerns, legal reasons, or logistics (Rood et al., 2016).

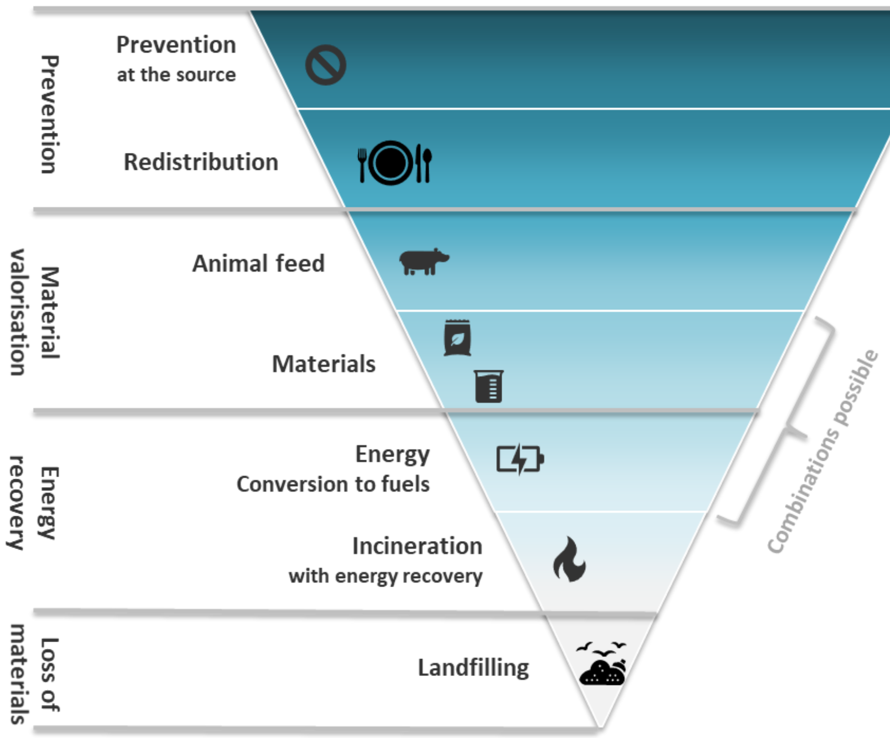

Figure 6 – Cascade for value retention for biomass in the food system
(source: adaptation of OVAM and departement Landbouw en Visserij, (2020)*)*

Human consumption of food is prioritised in the cascade because the nutritional need can only be fulfilled through food products, while energy and materials can come from other sustainable sources (De Boer & Van Ittersum, 2018). However, due to the ongoing shift away from fossil-based products, there is a rising demand for biomass for non-food purposes, creating competition between the production of biomass for food purposes and non-food purposes, like energy, fibre or bio-plastics. This may give rise to conflicts in the use of residual streams between circularity and climate objectives at company level. For example, when a company wants to reduce the use of fossil fuels through biogas generation from their own organic residual stream, while another company may have a higher possible valorisation for this stream (Rood et al., 2016). Flanders waste agency (OVAM), as part of their action plan on food loss and biomass, establishes the use of the cascade for the material hierarchy in Flanders, requiring substantiation through a LCA when deviating from the cascade (OVAM and departement Landbouw en Visserij, 2020). While there is an increase in the size and quality of the residual stream available from food processing due to an increased demand for processed foods, it remains uncertain to what extent the additional valorisation of residues will be sufficient to meet the rising demand for biomass for non-food purposes. Further optimization of the use of the residual biomass resulting from food production and processing is needed to fulfil the demand for biomass. Hence in a CE for food the potential of these residues should be taken into account from the beginning (eco-design), optimizing their availability by breeding crops not only for food yields, as is historically done, but also for the potential of their associated 'residues' (De Boer & Van Ittersum, 2018; Van Zanten et al., 2019). In the current cascade, animal feed comes after human consumption. However, as livestock breeding is associated with emissions to the environment, it may be opportune to use some residuals, low in nutritional value for animals, immediately for material applications, e.g., to improve soils. The trade-offs between different biomass uses are still a new and an evolving area of research (Van Zanten et al., 2019).

For the optimal use of residual streams, the separate collection of organic residue and waste streams is crucial. The more selectively a stream can be collected, the better it can be repurposed. Through the development of new processes in bio-refineries there are more and more high-level valorisation pathways available for residual streams. Novel processes for example even allow for the recovery of nutrients for human consumption from residual streams which are inedible (Van Zanten et al., 2019). Key issues for scaling-up the use of residual streams in the food system are that their availability is often seasonal, that they have only a short retention time or can be contaminated. Further, it requires investment capital to valorise a specific residual stream. This is only attractive to investors if the continuation of the stream can be ensured and a market for the resulting product is found. Therefore, techno-economic analysis (TEA) or life cycle costing (LCC) could be used. To provide a testing environment to actors along the food chain looking for novel valorisation methods the food pilot[4] was launched in Flanders in 2011. Further, there is a need for communication and cooperation between the different actors along the food chain. This in essence comes down to optimizing supply and demand. One actor's waste can become another's input. This cross-sectoral cooperation is typical for the CE, closing cycles at different levels. Lastly, a guiding policy framework to make higher valorisation options more attractive is needed.

To monitor the circularity of the organic waste stream in Flanders, insight is required on where organic food waste originates in the system, as well as on how well it is collected and processed in relation to the cascade of value retention. In Flanders, the monitoring on food waste, in combination with the monitoring on the collection of household and company waste already does this to a large extent.

B. Findings from the Delphi study

To compare our insights from the literature against stakeholders' expertise in Flanders, a two-part Delphi study was conducted. This section briefly discusses the main findings from the Delphi study, specifically the findings from the keyword analysis on the answers given to the open questions in the first round and the outcome of the ranking exercise in the second round. More detailed information can be provided by the authors upon request.

First Delphi round: a brainstorm

The first round of the Delphi was a general brainstorm, meant to capture stakeholders' insights very broadly. By means of open-ended questions, stakeholders were invited to share their vision on CE and food regarding 'production and processing' and 'consumption', as well as suggest possible indicators. In total 138 individual experts, of 54 unique organizations, were

[4] https://www.foodpilot.be/

invited to participate, resulting in 52 responses from 36 unique organizations. From these responses, 49 experts assessed that they had enough expertise to use their answers for both 'production and processing' and 'consumption'. Two experts identified as having only expertise in one of the two: one in 'production and processing' and another in 'consumption'. The answers given in the first round were analysed and coded using keywords. This helped to further structure and map the CE in relation to food. A detailed overview of the keywords encountered, and their relationships to each other, for both 'production and processing' and 'consumption' is given in appendix A2.I.

Figure 7 and Figure 8 respectively summarize the main keywords, defined by the coding analysis, used by respondents when sharing their vision on CE and food for 'production and processing' and 'consumption'. Figure 7 shows that for the question regarding 'production and processing' the keyword 'residual stream' was most often used. Within this category respondence mainly highlighted the importance of both prevention and valorisation of the organic residual stream. Second came 'the use of inputs', where the use of inputs was discussed in general terms, (e.g., 'renewable inputs', 'efficiency'), or specific inputs were discussed (e.g., 'water', 'energy', 'soil' or 'minerals'). The prevalence of these two keyword categories reaffirms the findings from the literature study in section 3.1.A, specifically that on the production and processing side it is vital in a CE for food to optimize the use of residual streams, as well as the use of inputs.

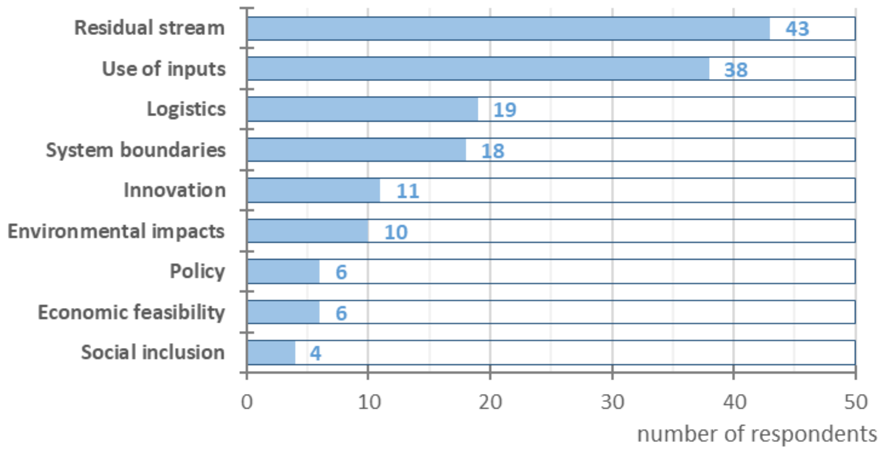

Figure 7 – Keyword analysis for 'production and processing' (n=50), 2021 (source: Delphi study by PRC)

Figure 8 shows that for the question regarding 'consumption' the keyword 'residual stream' emerged again as the most often used, with respondence highlighting the importance of both prevention and valorisation of the organic residual stream. Second came 'consumption pattern', with respondents mentioning aspects related to the amount of food, the type of food, and the origin of the food that is consumed. The prevalence of these two keyword categories is again in line with the findings from the literature study in section 3.1.A, specifically that on the consumption side it is vital in a CE for food to optimize the use of residual streams, as well as the use of food products themselves.

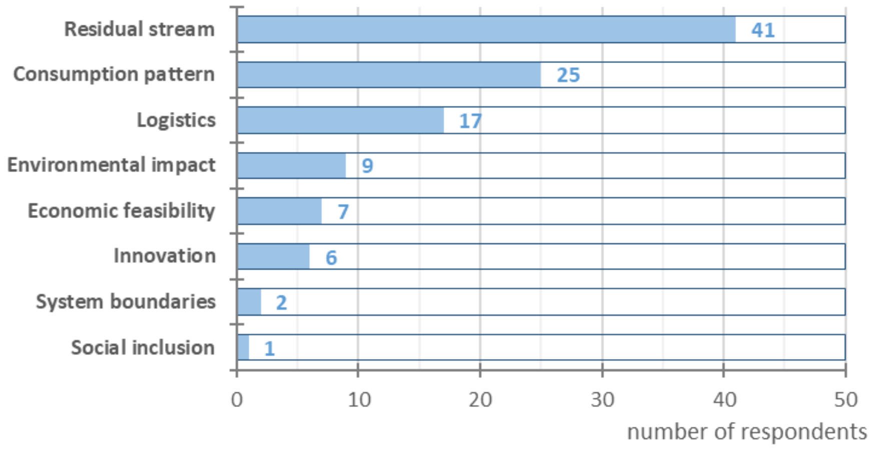

Figure 8 – Keyword analysis for 'Consumption' (n=50), 2021
(source: Delphi study by PRC)

Respondents were also given the opportunity to suggest indicators for the monitoring of CE in the food system. The same coding analysis was performed for the answers provided by the respondents on this second 'indicator' question. For both 'production and processing' and 'consumption' similar distributions of coding were found for most keywords when compared to the vision question. However, in general the counts were much lower when identifying indicators, which might point to stakeholders' current difficulties regarding the quantification of indicators.

In general, the answers given in the first round are in line with the findings from the literature. It can be noted that the visions shared in the first round revealed some topics about which there seems to be no consensus yet among stakeholders. For example, the visions differ about the role of local supply chains or animals in a circular system for food in Flanders. Here consensus will have to be built through clear, scientific communication and through interaction and communication.

Second Delphi round: ranking of indicators

To investigate how circularity of the food system should be measured and monitored, stakeholders were invited in the first round to propose possible indicators. The responses to this, as well as the answers on the vision question were used to create a list of relevant indicator-themes for the food system. This list is provided in appendix A2.II. In the second Delphi round, stakeholders were asked to rank the proposed indicator-themes, using best-worst scaling (BWS). The aim of this was to derive a consensus ranking, showing the relative importance of different indicator-themes. Of the 52 respondents from the first round, a total of 40 different experts responded again to the second Delphi round. From these responses, 38 respondents had expertise in both 'production and processing' and 'consumption'. From the 2 other respondents, one had expertise in 'production and processing', and another in 'consumption'.

The outcome of the second round is shown for respectively 'production and processing' and 'consumption' in Table 1 and Table 2. Each of the tables shows three numbers for each indicator-theme. The first number shows the average preference of the experts towards a certain indicator-theme, while the second and the third number represent the proportion an indicator is picked as the most or the least relevant. For example, in Table 1, the indicator-theme ‘food waste’ was shown 156 times in total to all respondents and chosen 86 times as ‘most relevant’ in a choice set, which leads to a 0,55 best count proportion (=86/156). ‘Logistics and transport’, also shown 156 times, was selected 71 times as the ‘least relevant’ theme, and therefore has the highest worst count proportion (i.e., 0,46=71/156).

It should be stressed that the average Hierarchical Bayes (HB) score expressing the average preference (provided in the second column of each table), is scaled relative to the other indicator-themes and should be interpreted as such. For example, for ‘production and processing’, the indicator-theme ‘food waste’ is considered almost 5 times as relevant as ‘logistics and transport’ to measure a circular economy of food in Flanders. It is thus not the aim to provide an absolute ranking of indicator-themes. Even though ‘food waste’ is considered more relevant by the experts than ‘logistics and transport’, this does not imply that ‘logistics and transport’ is irrelevant to assess progress towards a CE.

It can be noted that the indicator-themes ranked highest would show actual progress towards CE if data for monitoring is available, while lower ranked themes – like ‘Innovation’, ‘Logistics and transport’ or ‘Education and product knowledge’ – are rather enablers of system change which may result in improvements in the higher ranked themes. In both tables food loss is ranked highest, which is consistent with our findings in the literature and in the first Delphi round. Further, ‘consumption pattern concerning origin’ ranks third amongst the consumer themes, while ‘logistics and transport’ ranks last in production and processing. Even though there is no perfect overlap between these two indicator-themes, they are both concerned with where food in Flanders comes from and should go to. Here there seems to be some incoherence between how stakeholders envision each side of the system in a CE for food.

Table 1 – Results best-worst scaling of indicators regarding ‘production and processing’ (n=39), 2021

Indicator-theme	Average HB scores	Best count proportion	Worst count proportion
Food loss	19,19	**0,55**	0,05
Food residues	14,37	0,42	0,13
Water	12,53	0,31	0,08
Minerals	10,72	0,27	0,12
Soil	10,18	0,32	0,25
Industrial packaging and other waste streams	6,36	0,15	0,34
Energy	6,19	0,16	0,29
Land use	6,15	0,21	0,39
Innovation	5,95	0,17	0,35
Animal feed	4,31	0,07	0,29
Logistics and transport	4,05	0,12	**0,46**

(HB: Hierarchical Bayes score)
(source: Delphi study by PRC)

Table 2 – Results best-worst scaling of indicators regarding 'consumption' (n=39), 2021

Indicator-theme	Average HB scores	Best count proportion	Worst count proportion
Food loss	27,19	**0,57**	0,03
Consumption pattern concerning diet	18,51	0,43	0,21
Consumption pattern concerning origin	17,30	0,37	0,15
Food residues	9,68	0,16	0,29
Innovation	7,17	0,12	0,29
Price	7,06	0,13	**0,40**
Consumer packaging	6,93	0,09	0,32
Education and product knowledge	6,15	0,12	0,31

(HB: Hierarchical Bayes score)
(source: Delphi study by PRC)

The BWS results were used as a guideline to focus the efforts for this monitor, given the limited time available. Furthermore, the results can be used by academics and policymakers to determine future research needs. For example, when an indicator-theme is deemed highly relevant by the experts but is not yet been monitored in practice, this could indicate an existing research gap. Future research opportunities can be defined accordingly.

Lastly, a heterogeneity analysis was conducted on the results of the second Delphi round to assess whether stakeholders' responses differed based on their background. The results of this are included in appendix A2.III, but should be interpreted with some caution due to the small sample size.

C. Visual overview of reference framework for CE in the food system

Figure 9 gives a visual overview of the key concepts discussed in sections 3.1.

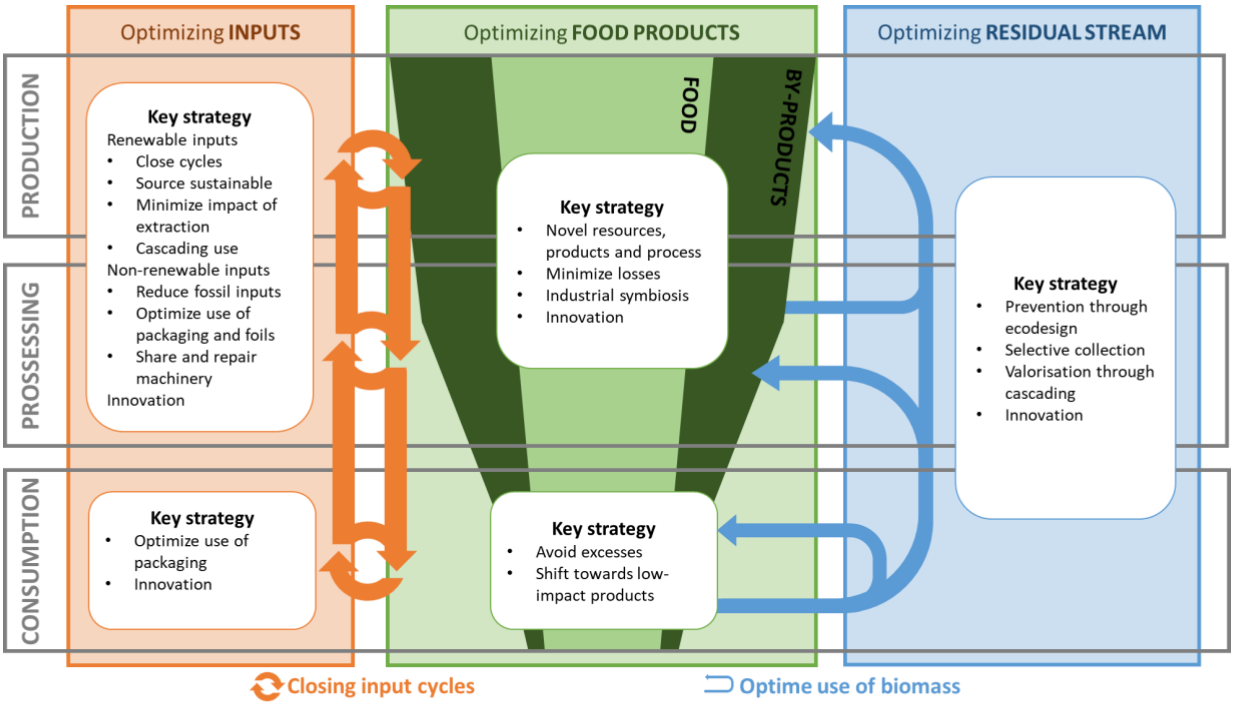

Figure 9 – Schematic overview of CE for the food system
(source: own creation)

3.2 Available data

This section discusses the most suitable data found for CE monitoring of the food system in Flanders. This selection is non-exhaustive, in the sense that not all data encountered will be explicitly dealt with in a high level of detail and that more data may be found in case of additional research. The focus of this section will be on the major insights and decisions along the process of collecting and evaluating data for use in terms of CE monitoring. References to the related background reports are given for readers looking for more detailed information. It should be stressed that it was not within the scope of this study to create new data gathering processes or new indicators, instead already existing data, from different monitoring purposes, are brought together and reframed within the context of CE.

Figure 10 gives an overview of how the different indicators discussed are grouped. The first set of indicators concerns the material cycles of the main inputs required for production, looking at the use and loss of inputs from and to the environment. Here the focus of the monitor is currently on primary production. Processing should be included in follow-up studies, as the developed framework does permit these indicators to be added. The second set of indicators relate to optimizing the use of food products, where first the final impact of consumption is disclosed, after which it is examined how this is influenced by our consumption patterns. The third set of indicators discusses the origin, collection, and valorisation of the residual streams throughout the entire food chain, differentiating between organic and inorganic streams. Lastly, interesting innovation cases are touched upon throughout the report.

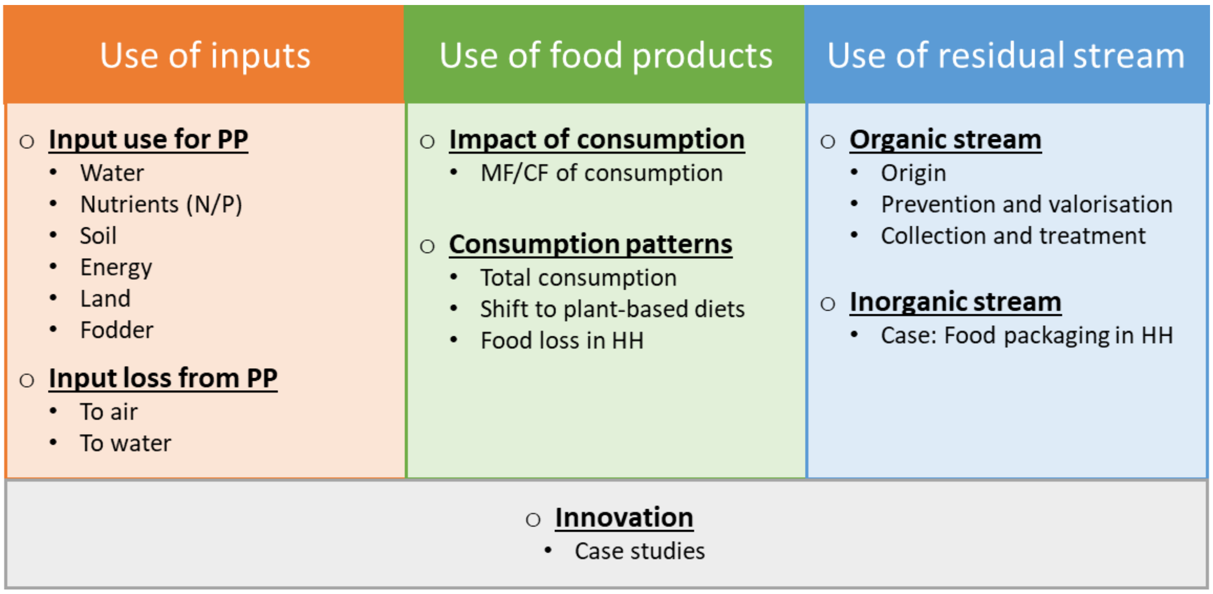

Figure 10 – Overview of currently available indicators for the food system
(PP: primary production - MF: material footprint – CF: carbon footprint – HH: households)

A. Use of inputs for production

This section looks at the main inputs required for primary production in Flanders. Over the years the agricultural sector in Flanders has evolved towards a specialised, intensive agricultural system, with 89% of farms in Flanders categorised as specialised holdings[5] in 2019 (Departement Landbouw en Visserij, 2021a). This specialisation has allowed farmers to achieve very high productivity, but also increased their dependency on outside inputs. A CE would like to change this through optimising the use of the various inputs. In first instance, this would entail attempting to reduce the total amount of inputs required, as this eliminates the efforts needed to gather these inputs, as well as reduces the adverse effects of input extraction and use on the environment. Secondly, as it is impossible to reduce the input requirement in the food system to zero it is important in a CE that the required inputs are sustainably sourced, reused where possible (cascading), and returned to sustain natural cycles (see figure 4).

Water

Water is an essential input throughout the primary sector, mainly for the irrigation of crops and watering of livestock. However, as the recent dry summers demonstrated, sufficient access to water cannot always be guaranteed to the sector. Water availability is a complex balance between inflows (from precipitation, rivers, etc.), outflows (due to evaporation, irrigation, etc.) and stocks (like lakes or groundwater reserves). Mainly due to Flanders' high population density and lack of large rivers, water is scarce. With about 1500 m^3/cap/year of water available, the region of Flanders has amongst the lowest water availability of OECD countries (Peeters, 2013). Further, the effects of climate change are expected to lead to more extreme fluctuations in water availability (VMM, 2021). All this makes efficient water use throughout Flanders crucial.

The water use in the primary sector in Flanders is monitored and reported on by the Department of Agriculture and Fisheries. This is done through an extrapolation of survey data collected from a representative sample of agricultural holdings. Figure 11 shows the evolution of water use in the agricultural sector[6], revealing an increasing trend in water use. Year to year variations can be explained by the specific weather circumstances between years. For example, the effect of the dry summers of 2018 is reflected in the higher water demand for this year. Water availability typically fluctuates with the seasons and when water demand from the agricultural sector is highest, the availability of water is typically the lowest. The primary sector is hence particularly vulnerable to the increasing water scarcity in Flanders. Historically, groundwater was a reliable and high-quality water source available to farmers year-round. In 2018, the agricultural sector accounted for 10% of the water use (excl. cooling water) in Flanders, but was with 53% by far the largest user of groundwater (VMM, 2021). However, as this water source is very slow to replenish itself, care should be given to avoid depletion. The renewability of the water source is important in a CE to ensure continued availability and prevent the environmental impacts of disruptions in the hydrological cycle. Figure 11 gives the different sources of the water used in the agricultural sector. In 2018, the

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[5] Specialization is determined by looking at what proportion of the total standard output is obtained from a particular cultivation. Roughly speaking, a holding is specialized if it gets at least 2/3 of its total output from a certain cultivation

[6] The direct water use of rain on fields is not included

largest source of water was deep groundwater (44%), followed by rainwater (23%). The Flemish department of Agriculture and Fisheries defined an indicator for 'sustainable water use' as the sum of all rainwater, 80% of surface water, and 50% of superficial groundwater, divided by total water use. The percentage of sustainable water use is shown by the line in figure 11. This percentage was increasing between 2013-2017, meaning that sustainable water use had been increasing relatively faster than the increase in total water use. In 2018, there is a noticeable decrease due to an increase in deep groundwater use and decrease in rainwater use, which was likely caused by the very dry summer.

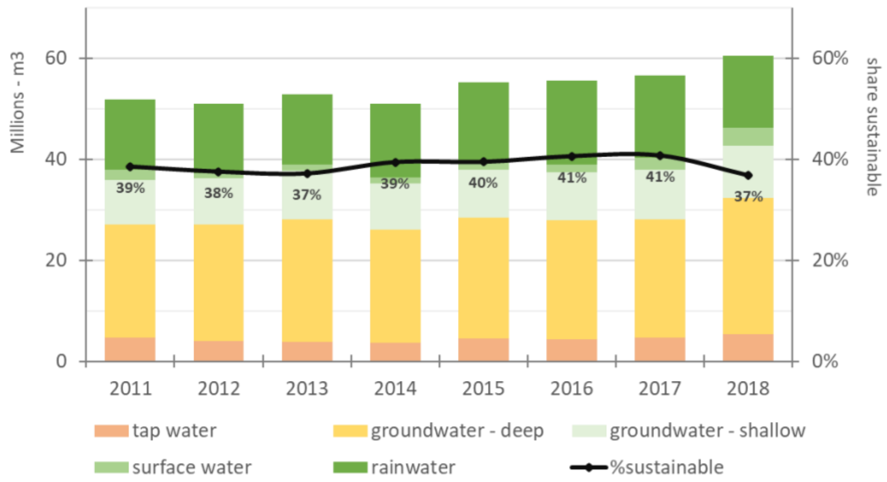

Figure 11 – Evolution of the water use in the agricultural sector, Flanders, 2011-2018
(source: Departement Landbouw en Visserij (Departement Landbouw en Visserij, 2021b)*)*

Ambiguity exists on the amount of water that is used by the primary sector. In 2018 the Department of Agriculture and Fisheries estimated that around 61 million m^3 water was used, of which 37 million m^3 was groundwater, while the VMM estimated that around 74 million m^3 water was used, of which 55 million m^3 was groundwater. This discrepancy is due to differences in calculation methods, which are being worked on by both organisations.

Overall, between 2011 and 2018, total water use increased with 17%, while total sustainable water use increased with only 11%. This means that, considering the CEs dual objective for optimizing inputs of decreasing total use and increasing the renewable share, water use in agriculture is currently not becoming more circular. The primary sector is actively working on addressing this by attempting to further increase the efficiency of water use. The best strategies to achieve this vary across the different sectors of primary production. For example, for cultivation in open air, improvements in irrigation can provide large gains (e.g., level-controlled irrigation), while for cultivation under glass more is possible in terms of water capture and reuse. Further, shifting to crops with a lower water demand through novel cultivations or novel varieties can reduce input requirement. To provide guidance at the level of individual farms the Department of Agriculture and Fisheries offers a water scan to farmers, mapping their water availability and water need to reveal inefficiencies and opportunities. The VLIF, or Flemish agricultural investment fund, also offers subsidies to increase the capture and reuse of water.

Fertilizer use

During agricultural production fertilizers are an indispensable input to optimizing yields. A whole range of minerals are added through fertilizers, of which nitrogen (N) and phosphorus (P) are the most used. In a CE, an efficient use of fertilizers is the main goal, meaning no more than required is used. This minimises total input requirement and subsequently also the adverse effects associated with input generation or loss thereof to the environment. Further, in a CE, fertilizers are obtained from renewable sources through closing nutrient cycles. In this section use and origin of N and P fertilizers are discussed, while section 3.2.B discusses the loss of these minerals to the environment and associated effects. Readers looking for a thorough analysis on fertilizers are referred to the yearly manure report ('het mestrapport') published by the Flemish government (VLM), which outlines the flow of N and P and the associated impacts in detail (VLM, 2021).

In Flanders three main categories of fertilizers are reported: animal manure, organic fertilizers[7], and synthetic fertilizers. Figure 12 shows the yearly use for each category of fertilizer with regard to (a) nitrogen and (b) phosphorus. In 2019, the total use of N fertilizers came to 147 kton and the total use of P fertilizers to 43 kton in Flanders. The total use of N fertilizer has remained approximately the same compared to 2011, while the use of P fertilizers shows a decreasing trend. This decrease for P can be explained by the increasing strictness of the norm set for P-use by the government.

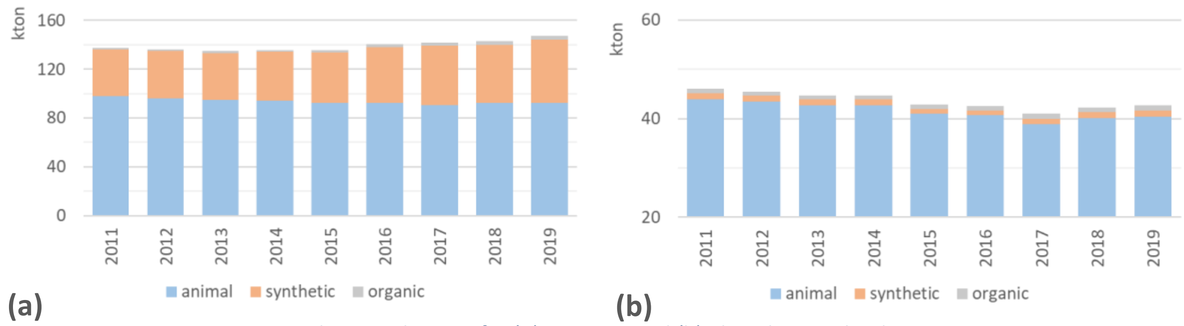

Figure 12 – Fertilizer use by type for (a) nitrogen and (b) phosphorus, Flanders, 2010-2019 (source: VMM – yearly manure reports (VLM, 2021)*)*

As the type of fertilizer used matters, each of the three types is discussed separately. Firstly, Figure 12 reveals that **animal manure** is the main source of N and P fertilizers in Flanders. Animal manure is available as a waste product from livestock breeding in Flanders, making it a locally available renewable input. The amount and quality of manure available in Flanders is determined by the number and type of animals, their feed, and type of stabling. Figure 13 shows the ratio between the manure produced by the livestock sector in Flanders and the use of animal manure within Flanders. In 2019 this ratio was 147% for N and 137% for P, indicating more manure is produced within Flanders than is used. Or put differently, only 73% of N and 68% of P generated by livestock in Flanders was reused within Flanders in 2019. The excess manure is further processed to fertilizers and exported. This is because more manure is generated than is needed, or is allowed to be used, on fields in Flanders (VLM, 2021). The VLM calculates the gap between the amount of N and P generated from manure and the maximum allowed use on fields according to the regulations. In 2019 the livestock sector in Flanders produced 127 kton N and 59 kton P_2O_5 from animal manure, while only 118 kton N and 47

[7] Organic fertilizer are those natural fertilizer which do not originate from animals, like compost.

kton P_2O_5 could be used according to regulations, revealing that there is a theoretical surplus of animal fertilizers. The actual gap is even bigger, as it is not needed to use the maximum allowed amount of animal manure everywhere. In Flanders only 92,4 kton N and 40,4 kton P from animal manure was used in 2019.

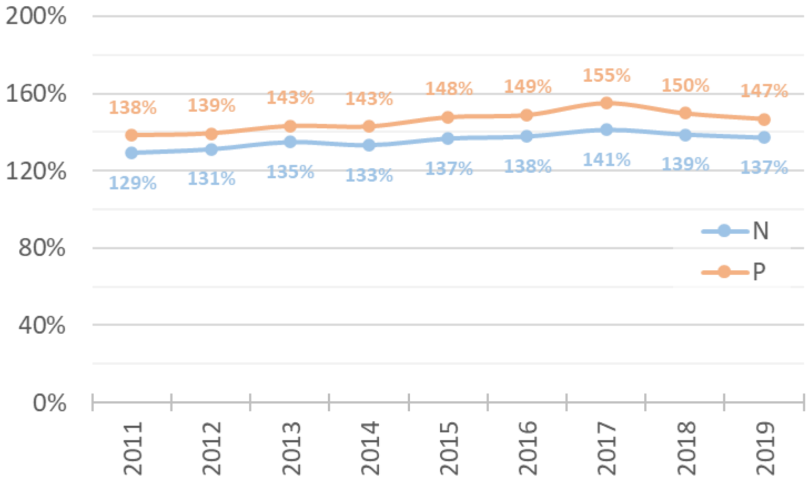

Figure 13 – Evolution of production/use ratio for animal manure generated in Flanders used in Flanders, 2010-2019 (source: VMM – yearly manure reports (VLM, 2021)*)*

Secondly, figure 12 further reveals that for N a significant fraction still comes from **synthetic fertilizers**. The data from VMM shows an increase in the use of synthetic N since 2007, from 36,8 to 52,0 kton N in 2019. The main reason for the use of synthetic N is that the norm on the use of P is the restricting factor in the use of animal manure. The N/P ratio in animal manure is lower than desired and not all N in manure can be used by crops, thus synthetic N fertilizer is used to supplement. The composition of synthetic fertilizers is also more accurate and consistent than that of animal manure, making application easier for farmers. However, the generation of synthetic N fertilizers is a very energy intensive chemical process. The P in synthetic fertilizers is not actually synthetic, as they are not created through a chemical process, instead P is mined from phosphate rock, which is a finite resource. P is considered a critical resource for the EU, and hence Flanders, thus the less virgin P input required the better. As show in figure 12 the direct use of virgin P is relatively low in Flanders.

There is some ambiguity over the exact amount of synthetic fertilizer used in Flanders. The numbers given above are those calculated by VLM, however the department of Agriculture and Fisheries also calculates an estimate of synthetic fertilizer use, by extrapolating their own survey data. For 2018, the department of Agriculture and Fisheries estimated 80 kton synthetic N and 2,1 kton P, while VLM estimated 48 kton synthetic N and 1,1 kton P. While the absolute numbers between the two sources do not match, the general trends found in the numbers do match. The numbers reported by VLM are suspected to be an underestimation of the actual use of synthetic fertilizer as during audits of agricultural holdings by VLM a common finding is the underreporting of synthetic fertilizer use (VLM, 2021). To improve monitoring, VLM is in the process of launching a new digital system to track synthetic fertilizer use.

Lastly, the use of **organic fertilizer** in Flanders is currently limited to 2,9 kton N and 0,98 kton P, or 1,9% of total use of N and 2,3 % of P in 2019. The processing of organic waste to organic fertilizers – e.g., through composting – has the potential to further close nutrient cycles within Flanders, bringing them from companies and consumers back to fields. In terms of CE, it is positive to see that the use of organic fertilizers in agriculture is increasing, both in absolute numbers as in relative share. Yet, there is still quite some potential to further increase the use of organic fertilizers in agriculture. Currently, the output from composting, compost, is mainly used for other purposes, with only 12% of compost generated in Flanders going towards the agricultural sector, representing about 19% of organic fertilizer use (Vlaco, 2019; VLM, 2021).

Overall, between 2011 and 2019, total fertiliser use increased with 7% for N and decreased with 7% for P, while the use of synthetic fertilizer increased with 36% for N and remained stable for P. This means that, considering the CEs dual objective for inputs of decreasing total use and increasing the sustainable share, fertilizer use in primary production is not meeting either objective for N, while use of P is evolving in the right direction. To gain more insight into the opportunities to improve the circularity of N and P use in the food system the flow of these nutrients should be mapped. The government (department Omgeving) and ILVO are currently collaborating on this. Further, Papangelou & Mathijs, (2021) put together the nutrient flow for N, P and K for respectively Flanders and Wallonia for 2014. The study reveals for instance that the N an P in animal manure originates to a large extend from imported animal feeds and the direct production of feed crops in Flanders. This while N and P leaves the food system in waste products from food processing, consumption, as exports or is lost to the environment. Through looking at nutrient flows, connections between different inputs like fertilizers, animal feed and soils become apparent. The research by Papangelou & Mathijs, (2021) puts forth a number of potential circularity indicators, which could be considered in future to improve upon the current indicators on N and P in the monitor.

Numerous initiatives are ongoing to change and improve current fertilizer use in the primary sector. Reducing total fertilizer use, while maintaining yields, could be obtained through building farmer knowhow and through the implementation of new technologies, like the use of drones. Both knowhow and technologies help ensure that fertilizers are only applied when and where needed. The total use of fertilizes could be reduced through smart crop rotations or combinations using legumes to fix nitrogen in soils either as cover crop (e.g., clover) or as main cultivation (e.g., beans). To decrease the use of synthetic N and novel P, and increase the circularity of N and P use, the industry is looking at enhancing nutrient recovery from animal manure, sewage water and the residual food stream. Especially enhanced processing of animal manure to create a product equivalent to synthetic manure is being developed. Under the term 'RENURE', or 'recovered nitrogen from manure', the final barriers both at the European and Flemish level are being worked out. A key obstacle is that these products are currently considered as animal manure and are hence regulated as such (under the European nitrate directive). The market value of RENURE is expected to increase if it is recognised as equivalent to synthetic fertilizers, which can then be the required push to increase the interest in nutrient recovery. The research by Papangelou & Mathijs, (2021) also demonstrates that the two other avenues for nutrient recovery, sewage water and the residual food stream from food processing, should not be overlooked. 'Nutricycle Vlaanderen' was created to provide a Flemish platform where the stakeholders involved could consult each other and exchange information. In 2020 specific working groups on improving nutrient recovery from manure, waste streams from food processing and sewage water were launched. It can be noted that the reuse of wastewater treatment products, for example treated sewage sludge, is currently prohibited by law in Flanders.

Soil

The quality of the soil determines its suitability for production and sequentially what yields can be obtained. Soil quality is determined by an array of factors, from the physical structure to the chemical balance and biological composition. Mismanaged soils can degrade, losing their fertility. At the moment little is reported about the general health of agricultural soils in Flanders, with mainly data on soil nutrients being available. Yet, due to their intensive use, soil quality of agricultural land is thought to be decreasing (Bardgett & Van Wensem, 2020). In Flanders a large fraction of agricultural soils fall under a tenure system, the resulting absence of long-term stewardship was found to be adverse to maintaining soil quality (Bardgett & Van Wensem, 2020). It is however crucial to keep soils healthy, not only to maintain food production but also to ensure the continuation of various ecosystem services provided by soils. Soils are a natural filter for water, store carbon, degrade waste, detoxify compounds and provide habitats for microbes, animals and plants (Bardgett & Van Wensem, 2020; ILVO, n.d.). Indicators on the chemical, physical and biological state of agricultural soils in Flanders are needed to evaluate their health, determine the best use, monitor trends and to track the effects of specific policies.

The 'Bodemkundige Dienst' of Belgium (BDB) keeps track of the chemical and physical state of soils in Flanders. The BDB reports on eight key soil fertility parameters for agricultural cropland and agricultural grassland. As measurements can vary strongly from year to year, values are reported in time periods of 3 to 4-years. The data discussed in this section is for Belgium, as the data for the geographical zone of Flanders was not readily available. However, if deemed desirable this could be obtained in the future. The BDB reports on the percentage of soils below, within or above the target zone for each parameter. The target zone is the optimal condition for that parameter, representing the range in which most crops can grow (Tits et al., 2020). The target zones are determined specifically for each individual sample, depending on the texture class and the organic matter content.

The BDB looks at seven soil nutrients which play varying roles in crop growth, as well as the acidity of soils (pH), as this determines the availability of nutrients and to what extent they can be absorbed. In the period 2015-2019 resp. 33% and 34% of crop- and grassland are within their target zone for acidity (pH), resp. 39% and 31% for organic-carbon (SOC), resp. 17% and 21% for phosphorus (P), resp. 39% and 29% for potassium (K), resp. 28% and 25% for magnesium (Mg), resp. 53% and 53% for calcium (Ca), resp. 9% and 16% for sodium (Na), and resp. 22% and 23% for sulphur (S). It is important to note that if a soil sample is in the target zone for one parameter, it is not necessarily for other parameters. For example, only 2% of cropland samples and 3% of grassland samples are in the target zone for both pH, SOC, and phosphorus (Tits et al., 2020). The evolution for five of the eight parameters is given in figure 14. The data on the evolution of Ca, Na and S was not readily available. Notable in figure 14 is the high percentage of soils with a low SOC and the high percentage of soils with a high content of P, K or Mg. All this gives at an aggregated level a view of the state of agricultural soils in Belgium and what is required to bring them into optimal condition. It further provides fertilisation recommendations needed to optimize the use of these inputs.

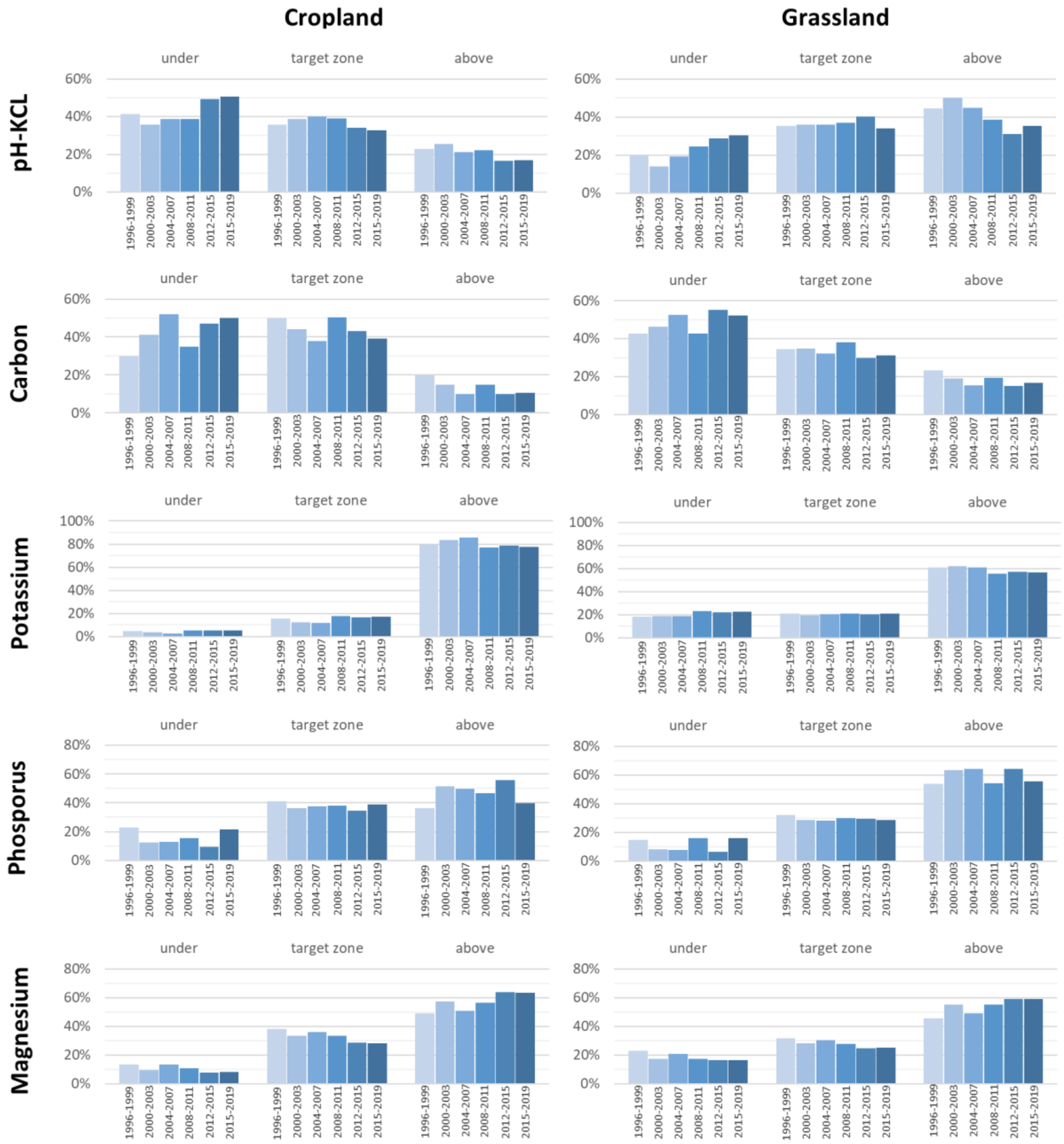

Figure 14 – Evolution of share of soils below, within or above target zone for five soil parameters on agricultural land, 1996-2019, Belgium
(source: Tits et al., (2020)*)*

However, soil health is more than nutrient availability, hence further data is needed, for example on soil structure (soil compaction) or soil biodiversity. It can be noted that the government in cooperation with ILVO (Flanders Research Institute for Agriculture, Fisheries, and Food) is currently in the process of building a monitoring network to track the quality of agricultural soils in Flanders (ILVO, 2018). This should initiate a more structured monitoring of soil health in Flanders. Even with proper monitoring and policies in place, some time will need to pass before any improvements become visible as soils are slow to react to new management systems. This makes the effect of policies on soil quality difficult to track. For more real-time data the ongoing 'efforts towards' soil improvement can be monitored, like the agricultural area under specific management systems (Bardgett & Van Wensem, 2020).

This section so far discuses soils on fields, some primary production however uses substrates, like peat and rockwool, mainly for horticulture under glass. The use of these substrates has a substantial environmental impact, with the extraction of peat releasing carbon and damaging ecosystem, and the production of rockwool being energy intensive. Hence the use of these substrates should be limited. Research into alternative substrates is ongoing (e.g., Interreg Horti-BlueC), with renewable resources like biochar and chitin emerging as promising candidates in terms of CE. Biochar can be made from organic residual materials - such as wood fibre or flax- which undergoes a heating process in the absence of oxygen (pyrolysis). Chitin is a polymer which can be extracted from the shell of crustaceans, which is for example available as a waste stream from shrimp production. There is also an increasing interest in non-soil bound production systems, like hydroponics.

Energy

To run an agricultural holding there is also an energy requirement, for example to run machinery or generate heat or cooling. With the CE's aim to minimize material input and the finite supply of fossil fuels in mind, it is worth looking at the energy use and energy mix of primary production in Flanders. In 2018, the agricultural sector accounted for only 2% of the energy demand in Flanders (VMM, 2021). The energy use within the primary sector in Flanders is tracked and reported by the Department of Agriculture and Fisheries. This is done through an extrapolation of survey data collected from a representative sample of agricultural holdings in Flanders. Figure 15 gives the yearly energy usage per fuel type for the agricultural sector. Fluctuations in yearly use are in part due to the specific weather circumstances, but there seems to be an upward trend. It can be noted that this trend is less pronounced when considering only net use, as the sector puts increasingly more energy on the grid. Through this the primary sector aids in keeping the grid balanced. It can be noted that there are large differences in the energy-use between agricultural sectors, with cultivation under glass easily accounting for the largest share (42%). With regard to the energy mix, natural gas is the main energy carrier used. The use of natural gas increased due to policies encouraging the use of cogeneration installations, which can provide energy, heat and CO_2 to cultivators under glass. By generating both simultaneously, fuel efficiency is improved, with the additional benefits of allowing flexible deployment and emitting less CO_2 and soot compared to other fossil fuels. Cogeneration installations are the main source of the energy the agricultural sector puts back on the grid. Further, figure 15 shows an increase in the use of biomass in the agricultural sector, from 2.362 TJ in 2011 to 2.991 TJ in 2018. While biomass is in principle a renewable resource, biomass should only be used for energy if no higher valorisation can be found in accordance with the cascade (see Figure 6). On farms pocket digesters are used to generate biogas from manure, also generating digestate which can be used as a fertilizer. Even though biogas can be used as an alternative to natural gas to cover the fuel demand, mainly for the cogeneration installations in greenhouses, the long-term goals should be to decrease the total energy need and to increase the share of renewable energy from solar and wind. Currently, there is no data available on the use of renewable energy from solar or wind in the sector.

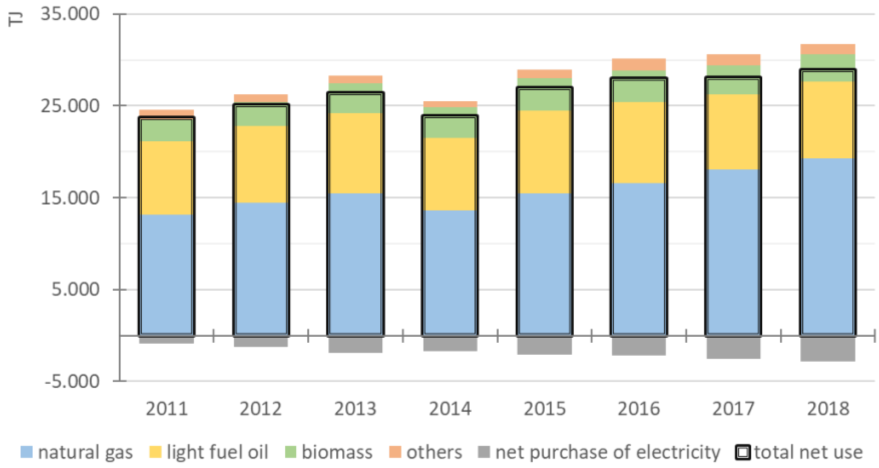

Figure 15 – Evolution of energy use in the agricultural sector, Flanders, 2011-2018
(source: Departement Landbouw en Visserij (Departement Landbouw en Visserij, 2021b)*)*

Overall, between 2011 and 2018, total net energy use increased with 22%, while the share of renewable energy is unknown. This means that, considering the CEs dual objective for optimizing inputs of decreasing total use and increasing the sustainable share, energy use in agriculture is not meeting the first objective and any progress towards the second objective is unknown. Hence further progress should be made towards increasing energy efficiency. One important tool for this is the VLIF, which provides multiple subsidies aimed at improving the energy efficiency of the sector. Further, the online platform 'Enerpedia' provides custom solutions for the energy related questions of producers. Opportunities to use the residual waste from companies, within or outside the food system, should also be optimally valorised.

Land use

Sufficient agricultural land is a vital input for primary production. However, land is used for multiple competing purposes. In Flanders there is a high pressure on land, mainly due to the high population density and sprawling residential land use. This can make it difficult for farmers to obtain sufficient space at economically competitive prices. In 2013 a first monitoring of land-use in Flanders was set-up, which is updated every three years (Poelmans et al., 2021). The spatial divide of Flanders in 2013 and 2019 is shown in figure 16, revealing that the agricultural sector uses about half of the available land. It is difficult to make decisive judgements on what percentage of the available land should go to what purpose. However, the percentages shown in figure 16 should be minded to minimize the adverse effects of LULUCF. Between 2013 and 2019 the total sealed surface in Flanders continued to increase with about 11.000 ha, further shrinking the remaining 'open space' (Poelmans et al., 2021). Within the open space of Flanders, there was a notable shift in land use of about 10.000 ha from grassland to cropland. More detail on the changes in land-use between 2013 and 2019 is given in appendix A3.

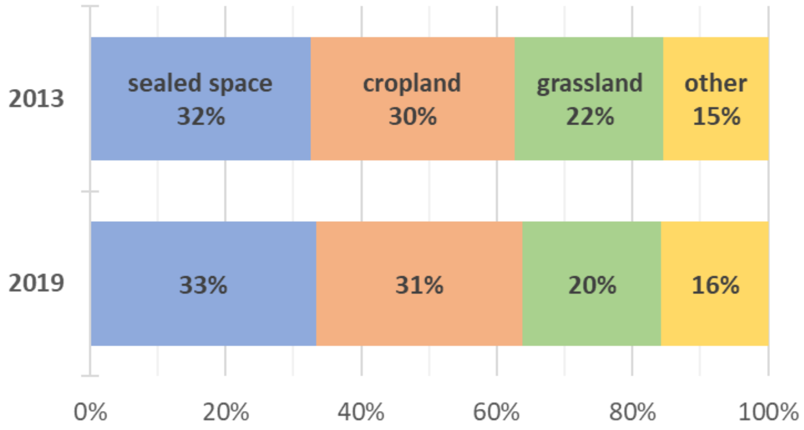

Figure 16 – Evolution of spatial divide, Flanders, 2013 and 2019
(source: VITO commissioned by the department of Omgeving (Poelmans et al., 2021))

The data above provides a general picture of the changes in land-use in Flanders. The numbers are based on macro data about the principal use of land in the spatial plans of Flanders. The Department of Agriculture and Fisheries keeps track of land-use in the agricultural sector in more detail. Figure 17 shows the use of agricultural land in Flanders, revealing that the total amount of available area has remained stable and that land is mostly used for food and feed production (Departement Landbouw en Visserij, 2021b). It can be noted that the before mentioned shift from grassland to cropland is not visible in this data. More than half of agricultural land is used for animal feed, mainly grassland (36%) and maize (20%). With the CE's aim to optimally use inputs it can be reasoned that direct production of animal feeds should be minimized, instead using land for food production, or when this need is met for other biomass applications that could replace fossil inputs, or be reconverted to nature. In this scenario animals are solely fed with residual biomass streams. While an argument can be made in favour of using low productivity land as grasslands for grazing, which can serve as a carbon stock and maintain unique ecosystems, the current fraction of land used for maize seems questionably high in terms of CE. Note however, that it can be assumed that efficient feed production in Flanders can be preferred over long-distance imports of feed for animal farms. The use of animal feed is further discussed in the next indicator section.

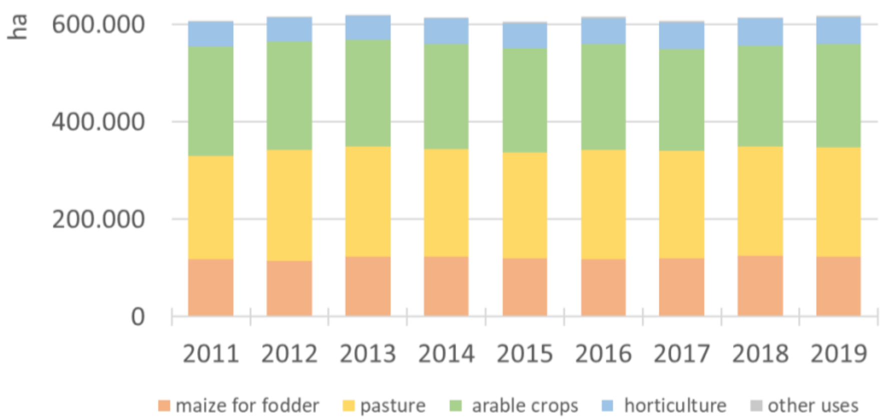

Figure 17 – Evolution in the use of agricultural land, Flanders, 2011-2019
(source: Departement Landbouw en Visserij (Departement Landbouw en Visserij, 2021b)*)*

Aside from assessing what is produced on the available agricultural land, it is also necessary to consider which production system is used. Broadly speaking, agricultural production can range from very intensive to very extensive. The circularity depends on the systems specific parameters, meaning that the focus in circular intensive agriculture can be different from the focus in circular extensive agriculture. Production in Flanders should be organised in such a way that the type of production in an area makes sense for that specific area, to optimally reuse residual streams and minimize environmental impacts. This could for example mean that when agricultural production is close to valuable nature reserves the focus is on more extensive agriculture. In other areas more intensive forms of agriculture should exist to ensure sufficient food production, but with still a strong focus on minimizing input use and loss as not to go beyond the natural ecological limits. At the moment no methodology exists to assess if agriculture production methods are optimally located. Only for livestock breeding some location bound criteria exist to decrease the pressure on valuable nature reserves under the nitrogen policy plan (PAS) (Vlaamse Regering, 2016a).

Animal feed

Animal feed is an indispensable input for the livestock sector. How much and what type of animal feed is required is determined by the size and composition of this sector. As with the previous inputs again total use and the origin of the input play a key role in determining the circularity. Traditionally the demand for animal feed was met with the residual streams generated during the production and processing of human food. However, as the consumption of animal-based products increased the available residual stream proved unable to meet the demand, both in quantity and quality. The compositions of animal feed today are specifically tailored to the needs of the animal in question. As a consequence, the production of crops grown specifically for animal feeds has increased. Today, a significant share of agricultural land is used specifically for providing feed and hence not used for the production of plant-based biomass for human consumption, or alternatively returned to natural habitats. Figure 17 demonstrates that a significant fraction (57%) of agricultural land in Flanders is used for feed purposes, where especially the high-productivity land used for maize production for animal feed is in direct competition with food production. Aside from this, a significant fraction of animal feed is imported from abroad, as demonstrated by the N and P flow in Papangelou & Mathijs, (2021). The use of cereals for animal feed is reflected in the composition of compound feed for animals. In 2018 cereals were with 45% the largest fraction of the raw materials used for compound feed in Belgium, of which about 25% were classified as residues (BFA, 2019). In 2018, 44% of the raw materials used to produce compound feed in Belgium is sourced from residues. The largest fraction of residues comes from oil-bearing seeds (48%), like soy. Figure 18 gives the evolution in the share of residual materials used for the production of compound feed in Belgium. It is the aim if BFA to raise the share of residual materials to 50% by 2030.

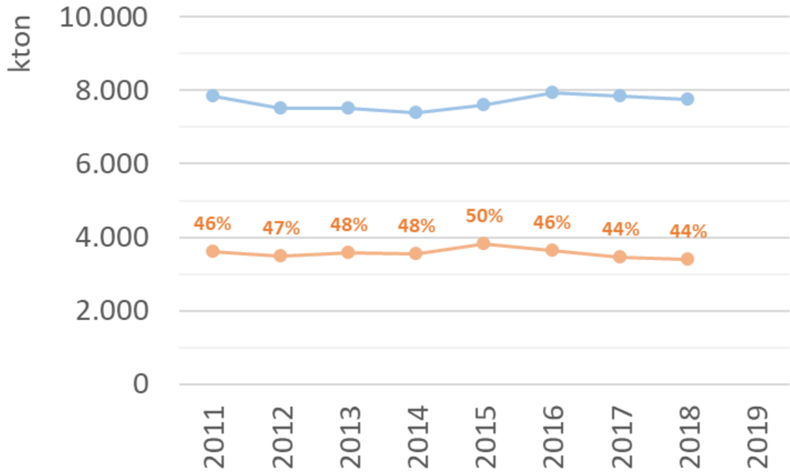

Figure 18 – evolution in the total use of raw materials for compound feed production (blue line) and share of residual materials (orange line), 2011-2019, Belgium
(source: BFA – yearly reports)

Thus, where historically animal-based products were produced in function of the residual stream from plant-based products, it seems that the balance in the current system has tilted to production of plant-based products in function of animal-based products. In a circular system the amount of animal production, and consequently consumption, should be based on the availability of residues from plant-production and local need for manure (De Boer & Van Ittersum, 2018). The availability of residuals for animal feed depends on (1) the type of food crops cultivated, which is determined by the human diet, (2) the amount of food waste, which is to be in first instance avoided altogether, and (3) competition with other functions for biomass, such as improving soil quality or production of pet food (Van Zanten et al., 2019).

The total feed requirement can be decreased through an increase in feed conversion, which is the efficiency by which feed is converted to bodyweight. For pigs this was decreased from 2,8 in 2005 and 2,7 in 2018 and for poultry from 1,66 in 2013 to 1,63 in 2018 (Departement Landbouw en Visserij, 2021b). Improvements were for example achieved through tailoring the animal feed to the life stage of the animal. Shifting the composition of animal feed toward residual materials is likely to reduce the benefits of using tailored feeds to reduce emissions from livestock production (Van Zanten et al., 2019). New feed sources, like insects and algae, can provide opportunities, as the production can be more input efficient. However, there are also possibilities to directly valorise these streams for human consumption. The EU has also recently relaxed restrictions on the use of processed animal protein (animal meal) sightly, allowing to feed non-ruminants with animal meal from ruminants (European Commission, 2021).

B. Losses of inputs from production to the environment

This section gives an overview on the loss of inputs from primary production to the environment for the most relevant flows. The CE attempts to close material circles as much as possible, this not only reduces the need for new inputs, but also prevents the environmental damage from undesired leakages to the environment. As stated in the introduction, CE is meant as a tool to minimize the material input as well as the adverse impacts of the economy on the environment. However, as it is impossible to perfectly close all cycles and hence losses will occur, the size of cycles should also be questioned in relation to their associated (unavoidable) losses and the carrying capacity of the ecosystem. This section first describes the losses of inputs to air and then to water.

Losses to the air

Losses from agriculture to the air contribute to two environmental challenges: global warming and acidification.

Emissions of greenhouse gasses (GHGs) from agriculture contribute to global warming and therefore climate change. The agricultural sector accounted in 2018 for roughly 10% of the GHG emissions in Flanders, which translates to 7.497 kton CO_2-eq[8] (VMM, 2021). Figure 19a shows that the total CO_2-eq emissions from the agricultural sector have been fluctuating around 7.000 kton CO_2-eq. The agricultural sector is unique in Flanders in the sense that most of its emissions come from non-energy related processes, with half of the CO_2-eq emissions coming from methane (CH_4). Only 26% of CO_2-eq emission are energy related in 2018 (Departement Landbouw en Visserij, 2021b). Most GHG emissions are related to livestock breeding (62%). Figure 19b, gives the activity responsible for the GHG emissions.

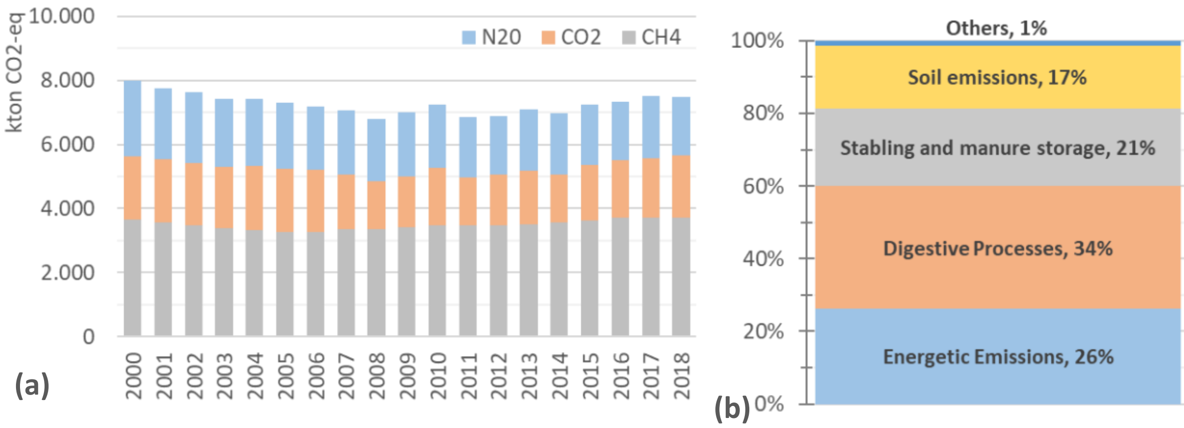

Figure 19 – Evolution of GHG emissions by the primary production by (a) type and (b) source in 2018, Flanders, 2000-2018 (source: VMM (VMM, 2020b)*)*

As figure 19 shows, methane is responsible for about half of the CO_2-eq emissions of the agricultural sector. In Flanders 205 kton methane was emitted in 2018, of which 75% originated from the agricultural sector (VMM, 2020a). Within agriculture, 94% of methane emissions come from livestock breeding. Further, the main share of methane emissions (70%) come from one source: enteric fermentation. This is the methane released by cattle during digestion. The remaining 30% of methane emissions come from manure storage. The second largest source of GHG emissions comes from CO_2, which are mainly energy related emissions. It can be noted that the energy related emissions also include any emissions from energy generation by the primary sector for the grid, shown in figure 15. Lastly, the N_2O emissions from agriculture are mainly cause by the use and storage of fertilizers on fields.

Targets for the reduction of GHG emissions have already been set in the Flemish climate plan. The primary sector will need to decrease GHG emissions with 26% by 2030 compared to 2005. To accelerate the progress on reducing enteric fermentation a specific covenant was created in 2019. The aim of the covenant is to reduce the emissions from enteric fermentation to 1900

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[8] CO_2-eq is a measure taking together the various GHGs, accounting for each gas's global warming potential (GWP). For CH_4 this is a factor 25 and N_2O it is 298.

kton CO_2-eq by 2030 (Departement Landbouw en Visserij, 2019). To achieve this the covenant looks at improving livestock management at farm level, feed management and genetics.

Emissions of ammonia (NH_3), nitrogen oxides (NO_x), and sulphur dioxide (SO_2) into the environment cause acidification, leading amongst others to the degradation of ecosystems. In 2019, the critical threshold for acidification was exceeded on 17% of the area of nature in Flanders (VMM, 2021). While this problem is transboundary, with a large share of nitrogen deposition originating from outside of Flanders, within Flanders the agricultural sector was, with an estimated 49%, responsible for the largest share of potentially acidifying emissions in 2018 (VMM, 2021). The potential effect of the acidifying emissions is reported by converting the acidifying potential of each pollutant to an acid equivalent (Zeq). Figure 20 shows the evolution of potentially acidifying emissions in the agricultural sector by type (a) and the origin (b).

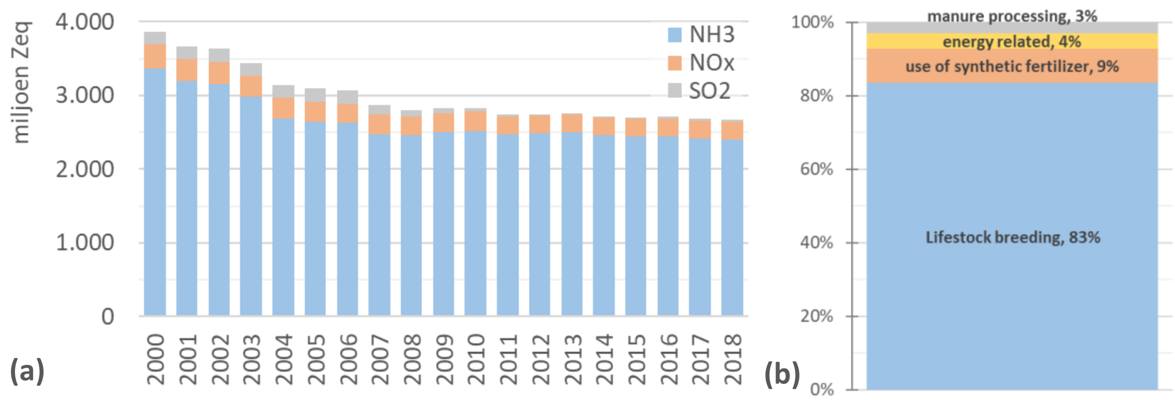

Figure 20 – Evolution of acidifying emissions from primary production by (a) type and (b) source in 2018 , Flanders, 2000-2018
(source: MIRA based on VMM (VMM, 2020b)*)*

As figure 20 shows, ammonia is the main source of acidifying emissions in the agricultural sector (90% in 2018). The agricultural sector was in 2018 responsible for about 95% of ammonia emissions in Flanders (VMM, 2020a), further 86% of all ammonia emissions are related to animal manure (VMM, 2020b). The primary sector is working on reducing their acidifying emissions. A Nitrogen policy plan (PAS) is under development by the Flemish government. Further, because most acidifying emissions occur during stabling and manure storage, it is mandatory since 2003 for all new stables to be low-emission stables. By 2018 this is estimated to have reduced ammonia emissions with 12% (VMM, 2020b).

Losses to water

Human activities cause an excess of nutrients to be released into the environment, mainly of nitrogen (N) and phosphorus (P). This excess disrupts natural ecosystems, causing species with low nutrient requirements to disappear. In 2019, the critical threshold for nutrient deposition was exceeded on 80% of the area for nature in Flanders (VMM, 2021). The agricultural sector was, with 50%, estimated to be responsible for the largest share of nutrient deposition in 2018 (VMM, 2021). Nutrient deposition from agricultural activities occurs for example through the precipitation of nitrogen oxides (NO_x) and ammonia (NH_3) emissions or run-off of fertilizers from fields. An excess of nutrients in water leads to eutrophication, disrupting the ecosystem and adversely effecting drinking water. Further, valuable nutrients, in particular phosphorus, are lost. To monitor the contribution of agriculture in Flanders on water quality the MAP-measuring network was set-up by the Flemish environmental agency (VMM) in 1999 with 260 measuring points and expanded in 2002 to 760 points. At these points the N and P concentrations in surface water are measured. The evaluation happens for each 'winter year', Which runs from 1 of July to the 30 of June (Vlaamse Milieumaatschappij (VMM), 2020).

Nitrogen in surface water is shown in figure 21, the evolution of the average concentration is given and the percentage of measuring points where the set threshold value (50 mg NO_3/l) was exceeded at least once. In winter year 2019-2020 the threshold was exceeded at least once in 32% of the measuring points (Vlaamse Milieumaatschappij (VMM), 2020). This is far away from the intended target. A trend analysis for each of the measuring points between 2010 and 2020 reveals that for most points there is no significant trend (79%), there is a significant decrease in 15% and a significant increase in 7% (Vlaamse Milieumaatschappij (VMM), 2020). It should be noted that the droughts in 2017, 2018 and 2019 caused a higher deposition of fertilizers into the environment. More detail about this can be found in (Vlaamse Milieumaatschappij (VMM), 2020).

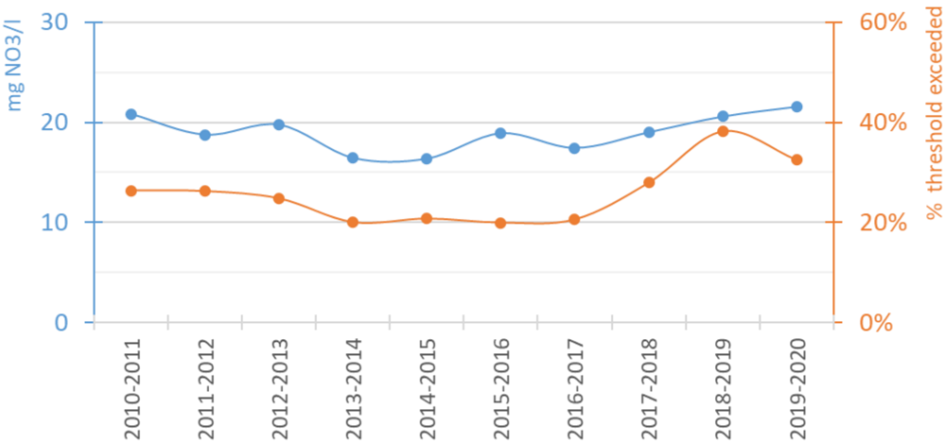

Figure 21 – Evolution of nitrogen in the surface water in agricultural land, Flanders, 2002-2020 (source: VMM (Vlaamse Milieumaatschappij (VMM), 2020))

For **phosphorus in surface water** the concentration of orthophosphate (PO_4^{3-}) is measured. Orthophosphate is the dissolved form of phosphate in water and thus available to organisms. The allowed concentration of phosphate varies between 0,07 and 0,14 mg P/L, depending on the type of waterway. In winter year 2019-2020 the critical threshold was exceeded at least once for 64% of measuring points (Vlaamse Milieumaatschappij (VMM), 2020). In figure 22 the measured concentrations for each point were categorised based on its performance in relation to its assigned threshold. In winter year 2019-2020 almost 30% of points fell into the worst category. A trend analysis revealed that between 2010 and 2020 there was no significant change for most points (70%), a significant decrease for 19% and a significant increase for 11% (Vlaamse Milieumaatschappij (VMM), 2020). The continued high occurrence of phosphate is for a large extent due to historic overuse of phosphorus, which caused an accumulation of phosphorus in agricultural soils. Whereas N is very mobile in the environment, is P immobile. Also, the droughts in the summers of 2017, 2018 and 2019 affect the results to some extent. More detail about this can be found in (Vlaamse Milieumaatschappij (VMM), 2020).

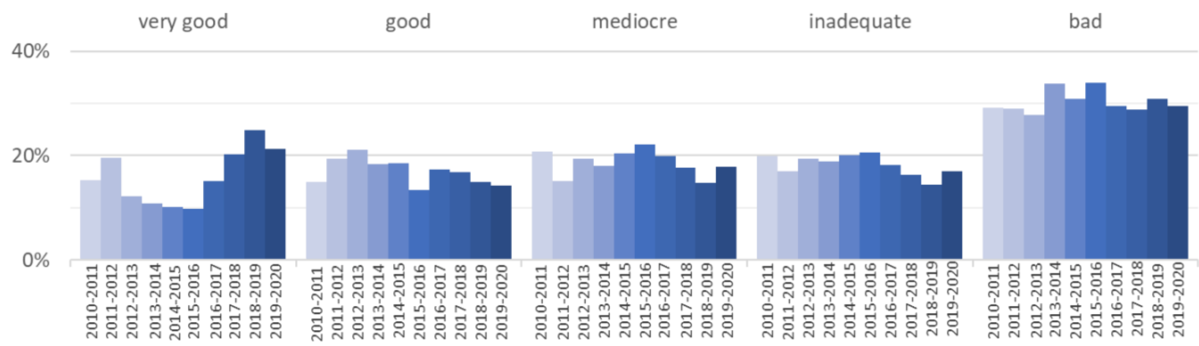

Figure 22 – Evolution of phosphate in surface water in agricultural land per category, Flanders, 2002-2020 (source: VMM (Vlaamse Milieumaatschappij (VMM), 2020)*)*

C. Impact of consumption

The impact of consumption is discussed using the material footprint (MF) and carbon footprint (CF). The MF shows the global primary material use needed to fulfil the final demand of Flemish households within a year, while the CF shows the total CO_2-eq emissions associated with this. They do this by aggregating all upstream steps from the beginning of a production chain until the end of its use phase, allocating them to the end-consumer. This provides insight into which consumption domains or product groups in Flanders are most responsible for global material need and carbon emissions. This is of interest in CE monitoring, because a lot of the material need and carbon emissions occur upstream, outside of Flanders. As the aim of the transition to a CE is to reduce the material need and associated environmental impact of Flanders as much as possible, the MF and CF are useful macro-indicators to guide this transition. Both footprints can never become zero, the aim is to reduce them enough to bring consumption in Flanders within what is possible considering the planetary boundaries for a save living environment for humanity. Ideally additional footprints would be available to assess the material needs and associated impact of consumption in Flanders, for example on land-use, water use and nitrogen.

This section uses the MF and CF to outline the food system from the side of consumption and determine which subdomains of consumption should receive further attention in the monitor. The MF and CF can be used to tie the different consumption systems to the wider economy in Flanders. In 2010, Flanders had a MF of 109.569 kton (or 17,5 ton/capita) and CF of 127.681 kton (or 20,4 ton/capita). Household consumption counts for respectively 61% and 72% of the MF and CF, while 'food' specifically accounts for respectively 19% and 13% of the MF and CF of Flanders (Figure 1). This translates to a MF of 20.732 kton (or 3,3 ton/capita) and CF of 17.216 kton (or 2,8 ton/capita) associated with food consumption in Flanders. To put this into perspective, the IPCC has estimated that the total CF has to decrease to 2 ton/capita/year by 2050 if global warming is to be limited to 2°C (Vercalsteren et al., 2017). The CF in Flanders drastically exceeds this, with merely the consumption of food already surpassing this target. Similarly, the UNEP IRP[9] estimates sustainable primarily resource use at 7 ton/capita, though this is still considered as to high according to some (Bringezu, 2015).

The available data for Flanders allows for further disaggregation on the MF and CF of food consumption to the level of product groups (Christis et al., 2019; Vercalsteren et al., 2017).

[9] UNEP IRP – United Nations Environmental Programme International Resource Panel

Figure 23 gives an overview of the main consumption categories in this system, revealing that 'meat', 'catering' and 'bread and cereals are the main contributors to the MF, while 'meat', 'catering' and 'dairy products' are the main contributors to the CF. The full list of consumption categories within the food system, with their MF and CF, are given in appendix A1.

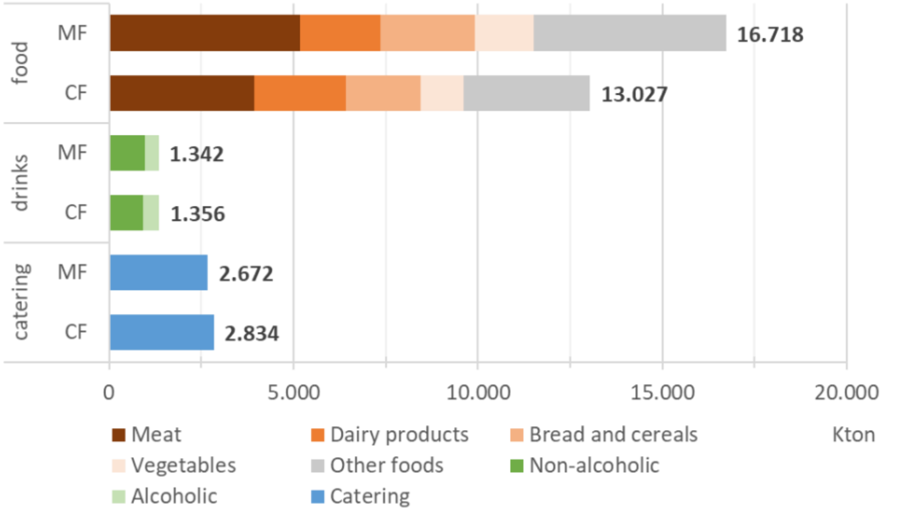

Figure 23 – Material and carbon footprint of food consumption by households in kton, Flanders, 2010 (source: Christis et al., 2019; Vercalsteren et al., 2017)

For food and non-alcoholic beverages, the CF was further dissected, emissions were allocated to the different actors in the food system and then further allocated based on their geographic location or type of GHG-emissions (Figure 24). This reveals that GHG emissions occur mainly during primary production, that methane (CH_4) and nitrous oxide (N_2O) are significant contributors to the CF and that GHG emissions occur mainly outside of Flanders (85%).

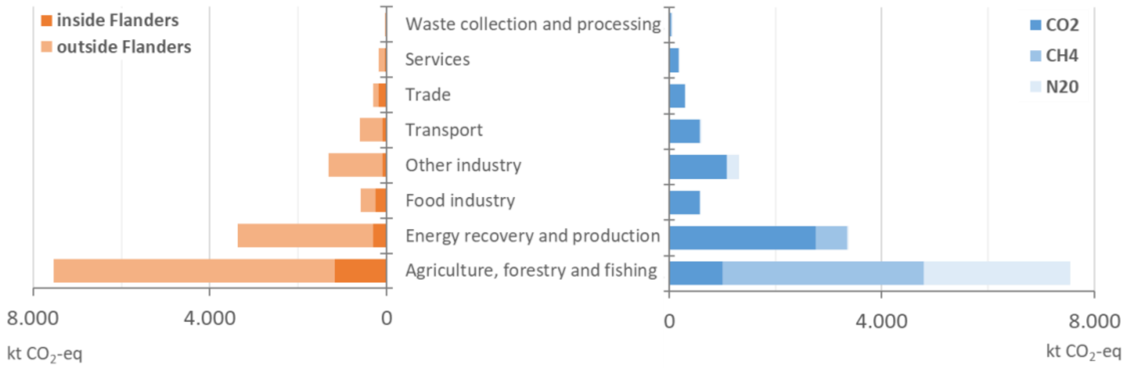

Figure 24 – Carbon footprint by sector and (left) geographic location or (right) type of emission related to food consumption by households in kton, Flanders, 2010 (source: Vercalsteren et al., 2017)

The MF and CF provide an interesting first look into the food system, however both indicators are not regularly updated due to the substantial effort required for assembling the underlying dataset and then processing the data into indicators (Alaerts et al., 2019b). Hence, currently only an initial data point for 2010 can be given. Yet, due to the macro nature of this indicator any changes or evolutions in the economy would anyway first have to have grown sufficiently large before being reflected in the MF or CF. Therefore, it can be assumed that the data for 2010 is likely still relevant today. During the finalisation of this report an update of these numbers became available, however as the methodology differs and less detail is available it was decided to keep the numbers from 2010 at this time. While the MF and CF may be based on raw approximations, these indicators provide an interesting baseline to guide the research by revealing how the different consumption domains are related to each other and what the key drivers are within a system. Furthermore, the MF and CF provides initial insight into some of the key topics in the debate around circular consumption. For example:

- **Consumption of animal products:** Figure 23 reveals that a significant share of both the MF and CF can be allocated to the consumption of animal-based products, like meat and dairy. Figure 25 gives the split between the impact of animal-based and plant-based products for the MF and CF. The consumption of animal-based products accounts for respectively 51% and 56% of the MF and CF. While this is only just over half, this is a relatively large impact considering only 28% of the dietary energy is obtained from animal-based products. Because of this, shifting consumption in Flanders towards plant-based products is being put forth as a way to lower the MF and CF. This is further discussed in the next section (section D)

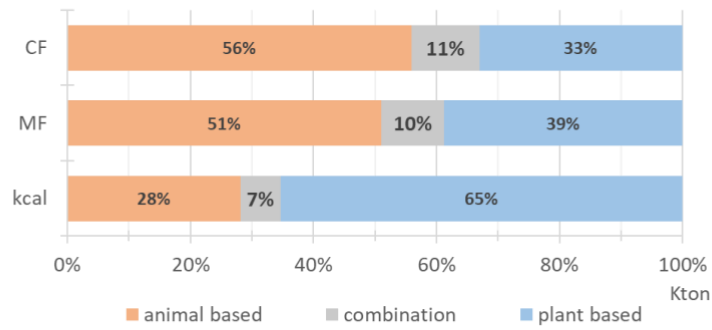

Figure 25– Division of caloric intake, material- and carbon footprint of the consumption, Flanders (data source: Christis et al., 2019; Vercalsteren et al., 2017; De Ridder, 2016b*)*

- **Local consumption:** Figure 24 reveals that the impact of transport is only a minor aspect of the CF (4%), certainly compared to primary production (54%). Keeping in mind that CE is a tool meant to reduce our environmental impact, focusing solely on increasing local consumption may not be the most efficient strategy to achieve this. As discussed in section 3.1.A, primary production preferably occurs where and when it makes most sense, considering optimal growing conditions and the carrying capacity of the surrounding natural capital. Initiatives around increasing local consumption undoubtably have their value in stimulating the local economy, providing better prices to farmers, increasing transparency and in bringing the consumer closer to food production again. But in general, the material and associated environmental gains of eating locally, without any change in diet, are for most products very limited[10].

[10] Exceptions to this do exist, specifically for those products that are flown by plane or require cooled transport.

Box 1 – LCA of diet in Belgium

In 2021 the WWF released a study, conducted by Blonk Consultants, in which the Belgian diet was optimized within dietary restraints to minimize the associated CO2-eq emissions according to the objective set in Paris of limiting global warming to 1.5°C using the LCA methodology. As demonstrated by the figure below (Figure 27), this type of study can reveal how the current diet in Belgium is preforming in relation to an 'optimized diet'. This can then provide a scientific basis to set targets for food groups and monitor how consumption is evolving towards this. The CO_2-eq reductions associated with the optimized diet is given in appendix A4.

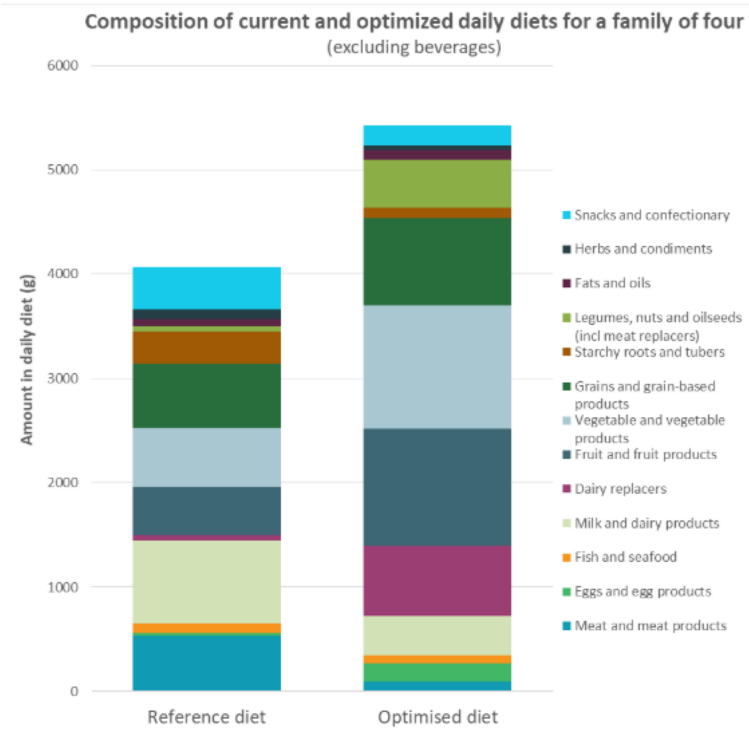

Figure 26 – Diet in Belgium optimized for GHG emissions (source: te Pas et al., 2021)

D. Consumption pattern

In a CE the nutritional need of citizens should be met with a balanced and healthy diet, while minimizing the material input and associated impacts. This can be achieved through minimising food waste and surplus consumption, and through shifting diets towards low-impact food choices.

Total consumption

By reducing the number of products which are consumed beyond the nutritional requirement total food production can be reduced, decreasing the material need and eliminating any adverse associated environmental effects. In essence there is overconsumption when **the average caloric intake**, which represents the energy content of consumed foods, is higher than the average caloric requirement, which is the energy required for the body to function. An excessive caloric intake can be caused by hefty portion sizes or through the consumption of high energy foods. Food consumption patterns in Flanders are monitored by Sciensano (formerly known as ISP-WIV) through the food consumption survey, which is a representative survey conducted every 10 years. The most recent survey took place in 2014 and found that the average caloric intake in Flanders was 2193 kcal/day for the age group 18 to 64 (De Ridder, 2016b). It is difficult to draw conclusions from this number with regard to overconsumption as the recommended caloric intake depends on various factors, most importantly gender, age and activity level. For example, for the age group 18 to 64 the recommendations vary between 1542 kcal/day and 4227 kcal/day. Caloric intake alone is not enough to evaluate overconsumption, it should be assessed against caloric requirement.

As the average caloric intake is not a convenient indicator to look at overconsumption in the population, alternatively **the average Body Mass Index** (BMI) can give an indication of possible overconsumption in Flanders. The BMI is a measure indicating whether an adult (19-59 years) has a healthy weight for his/her length and is calculated as: weight/length^2. The BMI is a regularly available macro indicator, as weight and length are more convenient to track then caloric intake. The BMI has been steadily increasing in Flanders over the last 20 years, as shown in figure 27. The percentage of overweighed or obese adults (BMI≥25), increased from 40% in 1997 to 48% in 2018. This increase is in part due to a decrease in daily activity levels. However, this aspect of BMI can be brought back to caloric intake as in a more sedentary lifestyle daily caloric requirements are lower, resulting more quickly in overconsumption.

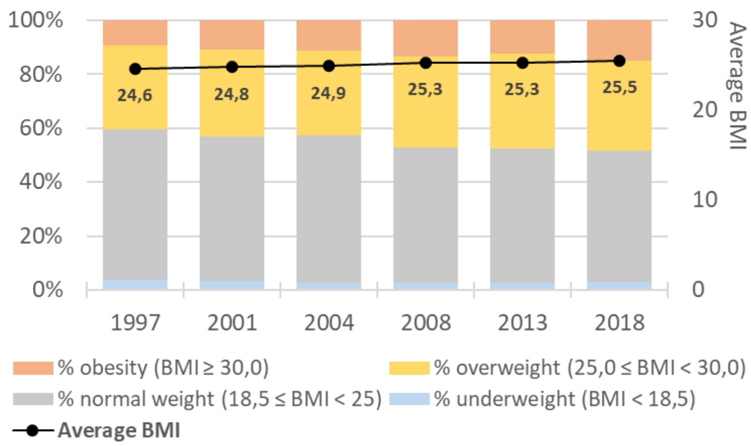

Figure 27 – Evolution of the BMI, age group 18-69, Flanders, 1997-2018 (source: Sciensano – gezondheidsenquête)

BMI is still only a proxy indicator for overconsumption, as non-dietary factors - like genetics - also influence a person's BMI. Overconsumption at an aggregated level is not evident to monitor. The clearly increasing trend in BMI does seem to indicate that there is overconsumption in Flanders. Moderating consumption and avoiding 'empty calories' are already included as guiding principles in the dietary guidelines of Flanders (Rubens et al., 2021). Empty calories are food products which are high in energy density but have little nutritional value (Rubens et al., 2021). Unguided reductions in consumption may however result in undesirable dietary outcomes, hence it is best to focus efforts on those product groups in which overconsumption occurs. To get a sense of this, table 3 provides an overview of daily recommended consumption compared to actual consumption for Belgium in 2004 and 2014. It can be noted that in 2019 dietary guidelines for Belgium, and subsequently Flanders, were updated (Hoge Gezondheidsraad, 2019), meaning this exercise should be updated. The last line of table 3 reveals the high consumption 'empty' calories. As they are not an efficient way to fulfil the nutritional need, the consumption of these products is also a suboptimal use of food products, and hence input use, in CE. In 2014 about one third of the average energy intake originated from such products. In the product groups 'cheese', 'meat, fish, eggs and vegetarian replacements' and 'lubricating and cooking fats' consumption was also above recommended levels. The main share of these products are animal-based products, which in general have a higher material need and environmental impact then plant-based products, as discussed in 3.1.A.

Table 3 – Daily consumption of adults (age 15-64) in gram compared to recommendations per product group, Belgium, 2014

product group	recommendation	consumption	
		2004	**2014**
water group	1.500	1.180	1.289
potatoes and pasta	240-350	149	142
bread and grain products	210-420	173	142
vegetables	300	167	157
fruits*	250	185	170
milk and calcium-enriched soya products	464	154	139
nuts and seeds	max. 20-25	1	3
cheese	max. 20	30	32
meat, fish egg and vegetarian replacements	100	159	149
meat		121	114
fish		24	25
vegetarian replacements		3	4
eggs	(min. 150 per week)	11	11
lubricating and cooking fats	35-60 lubricating fats 15 cooking fats	27	19
'empty' calories	max. 250 kcal	730 kcal	674 kcal

(consumption of fruits includes juices)*
(source: department landbouw en visserij (Platteau et al., 2016) *based on food consumption survey* (De Ridder et al., 2016)*)*

Shifting diets to plant-based products

Bearing in mind the aim of a circular food system to reduce both the material need and the associated environmental impacts, this section explores the possibilities of shifting consumption patterns in Flanders towards more plant-based products. Table 3 shows that in general the consumption of animal-based products is above recommended levels, while the consumption of plant-based products is below recommended levels. Any shift in diets should be done in such a way as to still ensure all macro and micronutrients required for a balanced diet are present in sufficient amounts. Macro nutrients – proteins, fats and carbohydrates – provide the main share of energy and nutrients, while an array of micro-nutrients – like vitamins – are consumed in much smaller quantities but essential to support the metabolism. The share of animal and plant-based products for caloric intake, as well as for each macro-nutrient, is shown in figure 28. This reveals that animal products especially provide us with proteins.

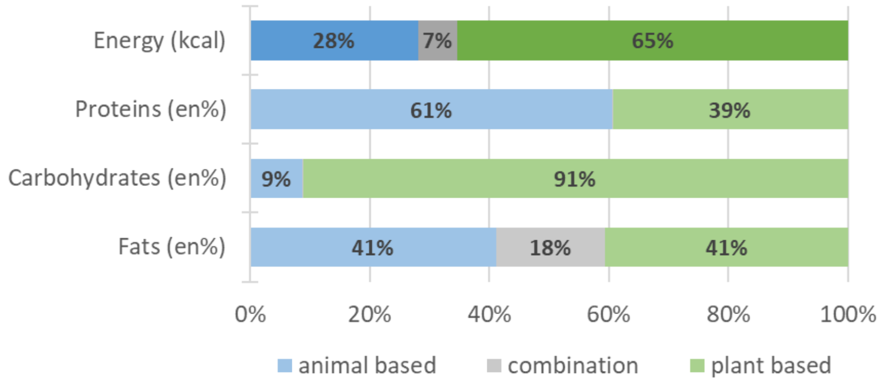

Figure 28 – Contribution to consumption of macro-nutrients by product type, Flanders, 2014 (source: Sciensano – voedselconsumptiepeiling)

In terms of CE, it is interesting to see whether it is possible to shift the ratio of protein consumption. To achieve this there are two possible pathways: (1) an absolute reduction in protein intake through an absolute reduction in the intake of protein from animal-based products or (2) a shift in protein intake from animal-based products to plant-based products. When considering any changes dietary recommendations should be taken into account. Proteins consist of various amino-acids, some of which the human body cannot generate, making them essential in the human diet. Animal-based products are considered a 'full-protein', because they contain all essential amino-acids within them, unlike plant-based protein sources - with the exception of soy (Rubens et al., 2021). Meaning that in a more plant-based diet various protein sources need to be combined to ensure balance diets.

With regard to the first pathway, the current consumption of protein in Flanders exceeds the recommended amounts. For an adult (18-59 years old) the average daily recommended amount is 0,83 g per kg bodyweight a day or on average about 52 g/day for women and 62 g/day for men (Hoge Gezondheidsraad, 2016). In 2014, the average daily intake of protein in Flanders was 74 g/day, or 64g/day for women and 84 g/day for men (De Ridder, 2016a). Thus, an absolute reduction in protein consumption is desirable. Further table 3 demonstrates that there is currently an overconsumption in protein-rich animal products, particularly meat and cheese. Thus, the circularity of consumption could be improved through an absolute reduction in protein intake achieve through lowering the consumption of animal-based products.

The second pathway offers opportunities to further reduce the consumption of animal-based products by shifting consumption towards plant-based protein from legumes, nuts and seeds or microbial protein from fungi, bacterial or microalgae. There is potential to shift consumption towards plant-based protein, as the consumption of legumes, nuts and seeds is currently below recommended levels (table 3). To ensure a successful reduction of animal based protein consumption, the Flemish government launched in 2021 the 'green deal - protein shift on the plate', as part of a wider protein strategy (Vlaamse Overheid, 2021b), for which the key objective is flipping around the current 60/40 ratio of protein intake by 2030 (Vlaamse Overheid, 2021a). Novel protein sources – like microbial protein – can also play a role in this shift. Here the further development of novel foods will play a key role. According to EU regulations a 'Novel food' is any food that was not consumed "significantly" prior to 1997 (Regulation (EU) 2015/2283). To aid the food industry in the development of novel food ILVO and Flanders' FOOD launched in 2011 the 'food pilot', where new products or processes can be tested.

Monitoring consumption

The numbers discussed on consumption so far mostly describe the situation 'as is' in 2014, mainly through using the food consumption surveys (FCS) by Sciensano. The advantage of the FCS is that it provides reliable data on actual intake, contains great detail on nutrient- and product groups and can be disaggregated across different population characteristics. However, conducting a proper FCS requires a lot of resources, making them expensive. The current frequency in Belgium (and subsequently Flanders) is every 10 years. This is not frequent enough to guide policy or ideal for a monitor. There are a number of alternative sources available to monitor food consumption, which come with their own advantages and disadvantages. Table 4 gives a, non-exhaustive and preliminary, summary of available alternatives, which are briefly discussed in appendix A5. Further research could explore the possibilities of these source for more regular monitoring of consumption pattern in Flanders.

Table 4 – possible data sources food monitoring diets

	FCS	**FBS**	**HCES**	**Consumer panel**	**Proxy indicators**
Frequency	10 years	yearly	yearly	quarterly	yearly
Region	BE/FL	BE	BE/FL	FL	FL
Scope	Actual intake	Apparent intake	Apparent intake; at home	Apparent intake; at home	Apparent intake
Disaggregation to…					
… population characteristics	Yes	No	partly	Yes	Yes
… specific products/nutrients	Yes	Yes	Yes	Yes	No

(abbreviations: FCS = food consumption survey; FBS = food balance sheets; HCES = Household Consumption and Expenditure Survey (HCES))

Shifting consumption towards circular products

The circularity of diets in Flanders can also be improved through increasing the share of lower-impact products within a product category. As this is achieved through certain efforts made during production and processing, it is typically not visible to consumers in the final product. Here labels are mostly used to inform consumers about a products' specific characteristics. At the moment it however remains unclear what circular products are, and hence without a clear definition it is at this time not possible to monitor this. Further, it may not be opportune to develop a new label specifically for circular products, as there are already a great deal of labels in use, which has been shown to confuse consumers. Instead, it may be better to integrate aspects of circularity into general 'eco-labels'. One possible aspect to monitor is the consumption of seasonal products. By producing products when the circumstances are opportune input requirement can be lowered, while the impact from transportation is minimized. The interest in buying directly from producers on markets, web shops, or at the farm is growing in Flanders. One initiative offering seasonal products to consumers is Community Supported Agriculture (CSA) farms, where consumers pay a fixed price for a part of the harvest year-round. In October 2021, there were 57 farms registered as CSA farms. This model is however mainly limited to fresh vegetables and fruits. Further research should be conducted to work out what circular products could entail and how this can be monitored.

Food loss in households

Another form of excess is food loss, which is edible food which is not consumed. Food loss in households should be avoided in particular because at this point the product has already gone through the entire production process. With each step along the production process the material footprint and associated environmental impacts increase. In 2015 households were the third largest source of food loss in the Flemish food system with an estimate 212 kton (Vlaams Ketenplatform Voedselverlies, 2017).

To gain specific insight into food loss in households, GFK was asked in 2018 by the Flemish government (Department Omgeving) to map food loss in Flemish households and to find out how and why this occurs (Criel & Fleurbaey, 2019). There are no plans to redo this study in the near future and hence any of its findings will not get monitored. The results are however still discussed because it provides a useful baseline on the occurrence of and reasons for food waste in households. This can be used to set the right policies. The study found that 241 kton of edible food was lost in Flanders in 2018, which is in the same order of magnitude as what was found in 2015. Figure 29 displays what types of food is wasted, based on weight, revealing that 66% is solid waste and 34% is liquid. Further, especially '*coffee and tea*' seem to be wasted.

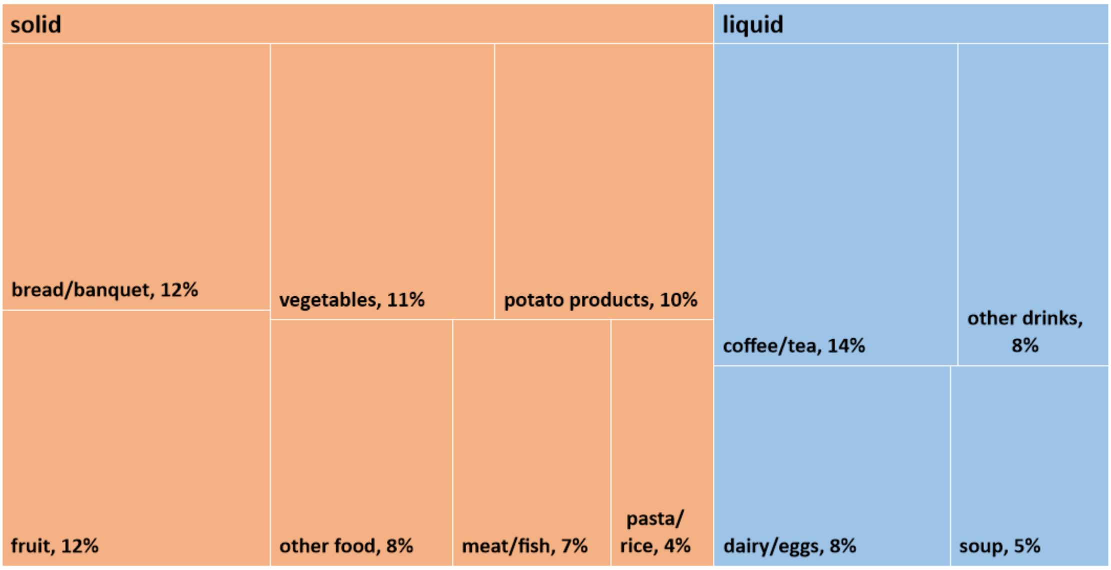

Figure 29 – Food loss in households, Flanders, 2018
(source: Departement Omgeving (Criel & Fleurbaey, 2019))

The main reasons given for food loss were: 'not used in time' (57%) and 'prepared too much' (30%). Leftovers are thrown out slightly more than fresh food, representing respectively 54% and 46% of food loss in households. The amount of food loss originating in households is clearly due to different causes, starting with what is purchased in the store, to how it is stored, and prepared. Making a grocery list in advance of shopping can for example help reduce food loss caused by the product not being used in time.

The study further investigated how the discarded food was disposed of, the result of which is shown in Figure 30. Solid food waste is almost half of the time still discarded in the residual waste bag, while liquid losses most often are disposed of through the plumbing. In both cases the materials are lost for valorisation. Selective collection and nutrient recovery are further discussed in the next section, 3.2.E, on the organic residual stream.

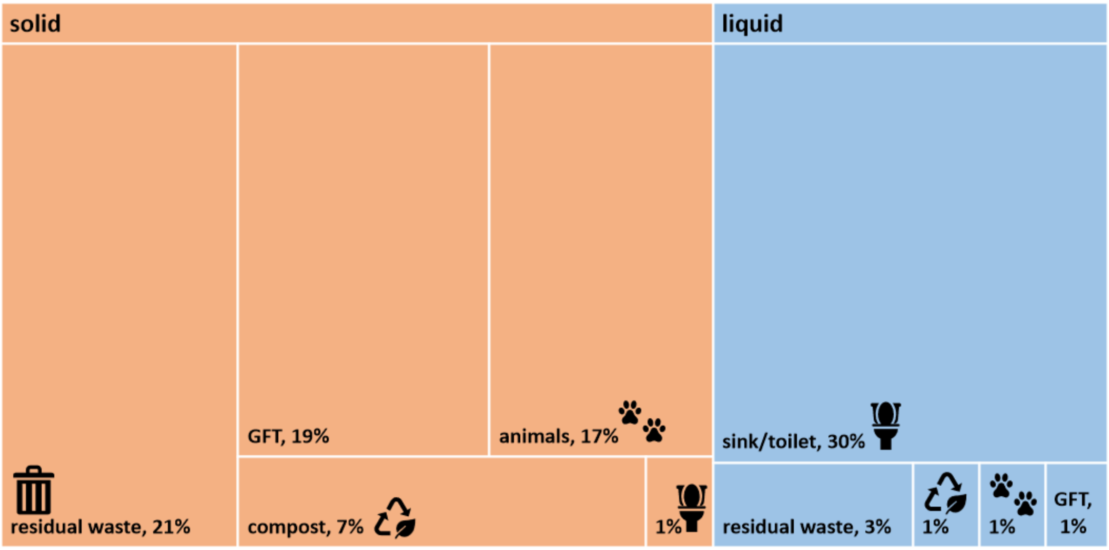

Figure 30 – Disposal method for food loss in households, Flanders, 2018
(source: Departement Omgeving (Criel & Fleurbaey, 2019))

E. Organic residual stream

The CE aims to eliminate waste wherever possible, in first instance by preventing the generation of residual streams through maximizing the use of products. Then, where residual streams are unavoidable by optimally valorising them. The cascade for value retention is used as a guiding framework for the valorisation of residual organic streams from the food system (figure 6), henceforth referred to as 'food waste'. Food waste consists of two main fractions: 'food loss' and 'residues', as shown in figure 31. Food loss refers to the fraction of food that could have been consumed by humans, but was instead discarded, making it an avoidable waste stream that should be prevented. While residues are unavoidable and should be valorised as best as possible. This section looks at food waste throughout the food chain.

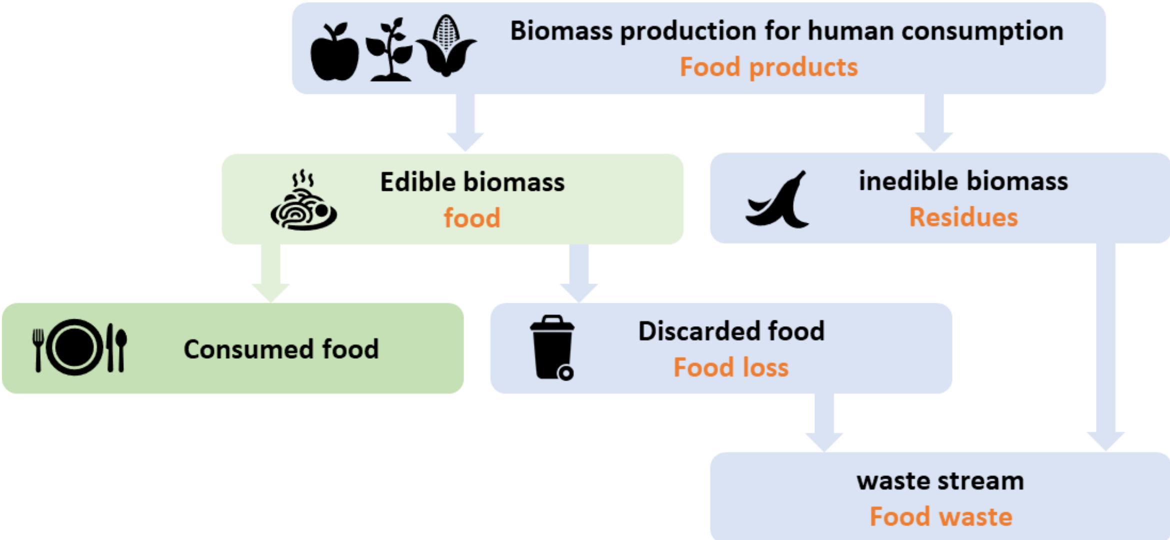

Figure 31 – Different fractions of biomass produced for human consumption
(source: own figure based on Vlaams ketenplatform voedselverlies (Vlaams Ketenplatform Voedselverlies, 2017))

Origin of food waste

Flanders is already actively working on reducing and valorising the organic residual stream, making an engagement to decrease food loss throughout the whole chain with 15% by 2020 compared to 2015 and with 30% by 2025 (OVAM and departement Landbouw en Visserij, 2020). To be able to assess this target, a monitoring program was set up with the aim of mapping food waste throughout the chain in 2015, 2017 and 2019. The monitoring will be continued structurally after this by OVAM. The results of the monitoring for 2015 and 2017 are currently available in respective reports (Vlaams Ketenplatform Voedselverlies, 2017, 2019). Both reports give detailed data and describe the data gathering methodology for each link in the food chain. The calculations for 2019 are still ongoing and expected in the 4th quarter of 2021. As the monitoring in 2017 does not contain data for the entire chain, the results from 2015 are discussed in this section. As the report of 2015 was the first implementation of the methodology, the results should be interpreted with some caution.

The baseline measurement for 2015 estimated that there was 3.485 kton of food waste in Flanders (figure 32). Of this 907 kton was food loss (26%) and 2.578 kton was residues (74%). In agriculture most edible food was lost, while food processing generates most residues. The numbers in figure 32 should be seen in the specific context of each actor in the chain. It is for example to be expected that during food processing the main share of residues is generated. Further, some food waste associated with a link in the chain can be generated by the actions of a different actor in the chain. An example of this are cosmetic requirements for fruits and vegetables, which may result in food loss at farms or at auction caused by decisions made further in the chain.

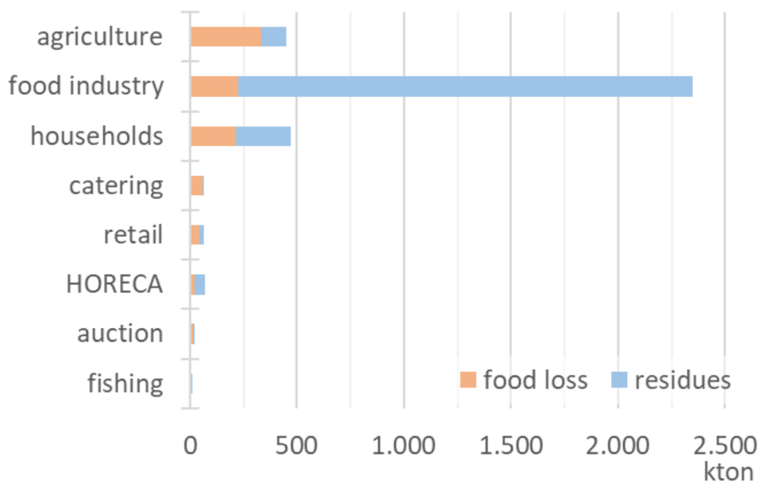

Figure 32 – Origen of residues and waste products per sector, Flanders, 2015
(source: Vlaams ketenplatform voedselverlies (Vlaams Ketenplatform Voedselverlies, 2017))

Prevention and valorisation

The previous section focused on the origins and size of the food waste stream. It is the aim of CE to reduce this stream as much as possible and ensure the highest possible valorisation for the remaining fraction. The guiding framework for this in the food system is the cascade for value retention, as shown in Figure 6. This section looks sequentially at the strategies proposed in the cascading framework: (1) prevention at the source, (2) prevention through donation and (3) valorisation.

In first instance, food waste can be reduced through **preventive measures** meant to eliminate the generation of food waste at its source. Ideally, supply and demand are in perfect sync so that the right amount of food is available exactly when needed and proper channels are in place to handle all residues. While smart database systems can contribute to improving the coordination of supply and demand, a perfect synchronisation is not achievable. However, food waste can be further prevented through optimizing processing methods, storage methods and logistics. Further, food products that now become waste could be upgraded by reworking them, e.g., by processing unsold vegetables from the auctions to soup. The effects of preventive measures are difficult to quantify as it is difficult to know what would have been if they were not in place.

Next, the generation of food loss can be prevented by **donating** it to a party which is able to still consume it in time. Practically, this is often done through donations to charities which then offer the food to those in need. This is in Flanders already an established practice, with in 2015 at least 12.599 ton donated by the food processing industry, 2.356 ton by large retailers and 1.477 ton by vegetable and fruit auctions. Food donations serve a social purpose of providing nutritious meals to those who may otherwise not be able to afford it, it is however not a structural solution to poverty or excess food.

Lastly, any food waste which could not be prevented should be optimally **valorised**. Table 5 shows for the food system as a whole and for each sector the valorisation path of the residual stream and gives the sectors 'cascade index'. This score was created to accumulate the different waste treatments into one general score, based on a weighing factor determined by the cascade of value retention. The methodology behind this is explained in Vlaams Ketenplatform Voedselverlies, (2017). It should be noted that not all waste streams can be valorised at the highest level of the cascade due to practical reasons like food safety. Hence for some parts of the chain high level valorisation is more difficult. Table 5 reveals that in 2015 the cascade index for Flanders was 8,2. Noticeable is that for fishing the entire waste stream is lost, resulting in a cascade index of 0, this is because in 2015 it was common practice to throw undesired fish - 'by-catch'- back in the sea. This practice is however no longer allowed by European law since 2019, requiring all caught fish to be landed in ports. HORECA and catering also have each a notably low cascade index, caused by the lack of selective collection in these sectors, resulting in the incineration of waste streams. This will change due to new requirements under VLAREMA[11], mandating the selective collection of all organic waste at the source by 2023 at the latest. Lastly, also in households and retail significant fractions of food waste are still incinerated, resulting in a loss of materials. In 2015, the auctions and food industry achieved the highest cascade index, each at 8,8.

[11] VLAREMA, or 'Vlaams Reglement voor Afval- en Materialenbeheer', implements the legal framework around waste and materials management for Flanders.

Table 5 - Valorisation and cascade index of organic residual stream per sector, Flanders, 2015

	Residual stream (kton)	feed	materials	soil	fermentation	compost	energy	incineration	disposal	unknown	CASCADE INDEX
fishing	10,4	-	-	-	-	-	-	-	**100%**	-	**0,0**
agriculture	449,4	11%	-	**70%**	4%	4%	1%	-	4%	6%	**7,9**
auction	15,3	**36%**	-	28%	11%	17%	-	-	-	8%	**8,8**
food industry	2.349,4	**55%**	0%	11%	26%	-	7%	0%	-	-	**8,8**
retail	64,8	3%	2%	-	**49%**	16%	-	29%	-	-	**6,3**
HORECA	67,5	-	-	-	31%	-	-	**69%**	-	-	**3,9**
catering	60,1	-	-	-	24%	-	-	**76%**	-	-	**3,4**
households	468,3	28%	-	-	6%	**40%**	-	24%	3%	0%	**6,9**
Total	**3.485,2**	**43%**	**0%**	**17%**	**21%**	**6%**	**5%**	**6%**	**1%**	**1%**	**8,2**

(source: Vlaams ketenplatform voedselverlies (Vlaams Ketenplatform Voedselverlies, 2017))

Selective collection and treatment

Selective collection of waste is a key element within CE to enable the use of waste streams as secondary resources. This section goes into what happens to food waste which ends-up in the organic waste fraction, meaning residual streams from e.g., food processing which are directly redirected towards valorisation processes are not included here. When food waste is collected separately as a waste stream it is part of the wider selective collection of organic waste. In Flanders, OVAM oversees the selective collection of organic waste from households and companies, while Vlaco reports on the treatment. The municipal solid waste (MSW) from households is collected either selectively or non-selectively in Flanders. There are in total 17 different fractions of household waste which are collected separately with the aim to guaranty optimal waste treatment. Food waste in households is in Flanders collected separately as part of the 'Vegetable, Fruit and Garden' (VFG) fraction. Organic waste from companies is collected as 'OBA', loosely translating to 'Organic-biological waste'. The waste from these two fractions is transferred together with the other organic fractions to the different composting and fermentation installations. The amount of input for each organic stream is given in figure 33. The weight of the organic residual stream is influenced by the seasons and particular weather conditions of a certain year. There is a notable increase in the treatment of OBA and manure, while VFG seems to remain stable.

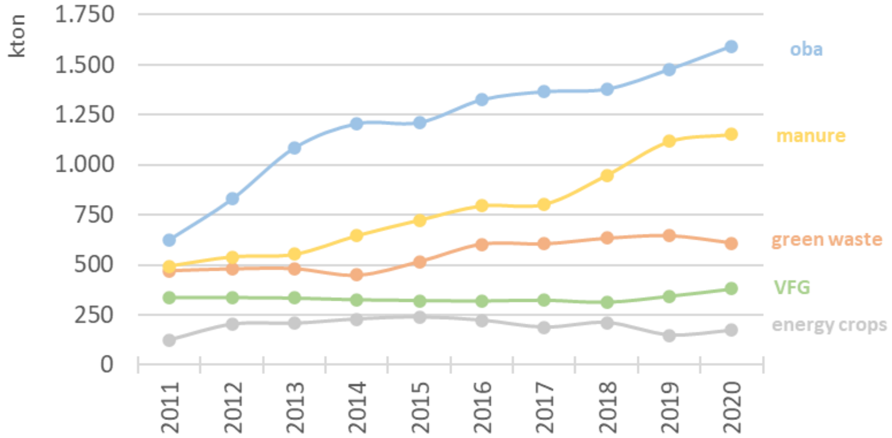

Figure 33 – Evolution organic input streams for waste treatment (composting or fermentation), Flanders, 2013-2018 (source: Vlaco – yearly reports)

As stated, the mixed organic waste collected from households and companies has two main treatments: composting or fermentation. Composting is a biological process whereby, in the presence of oxygen, organic-biological material is converted into compost, which can be used as a soil improver (Raes et al., 2020). Fermentation is an anaerobic process in which micro-organisms break down biomass into stable digestate (a fertiliser) and biogas (Raes et al., 2020). Both compost and digestate can play a role in closing nutrient cycles by returning nutrients to fields. At the moment most of the digestate is use again in primary production, as animal manure, while most compost is used for other purposes outside of primary production. Figure 34 shows the destination of digestate in Flanders, revealing an increase in the processing of animal manure. The data needed for showing the evolution of the destination of compost could at this time not be obtained from Vlaco.

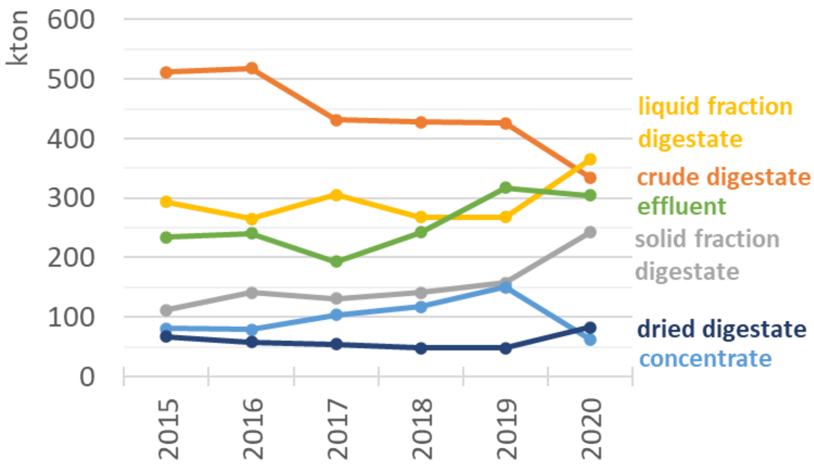

Figure 34 – Destination of digestate, Flanders, 2015-2018 (source: Vlaco – yearly reports)

While a considerable fraction of organic waste is separately collected and processed, there is still also a fraction of organic waste from households or companies which ends up in residual waste. To gain inside into this the 'Public Waste Agency of Flanders' (OVAM) periodically studies the content of the residual waste from households and companies. Such a study for household residual waste is currently ongoing (2021), but the results are not yet available. The last completed study dates from 2013/2014 and disclosed that VFG-waste accounts for 15%

of residual waste, or 105 kton (De Groof, 2015). Of this about 60% was compostable kitchen waste, translating to about 62 kton waste from the food system that could have been additionally valorised. In an additional study, OVAM looked in further detail at the composition of both non-compostable and compostable kitchen waste in residual waste, finding that 44% (or 47 kton) of all kitchen waste (108 kton) could be identified as avoidable waste, meaning it was still edible when it was discarded (De Groof et al., 2015). Figure 35 shows the evolution of the residual waste collected from households in Flanders, as well as the fraction compostable kitchen waste. It is positive to note that the absolute amount of residual waste is decreasing, as well as the amount of organic waste in residual waste, both in absolute and relative terms.

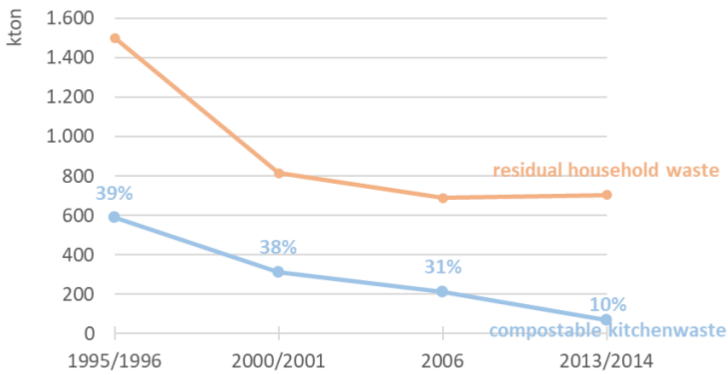

Figure 35 – Evolution of compostable kitchen waste in residual waste from households, Flanders, 1995-2014 (source: OVAM (De Groof, 2015))

A similar sorting exercise was conducted by OVAM on company waste in 2017 (OVAM, 2018). In general, was the fraction OBA found in residual company waste small. However, the composition of company waste is strongly dependent on the sector in which it operates. Residual waste from the food industry, wholesale and retail trade, and HORECA was found to contain relatively more OBA. As part of the new sorting requirements for companies under VLAREMA, companies will need to step-up efforts on selective collection of kitchen and food waste. Starting in 2021 with companies that generate large organic streams, e.g., with a company restaurant, to all companies in 2024.

Lastly, it can be noted that, between the disposal of organic food waste (figure 30) and human excreta, sewage water contains valuable nutrients, most notably phosphorus (Papangelou & Mathijs, 2021). Aquafin, the company responsible for wastewater treatment in Flanders, is through pilot projects looking into methods for nutrient recovery from sewage. Reuse of nutrients from sewage is not evident as it may contain hazardous substances and pathogens. At this time the use of treated sewage sludge on agricultural fields is not allowed in Flanders (Papangelou & Mathijs, 2021). Additionally, it can be noted that according to the VMM, 1 in 8 households in Flanders is not yet connected to the sewage system, eliminating the possibility of nutrient recovery and resulting in harmful losses to the environment.

F. Inorganic waste stream

Inorganic residual streams are generated along the entire food chain, from production to consumption. As with organic residual streams, waste should in first instance be prevented and then optimally valorised. For inorganic streams this can happen through prevention, reuse and recycling. Key here is eco-design, where the End-Of-Life (EOL) stage is already considered during product design. While there are various inorganic streams that are generated within the food system, this section focuses on food packaging. It was decided to focus on this topic because a significant fraction of the waste generated by consumers is packaging waste, mostly originating from food products or beverages. Important industrial inorganic residual streams, like agricultural films or company packaging waste, are not discussed in this report, but should be added in future. Especially as the sorting exercise conducted by OVAM in 2017 on companies residual waste revealed that foils make-up a significant fraction (OVAM, 2018).

CASE: Food packaging

One of the key principles of CE is the avoidance and reduction of waste streams. Yet, in our current food system, food packaging is a key element in getting food to consumers and presenting them with information about the product. Food packaging helps ensure food reaches consumers in an optimal state and elongates the shelf life of products. Within a CE for the food system the right balance has to be found between useful packaging and minimizing the associated waste stream. This balance is studied in Sarlee et al. (2015). In general, any unnecessary packaging should be avoided, while necessary packaging should be designed in such a way as to optimize use and facilitate high quality recycling.

To ensure the collection and recycling of packaging, companies are responsible for the consumer packaging they Put-On-Market (POM) and have to report on this as part of the European extended producer responsibility legislation. To simplify this, most companies elect to do this via Fost Plus, the producer responsibility organization (PRO) for consumer packaging in Belgium. Fost Plus coordinates for their members the mandatory reporting to the government, as well as the organisation of an uniform collection system to gather and recycle consumer packaging. As Fost Plus operates at the national level, the numbers below are for Belgium. Of the packaging POM in Belgium about three quarters is related to food and drinks (figure 36a). In first instance the goal of CE would be to reduce the amount of packaging POM as much as possible. However simply eliminating packaging is not opportune, because while packaging may come at a material and environmental cost, it plays a crucial role in ensuring food safety, efficient transport, communication of information, and avoiding food loss by elongating shelf life. The strategy should be to maximally avoid unnecessary packaging and ensure necessary packaging is re-usable or recyclable. This depends to a large extent on the materials used, the evolution of POM per general material type is given in figure 36b. The numbers in figure 36 and figure 37 were taken from the yearly reports of Fost Plus. While the yearly report for 2020 has been published, it seems that since 2018 less concrete data is available in these reports, making it impossible to further update the graphs based on the publicly available yearly reports alone.

Figure 36 – Evolution of packaging POM by members of Fost Plus by (a) product type and (b) material, Belgium, 2013-2019 (source: Fost Plus – yearly reports)

To allow for the re-use or recycling of packaging selective collection is essential. Fost Plus coordinates this through three channels:

1) The use of a separate garbage bag, known as 'P+MD', specifically meant for all plastic packaging, metal packaging and drinking cartons;
2) The separate collection of paper and carton from households and
3) communal collection points for packaging glass.

As the collection is focused on all consumer packaging, it is currently impossible to analyse the collection and recycling of food packaging specifically. Thus, the numbers discussed from now on relate also to the 25% non-food related packaging POM. Figure 37a shows the collection of consumer packaging through Fost Plus, while figure 37b shows how this relates to the amounts POM. The collection percentages are very high for all categories except plastics. While this is positive, it should be noted that the collected/POM ratio gives an overestimation, as demonstrated by a collection rate of more than 100% for glass. This has several reasons, like the fact that not all consumer packaging POM is reported to Fost Plus, that some of the collected packaging comes from abroad and that also some waste is collected which is not packaging. Hence the numerator, the amount of packaging POM, is an underestimate and the denominator, the amount of packaging collected, is an overestimate. Noticeable is the considerably lower percentage for plastics, to address this Fost Plus redefined what can be collected through the PMD-bag.

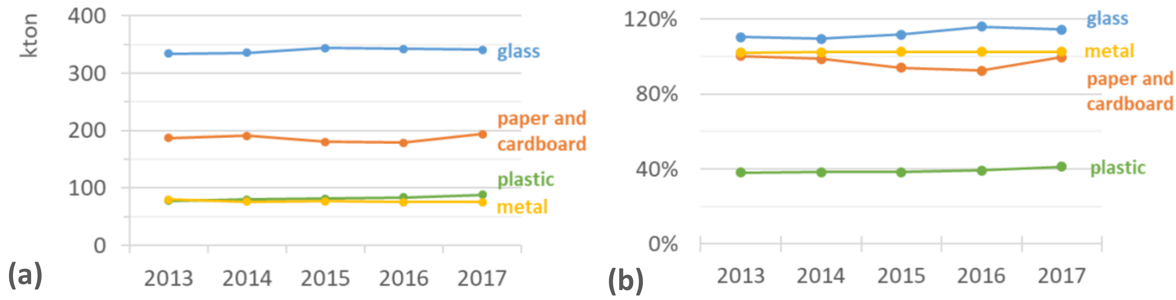

Figure 37 - Evolution of (a) selectively collected packaging waste and (b) collection percentages, Belgium, 2013-2017 (source: Fost Plus – yearly reports)

After collection little data is available about the recycling process, making it currently impossible to monitor how much of the collected packaging is recycled or to what end. Some of this is being addressed through a new calculation method starting from the reporting in 2020. Further, it would be interesting to know more on aspects like the recyclability of packaging POM. This should in part be possible to assess through analysing the data available through Fost Plus' eco-modulation set-up, which is meant to encourage the eco-design of packaging. Here Fost Plus members pay for the packaging they POM based on the type of the packaging. Packaging which is more difficult to sort or non-recyclable is more expensive. For this inspiration could be drawn from the WUR[12] in the Netherlands. In terms of CE monitoring, it would be interesting to know not only the material type in more detail, but also the amount of packaging POM in number of pieces, as the production, collection and recycling of each packaging piece comes at a material and environmental cost. Hence, decreases in the weight POM through a shift towards lighter packaging, possibly masking an increase in the number of packaging POM, does not move the system towards more circularity. Lastly, the recycled

[12] Project: Recyclebaarheid verpakkingen op de NL markt – Projectcode: 6229116200

content of packaging would be of interest to monitor, as this reduces the need for novel resource extraction.

While selective collection of consumer packaging in general functions well in Flanders, not yet all packaging is collected separately, instead ending up in the residual waste fraction or in 'out-of-home' waste fraction. To gain insight into the composition of the residual waste fraction from households in Flanders OVAM periodically sorts a sample of residual waste bags. Such a study for residual household waste is currently ongoing (2021), but the results are not yet available. The last available study is from 2013/'14, which revealed that 27% of the residual waste bag was packaging, of which 15% could have been collected through a selective channel (Figure 38a). This translates to an additional 137 kton that could have gone towards recycling in Flanders. Figure 38b shows the evolution compared to the previous sorting exercise in 2006. The total amount of residual waste has gone down slightly compared to 2006 (-3%), while the fraction of packaging increased (+10%). From the selectively collectable packaging fractions, the amount of beverage cartons increased most in relative terms (+128%), while plastic bottles increased most in absolute terms (+1,49 kg/cap). Metal packaging decreased most in both relative and absolute terms. It can be noted that the selective collection of packaging waste has been extended (P+MD) since the 2014 sorting exercise, hence it will be interesting to see how this influences the results of the ongoing sorting exercise.

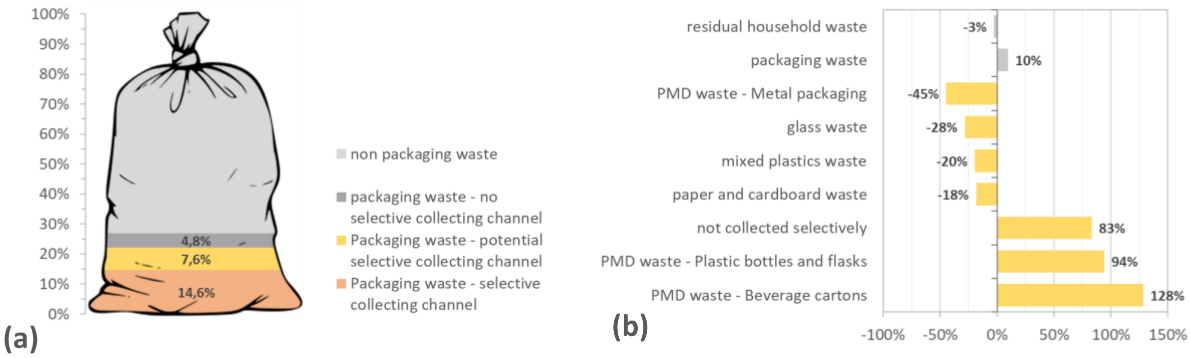

Figure 38 – Packaging in residual waste, (a) amount in 2013/'14 and (b) evolution 2013/'14 vs 2006, Flanders (source: OVAM (De Groof, 2015))

Some consumer packaging ends up outside of the household. This 'Out-of-home waste' is reported in three fractions: street litter, illegal dumping and street bins. Every two years OVAM reports an estimate of these fractions, as shown in figure 39. It is currently unknown what fraction of this is packaging waste, to gain insight into the composition of out-of-home waste a sorting exercise on this fraction is currently being conducted by OVAM.

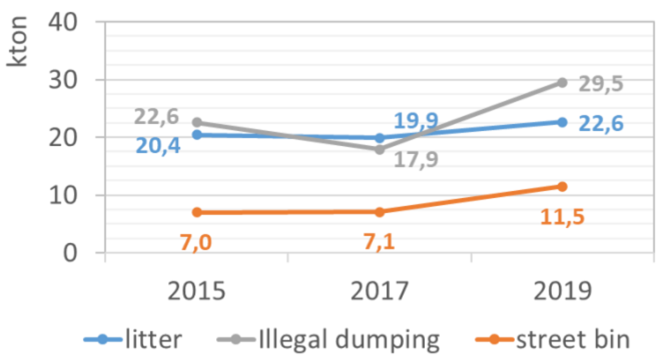

Figure 39 – Evolution of out-of-home waste, Flanders, 2015-2019 (source: OVAM (Schnitzler & Vanstockem, 2020))

4 Discussion and Conclusion

4.1 Progress towards CE

Given everything discussed throughout this report, this section first briefly discusses the created reference framework on CE and food. After this, the main findings from analysing the available data found for monitoring the circularity of food systems in Flanders is discussed.

Creation of a reference framework for CE in the food system

The food system is very complex, crossing multiple policy domains, like agriculture, environment and health. Due to this, current expertise and initiatives on circularity within the food system are spread out among numerous different stakeholders. None of the stakeholders contacted identify themselves as having sufficient insight into the food system as a whole to make an assessment on what a CE for the food system should entail. This is reflected in the fact that a holistic vision on CE for the food system for Flanders is currently missing. A clear vision is however required as a basis to assess what to include in the monitor and to evaluate whether the system is evolving in desirable directions. The literature review conducted for this study, as well as the underlying Delphi study, have contributed to address this gap.

A circular system for food in essence comes down to minimizing the material demand and associated environmental impact of this system, while still ensuring that the nutritional need in Flanders is met for all citizens through a safe, balanced and healthy diet. Starting from this a framework was created around three central themes: (1) the optimization of inputs, (2) the optimization of food products, and (3) the optimization of residual streams. For each of these themes, strategies to minimize the material demand and associated environmental impacts of the food system were researched. Figure 9 in section 3.1.C gives an overview of the key interactions and strategies for the three themes. The framework provides a common starting point for the different stakeholders working across policy domains on the different aspects of CE for food and can be used to provide guidance for future policy initiatives.

The creation of a reference framework has not been easy, and several obstacles have been encountered. Firstly, the food system is unique in the CE due to the single-use and biological nature of food products. A general idea in CE is to increase and extend the use of products, as such that fewer products are required. This idea cannot be applied to the food system, after use the product becomes mainly excreta. This also implies that the general idea of 'Reduce' should be tuned towards the question what would be circular targets. Secondly, there are still a number of ongoing discussions, mainly caused by differences in values and priorities. For certain topics - like local vs global production - a consensus is yet to be reached on what the aim in Flanders should be. Here additional, robust, science-based data on what could be optimal sizes for cycles for which products is essential to ensure good policy making. Another obstacle which emerged is that it is difficult to obtain clarity between the concepts of circularity, sustainability and health which are all prominently coming together in the food system. In those instances where clear synergies are found between circularity and other topics, policy initiatives should try to maximally exploit them as these are spots where consensus can be anchored. Even within the food system care should be given, as a circular primary production is not the same as a circular food system. Lastly, defining the system boundaries proved challenging. The demand for biomass is rising as more producers consider it as a renewable alternative to replace fossil fuels to use as materials or as energy fuels. This creates increasing competition for the biomass produced by the primary sector. While there are opportunities to valorise waste streams and residues from the food system for non-food purposes, it is difficult to determine when this is optimal. As the focus of this report is on the food system, priority was given to food purposes for residual streams, in line with the cascade of value retention. However, bearing in mind the rising demand for biomass to replace fossil fuels, it may be opportune to expand this cascade towards 'optimal use of biomass for human purpose'. Depending on the scarcity of biomass in Flanders, combined with novel processes in biorefineries, may make traditional valorisation pathways no longer the most optimal.

Progress towards CE

The monitor presented in this report is a first attempt at summarizing the food system in Flanders in terms of CE. The high number of indicators discussed in section 3.2 of this report demonstrates that the food system will not be easily analysed or summarized. Further, due to the time invested in creating the reference framework for CE in the food system, and the fact that this study is based on reframing the already accessible data, it was not yet possible to work out first-best indicators for all relevant aspects. As it stands, it is acknowledged that this first version of the monitor is still limited in its current form and will need to be further finetuned over the coming years with additional or improved indicators. Indicators on processing of food are currently missing and will need to be added in the future. However, this study does fill in the current need for a framework around CE for the food system and provides a first impetus of what is possible with the available data.

From what was found, it seems that while the food system is intrinsically circular to a certain extent – due to its connection with the biosphere – industrial intensification and increasing consumption have moved the system away from the underlying natural cycles. Subsequently today there is a lot of room to optimize the circularity of the system on all three fronts of input use, product use, and use of the residual streams. Input use has to be brought in line with the carrying capacity of natural ecosystems through further reduction in total use, further increases in the share obtained from environmentally sustainable sources, and by halting losses to the environment. This may become more prominent when external pressures further threaten input availability, e.g., through the increasing pressure on land use in Flanders or fluctuations in water availability due to climate change. The use of food products can be further optimized by addressing excesses – in the form of overconsumption and food loss – and through shifting diets towards low-impact products. Lastly, the use of residual streams from the food system can be further optimised by increasing selective collection and facilitating more high-level valorisation according to the cascade.

The different actors in the food system acknowledge the various challenges the system faces and are already trying to address them. There are numerous innovation projects ongoing throughout the food system. So far, the initiatives seem to have been mainly focused on technological innovations and less so on system innovation. The effects of technological innovation can for example be seen in the use and loss of inputs, where large improvements were made in the early 2000s through novel production techniques. For example, NH_3-emmisions decreased through improving animal feed, low-emission stables and smarter use of animal manure (VMM, 2020b). But to reach the set goals on sustainability there appears to be a need to go beyond this, shifting mindsets regarding both the production model and consumption pattern, as confirmed by FPS Public Health & DG Environment, (2021). **The CE**

allows for this required dual focus, by using technological innovations to optimize current cycles, while also focusing on system innovation by questioning the existence and size of current cycles within the limits set by the planetary boundaries.

To address the current impact of the food system, system-wide changes are required. System innovation transcends the boundaries of individual companies, changing societal, technological, economic, environmental, and institutional rules and practices (Hoes, 2018). The need for a system wide change in production and consumption patterns seems to get increasingly acknowledged by policymakers in Flanders, as is reflected in recent initiatives like the Flemish protein strategy (Vlaamse Overheid, 2021b), the work agenda on CE and food launched by Circular Flanders, and the ongoing work on a Flemish food strategy. Implementing system change is not easy, it requires all actors to participate and is slow (Selnes & Tacken, 2019). Participants of the Delphi study highlighted that economic feasibility will be a key factor determining whether the transition of the food system to a CE will succeed. Systemic change implies a period of transition, where certain practices are phased out because their associated material demand and environmental impact is deemed too steep. Where these choices are made, transition plans have to be implemented to ensure a just transition.

The emphasis of CE for the food system differs for the various actors along the food chain. This study focused on the three foremost links in the food chain: primary production, consumption, and the residual stream. **Primary production** in Flanders is already very efficient. Novel resources, products and production methods bear the potential to move the system towards more circularity. The fourth industrial revolution will offer new opportunities through increased data availability, which can help to further optimize the system, aiding amongst others in reducing input requirements and food loss. But while through technological innovation further efficiency gains can certainly be obtained, this alone will likely not be enough to bring primary production within local and global environmental boundaries. This is illustrated by the fact that in recent years trends on input use have stagnated, with no reductions in absolute use and no clear increase in the share of inputs sustainably sourced. This is likely a result of the current functioning of the food market, where efficiency increases may have resulted and may further result in production volume increases. Technological innovations are typically implemented at the company level and may not be automatically reflected in reductions in the total material needs and associated environmental impacts at the level of the food system. These 'per unit' efficiency gains, which may increase circularity at the farm level, may be neutralised by an increase in production, as such falling short of reaching the high-level circular goal of bringing the food system within its biophysical limits. Further, with technological innovation care has to be given to avoid 'lock-ins', for example investments in technological innovations should consider long term goals, so that producers are not locked into production systems which only make sense to meet short term goals (Vink et al., 2021). This also implies that for primary producers to invest in CE clear long-term policy objectives need to be set.

In the current situation, it is not evident for primary producers to transition towards circularity. For producers operating at very low profit margins, it is not evident to change production models. Where actors are placed in a difficult position, initiatives are needed to provide support. Already available examples of this are 'boeren op een kruispunt' (farmers on a crossroads) or the restructuring options offered to livestock farmers close to valuable nature reserves under the nitrogen policy plan (PAS). Another aspect required for systemic change are policies and legislation enabling and encouraging cooperation between different actors along the food chain. A correct price for agricultural products is required to allow producers to shift their focus away from lowering costs (and increasing production) to increasing circularity.

In section 3.1.A the balance between the production of plant-based and animal-based products in a CE was discussed. It was explained that animal-based products have a central role in a circular food system - with animals serving as nutrient converters, valorising residues that are not consumable for humans through animal feed and producing manure that can be used as input for crop production. However, the balance between the two systems in Flanders seems to be towards animal-production. This results in the current size of production increasingly running up against system boundaries: (1) exceeding the local and global carrying capacity of natural systems, mainly through nitrogen depositions and methane emissions, (2) cannot be maintained with residual streams, using a significant share of agricultural land directly to produce animal feeds, and (3) linear nutrient cycles, through the use of synthetic nitrogen and virgin phosphorus inputs for the production of animal feeds, and still significant losses of these nutrients to the environment.

Within the food system, initiatives relating to CE have in the past mainly focused on production processes. Less action has been taken with regard to **food consumption**. However, the MF and CF of food consumption in Flanders, as well as initial LCA results reveal the significant impact of the current diet. In the transition to a CE for the food system, excesses within the diet and product choice should be further addressed. Through addressing excesses, in the shape of overconsumption and food waste, the material needs and associated environmental impacts of the food system will be reduced, as less products are required to meet the same need. This has two sides: reducing overconsumption and reducing food loss. With the available data it is difficult to make conclusive remarks about overconsumption in Flanders, but certain aspects like the increasing percentage of overweight within the population and high consumption of empty calories, indicate that excesses in food consumption are present. Further, the consumption of animal-based products is well above recommended dietary guidelines. As the production of animal-based products is associated with a higher material need and environmental impact than plant-based products, the consumption of animal protein should be reduced in absolute terms, as well as a further shift in consumption of protein towards plant-based products in Flanders. The work on this is shifting to a higher gear in Flanders with the launch of the Green Deal for the protein shift (Vlaamse Overheid, 2021a). Food loss in households should be further reduced as this loss has the highest relative impact, as all preceding inputs used during production and processing are wasted. Valorisation opportunities are also limited, with this stream being at best collected as part of a mixed organic waste stream going to composting or fermentation and at worst discarded with residual waste or flushed into the sewage system. This latter is also the case with respect to human excretions, resulting in the loss of valuable nutrients like phosphorus from the food system. Plans for addressing food loss, and in more general food waste, are outlined in the new action plan on ‘food loss and biomass (waste)streams’ (OVAM and departement Landbouw en Visserij, 2020). Lastly, the impact of consumption could be further reduced if consumers shifted more toward the low-impact products within a product category. It is currently almost impossible for consumers to assess the circularity of products in stores. Some indication is given through labels on seasonal products for fruits and vegetables. Labels like the eco-score, which attempt to inform consumers, are under development, and while they are not specific to circularity, they can guide consumers to low impact products.

Regarding the **residual streams** generated by the food system, it is positive that there is already a monitoring available and a specific action plan in place (OVAM and departement Landbouw en Visserij, 2020). The established importance given to this stream was reaffirmed by stakeholders in the Delphi study. For the inedible organic fraction originating throughout the food system further valorisation channels should be investigated and developed, ensuring optimal valorisation. Currently, the most economically profitable valorisation channel is not necessarily the most circular. For example, because of a focus on non-fossil energy generation. It is required to create opportunities through the correct policy incentives or discouragements. Hence, the use of the cascade for value retention of biomass was embedded in the material hierarchy in Flanders by OVAM. The highest possible valorisation of a residual stream is not always achievable as food safety needs to be ensured, strong fluctuations in amounts are possible, and the window of opportunity is short given the fast degradation processes in residual streams. Policies to increase cooperation between companies and transparency about the available streams can help to facilitate this. A key enabler is efficient selective collection. In the coming years the share of organic streams in residual waste from companies and households should decrease further due to new sorting requirements under VLAREMA, the legal framework around waste and materials management in Flanders. Also, all opportunities to recover nutrients should be further explored. Nutrient recovery is a key step in closing nutrient cycles in Flanders. This is especially important for phosphorus, as it is a non-renewable resource which is key in primary production. Nutrients can be recovered from manure, sewage water, and the residual streams from food production. At the moment it is not allowed to use treaded sewage sludge on agricultural fields in Flanders. Regarding the inorganic stream, it can be noted that three quarters of consumer packaging put-on-market in Belgium are for food products. Packaging has it uses regarding food safety, transport, information and preservation, but as it takes a significant effort to correctly collect and recycle packaging, prevention and re-use should be prioritised.

Further research

Due to the size and complexity of the food system it was not achievable to fully analyse this system. Throughout the creation of this report, choices had to be made with regard to which aspects to focus on. The research was guided in first instance by the aspects emerging as most relevant from the literature and Delphi study. The focus of the monitor is currently on primary production, consumption and the waste collection and treatment stage. Further work should be done to integrate steps like 'processing' and 'distribution' into the monitor, as displayed in figure 40. In this context, it has to be mentioned that the development of indicators at the level of companies or industrial sectors is currently in a premature stage, with many important open questions, like how to match the material efficiency approach with the systemic approach and where to put the boundaries of processes for defining indicators. Hence besides setting up indicators for processing and distribution in the food system, further efforts to solve more fundamental indicator development issues will be additionally needed.

	Use of inputs	Use of food products	Use of residual stream
Primary production (excl. fishing)	(green)		(green)
Food processing and distribution	(orange)	(orange)	(green)
Consumption		(green)	(green)

Figure 40 – Overview of current focus of indicators
Green: indicators are discussed – orange: indicators are not discussed

The input indicators on primary production currently address all primary production on land in Flanders, not just food production, while leaving out fisheries. For primary production on land the indicators hence go beyond the food system, to the wider bio-economy. Currently, considering the need to bring primary production within what is possible to sustain by the biosphere, it may be positive to still include non-food production here, until a similar monitoring is established for other products in the bio-economy. Further, while it is clear that current input levels bear very high material demands and environmental impacts, it is currently not at all clear which targets should be strived for with regard to local and global environmental boundaries. Further research could focus on the development of scenarios for a circular food system, enabling to assess the implications of scenarios and providing input for setting target values for particular indicators. Additional research is also required to fill in the remaining gaps and improve upon indicators for which good data is lacking. For processing, indicators on input use similar to those for primary production could be added for inputs like water and energy. Additionally, the impact of processing food could be assessed to establish the additional material need and environmental impact of more processed products. For consumption more regular insights in diets are needed to track if any change is occurring, to assess consumption both intake requirement and actual intake should be known.

During the current study many trade-offs have been encountered between circular strategies. One example is the trade-off between packaging increasing the shelf life of food productions and the limited circularity of packaging. While the monitor is not meant to provide general solutions to such trade-offs, many of them have been highlighted and further research will be needed to get more clarity into which circular strategy is to be followed in which situation. Also, given the need to discover what could be ‘circular targets’, additional research could focus as well on scenario development based on proposed targets.

4.2 Fulfilment of societal needs as a basis for monitoring

This report is a third application of the conceptual framework of the fulfilment of societal needs developed by Alaerts et al. (2019a), which aims to provide policy makers with more direct feedback by combining information from the macro to the micro level.

The food system is unique compared to the other three systems - mobility, housing and consumer goods – in the sense that the products in this system can only be used (= consumed) once and have a limited shelf-life. Typical ‘inner circle’ CE strategies which aim at increasing the number of uses per product, like reuse and sharing, cannot be applied in this system. Strategies to extend the lifetime of products, like smart packaging, help to ensure food products are used once, reducing waste, but cannot increase the number of uses for a product. Further, the production processes in this system strongly depend on biological inputs, which need to cycle through the biosphere and hence cannot be kept indefinitely in the economy. Production for this system is prominently present in Flanders, and can thus be influenced through policy, which was much less the case with e.g., the consumer goods and mobility systems. The monitor created in this report demonstrates that the need system framework is able to include production. Upon further elaboration of this system in the future, integration between the production and the consumption perspective is to be further developed. While handling this dichotomy is always challenging in environmental modelling and cannot be simply solved, the need system approach allows to highlight both production and consumption aspects and their interlinkages under one umbrella. Further, the food system, even more than previous systems, crosses policy domains. The presented framework allows to bring all relevant aspects together in one place.

In this study, CE is used as a tool to address and monitor the environmental challenges in the food system. However, also considering the social and economic challenges within this system will be crucial to enable the required environmental changes, and subsequently create a sustainable food system.

4.3 Data availability and governance

This study outlines a first step towards centralizing the available data on the food system in Flanders with the purpose of monitoring the transition of this system towards a CE. Because data gathering specifically for the purpose of CE monitoring is still in a start-up phase in Flanders, this monitor is set up with data already available for a different purpose. Therefore, it was not collected with CE monitoring specifically in mind, making it not unexpected that not all desirable data was available. Further, some of the data encountered is based upon certain assumptions, extrapolations or approximations. Interpretations based upon the report should be made with a degree of caution and sufficient understanding of the underlying methodologies.

It can be noted that for this system data was drawn from a very extensive group of stakeholders over multiple policy domains. In general, the different agencies and departments did seem well informed about the existence of other data sources. By putting together data from different sources and reframing it within the context of CE monitoring it was possible to give a first impression of what is known about the circularity of the food system in Flanders. In the future more and more intense policy initiatives in the context of food are to be expected. The data generated under such initiatives will help to complement this CE monitor, while the monitor may also contribute to enhance and align different initiatives and datasets. With the growing importance of CE in Flanders, more data gathering specifically for CE monitoring will be required to properly follow up the transition.

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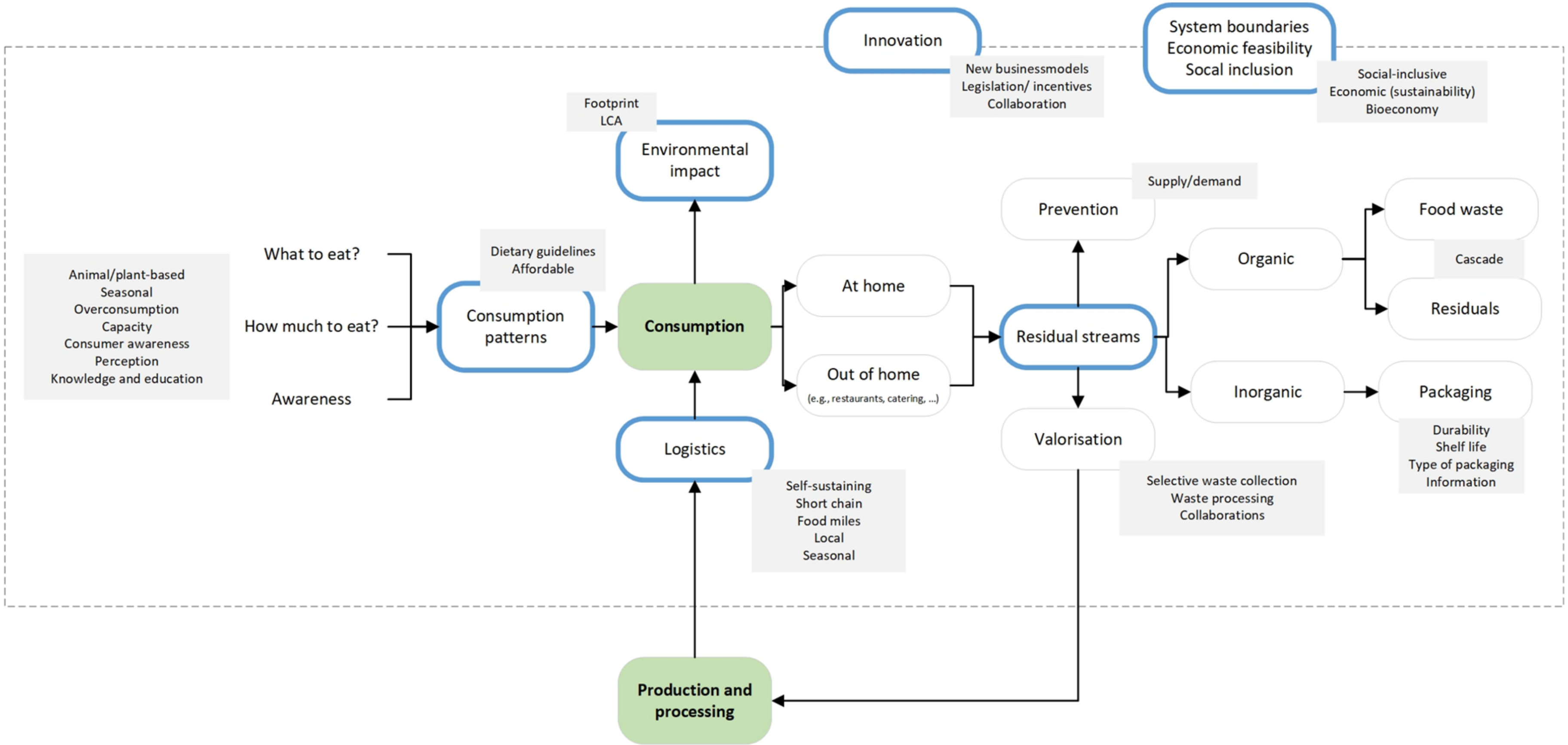
Appendix

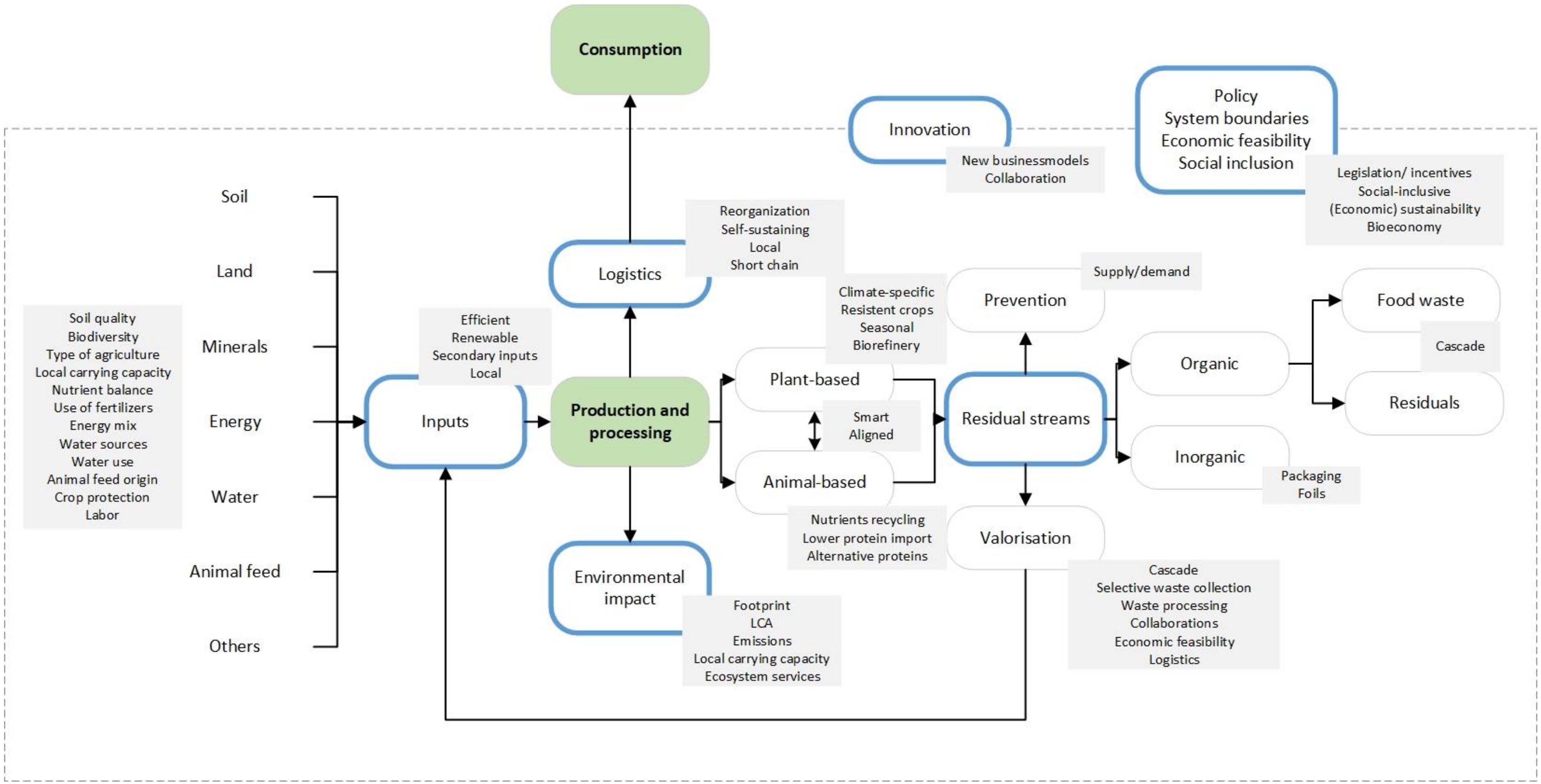
A1. Material and carbon footprint of the food system

		catering		drinks		food	
		CF	MF	CF	MF	CF	MF
animal based						**7.290**	**8.525**
Meat	01.1.2					3.922	5.166
Dairy products	01.1.4					2.488	2.190
Vis en schaal- en schelpdieren	01.1.3					880	1.170
plant based						**4.303**	**6.484**
Bread and cereals	01.1.1					2.028	2.552
Vegetables	01.1.7					1.169	1.614
Fruit	01.1.6					590	923
Suiker, jam, honing, chocolade en suikerwerk	01.1.8					516	1.396
combination						**1.433**	**1.709**
Oliën en vetten	01.1.5					366	451
Voedingsmiddelen, n.e.g.	01.1.9					1.067	1.258
Non-alcoholic	01.2			929	981		
Alcoholic	02.1			427	360		
Catering	11.1	2.834	2.672				
		2.834	**2.672**	**1.356**	**1.342**	**13.027**	**16.718**
						17.216	

A2. Delphi study

A2.I Schematic mapping of keywords





Consumption
Innovation
New businessmodels
Collaboration
Policy
System boundaries
Economic feasibility
Social inclusion
Legislation/ incentives
Social-inclusive
(Economic) sustainability
Bioeconomy
Soil
Land
Minerals
Energy
Water
Animal feed
Others
Soil quality
Biodiversity
Type of agriculture
Local carrying capacity
Nutrient balance
Use of fertilizers
Energy mix
Water sources
Water use
Animal feed origin
Crop protection
Labor
Logistics
Reorganization
Self-sustaining
Local
Short chain
Efficient
Renewable
Secondary inputs
Local
Inputs
Production and processing
Climate-specific
Resistent crops
Seasonal
Biorefinery
Plant-based
Smart
Aligned
Animal-based
Nutrients recycling
Lower protein import
Alternative proteins
Environmental impact
Footprint
LCA
Emissions
Local carrying capacity
Ecosystem services
Prevention
Supply/demand
Residual streams
Valorisation
Cascade
Selective waste collection
Waste processing
Collaborations
Economic feasibility
Logistics
Organic
Inorganic
Packaging
Foils
Food waste
Cascade
Residuals

A2.II Indicator list

	Indicator-theme	Definition
Production and processing	Land use	the use of land: amount (e.g., for plant- or animal-based food) and management (e.g., intensive or extensive use)
	Soil	the use of soil as input (including soil fertility, soil biodiversity, etc.)
	Minerals	the composition and (re)use of minerals and the losses to the environment (including nitrogen, phosphorus, potassium, and other trace elements)
	Energy	source and (re)use of energy
	Animal feed	origin, composition and use of animal feed
	Water	Source and (re)use of water
	Food waste	Food waste (edible) such as food surpluses on the land and food losses in the industry, retail, and auctions: amount and (cross-sectoral) reuse concerning waste collection and processing, taking into account the cascade of value retention*
	Residues	Residues (non-edible) such as surpluses on the land and losses in the industry: amount and (cross-sectoral) reuse concerning waste collection and processing, taking into account the cascade of value retention*
	Industrial packaging and other waste streams	Industrial packaging and other waste streams (e.g., foils and rock wool) in the production and processing of food: origin, use and (cross-sectoral) reuse concerning waste collection and processing
	Logistics and transport	logistics and transportation in the production and processing of food: logistics organization (e.g., central or decentralized), food miles, and its final destination (local, national, European, or international)
	Innovation	product and process innovation in the production and processing phase of food, like the design of products (e.g., concerning durability), digitalization, and new processes concerning end-of-life
Consumption	Food waste	Food waste (edible) at households and the hospitality industry: amount and reuse concerning waste collection and processing, taking into account the cascade of value retention*
	Residues	Residues (non-edible) at households and the hospitality industry: amount and reuse concerning waste collection and processing, taking into account the cascade of value retention*
	Consumer packaging	packages used at the consumption stage: origin, use and reuse concerning waste collection and processing
	Price	price(trends) of circular food, considering the environmental and/or social costs and the affordability of circular food
	Education and product knowledge	knowledge of circular food: education, awareness, transparency and knowledge sharing, through e.g., labels and packaging
	Innovation	innovative business models for a circular economy concerning consumption (e.g., new revenue models)
	Consumption pattern concerning origin	the share of local and seasonal food in consumption patterns, considering food miles
	Consumption pattern concerning diet	the share of animal- versus plant-based food, healthy food (e.g., 'nutriscore' or food triangle), and overconsumption

A2.III Results heterogeneity analysis

Four types of stakeholders were defined: 'Research and education', 'Governmental bodies', 'Sector federations and commercial organizations' and 'Non-profit organizations'. A latent class analysis was used to determine groups with similar preferences regarding the indicator themes, resulting in four groups. For 'production and processing', the respondents seem to be quite evenly divided over the four different groups, taking into account the group sizes and the number of experts belonging to a certain stakeholder category. For 'consumption', some stakeholder-related differences were found. A first group, which held more stakeholders from governmental bodies, showed a higher preference towards the indicator-themes 'consumption pattern - concerning diet' and 'education and product knowledge', while less preference was given to 'food residues'. Another group of respondents, which had more stakeholders from research and education, showed a higher preference towards the indicator-themes 'food residues' and 'consumer packaging', while the 'consumption pattern concerning origin' was moved to a lower-ranking position.

(1) Preference scores for 'production and processing' within each group, analysed using latent class analysis

Indicator-themes	Latent class analysis - Rescaled scores*			
	Groups			
	1	2	3	4
Food waste	13,73	21,37	15,41	19,06
Residues	1,04	22,10	18,44	10,80
Water	16,70	7,19	19,59	9,92
Minerals	3,79	8,82	5,75	17,96
Soil	8,72	1,88	10,90	19,31
Industrial packaging and other waste streams	13,75	13,38	2,04	1,16
Energy	8,17	3,12	18,16	3,01
Land use	16,04	2,48	0,71	10,06
Innovation	6,82	8,36	2,75	3,03
Animal feed	0,99	5,25	4,23	4,89
Logistics and transport	10,26	6,03	2,00	0,80

*It should be noted that these preference scores are calculated differently compared to the HB preference scores. Latent class provides a discrete model of respondent heterogeneity, whereas HB assumed a continuous model of heterogeneity following a multivariate normal distribution.

(2) Distribution of different stakeholder categories in the four defined groups for 'production and processing'.

Stakeholder category				
	Groups			
	1	2	3	4
Research and education	2	3	2	3
Governmental bodies	1	5	1	7
Sector federations and commercial organizations	2	2	2	1
Non-profit organizations	0	3	2	3
Total experts in a group	5	13	7	14

(3) Preference scores for 'consumption' within each group, analysed using Latent Class analysis

Indicator-themes	Latent class analysis - Rescaled scores*			
	Groups			
	1	2	3	4
Food waste	21,81	29,43	29,74	16,56
Consumption pattern concerning diet	27,33	0,70	28,58	3,53
Consumption pattern concerning origin	21,71	9,60	9,41	32,24
Residues	1,25	23,97	14,31	2,57
Innovation	6,17	18,04	4,02	3,91
Price	13,61	0,42	3,69	11,05
Consumer packaging	1,04	10,62	7,96	13,75
Education and product knowledge	7,07	7,23	2,29	16,40

*It should be noted that these preference scores are calculated differently compared to the HB preference scores. Latent class provides a discrete model of respondent heterogeneity, whereas HB assumed a continuous model of heterogeneity following a multivariate normal distribution.

(4) Distribution of different stakeholder categories in the four defined groups for 'consumption'.

Stakeholder category				
	Groups			
	1	2	3	4
Research and education	2	2	6	0
Governmental bodies	7	3	4	1
Sector federations and commercial organizations	1	1	1	3
Non-profit organizations	2	2	2	2
Total experts in a group	12	8	13	6

A3. Land-use change in Flanders between 2013 and 2019

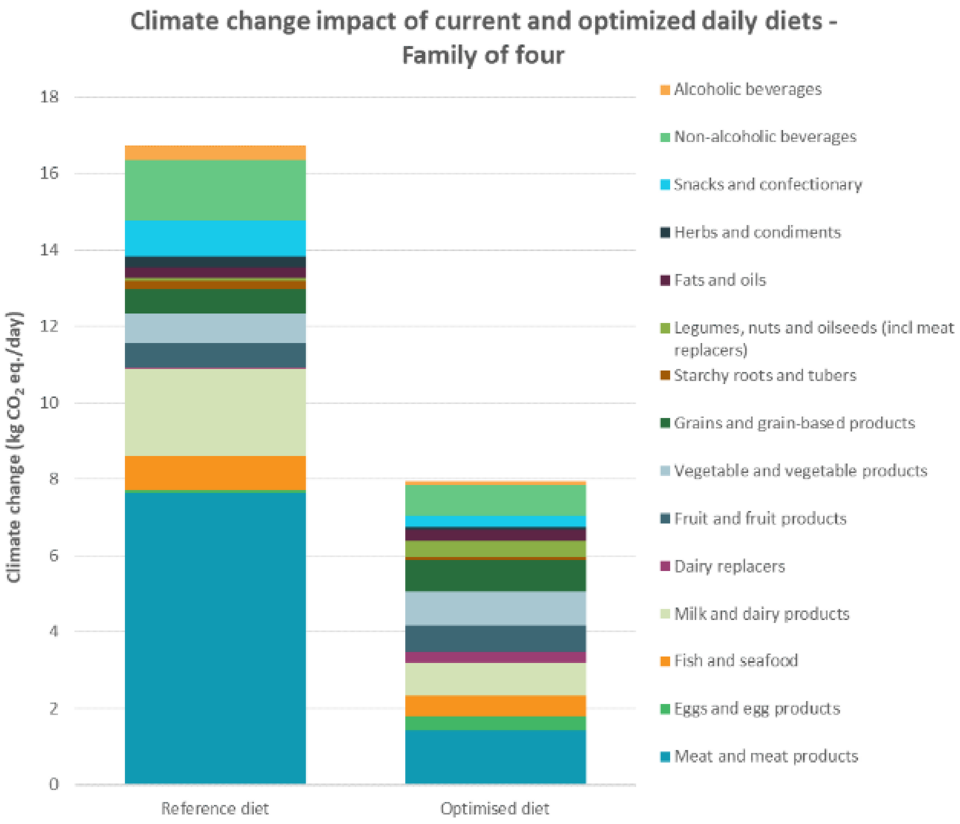
Land-use change ‘from’ and ‘towards’ between 2013 and 2019 in ha

Van / Naar	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Totaal in 2019
1	150084	2186	753	1574	42	482	720	8606	2934	0	0	448	572	2349	199	28	27	1	171004
2	2042	30977	621	1337	50	68	118	903	473	12	0	165	271	768	341	38	29	4	38216
3	841	673	4622	248	11	75	54	363	129	0	0	25	36	128	23	5	4	0	7235
4	1780	1537	260	12978	18	340	43	649	319	0	0	89	75	295	134	7	5	7	18534
5	110	82	19	79	79640	143	3	127	780	4	0	273	250	752	179	48	45	7	82541
6	388	81	69	420	22	29705	32	233	230	1	0	457	48	580	77	7	78	4	32433
7	900	70	9	36	2	8	6729	671	320	0	0	21	462	618	2	18	6	0	9870
8	7237	461	200	376	28	155	499	26802	2799	2	0	737	1329	4111	215	53	61	6	45069
9	1477	510	82	167	255	183	145	2335	38757	18	0	436	121	1062	200	49	106	21	45924
10	0	12	0	0	1	0	0	1	0	1008	0	16	9	71	36	11	19	0	1185
11	0	0	0	0	0	0	0	0	0	0	1475	0	0	0	0	0	0	0	1475
12	139	121	77	31	71	477	5	482	312	5	0	129216	1058	5413	1966	123	140	209	139842
13	140	42	9	8	7	40	30	675	253	12	0	744	368070	45689	178	111	47	11	416065
14	478	175	14	49	74	211	56	1576	473	11	0	3746	38723	230251	889	443	333	89	277592
15	26	136	12	28	33	157	1	124	249	27	0	2602	220	2600	24732	190	86	96	31320
16	10	44	0	4	13	9	7	57	25	2	0	182	217	875	117	4802	150	17	6532
17	19	32	3	6	26	150	2	61	105	99	0	565	402	1901	290	279	29457	213	33610
18	1	4	0	0	4	23	0	2	51	0	0	202	18	360	109	2	101	3117	3995
Totaal in 2013	165670	37145	6749	17338	80298	32226	8444	43665	48208	1199	1475	139924	411881	297822	29688	6215	30694	3803	1362444

1	2	3	4	5	6	7	8	9
Huizen en tuinen	Industrie	Commerciële doeleinden	Diensten	Transportinfrastructuur	Recreatie en sport	Landbouwgebouwen en -infrastructuur	Overige bebouwde terreinen	Overige onbebouwde terreinen
10	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Groeves	Luchthavens	Bos	Akker	Grasland	Struikgewas	Braakliggend (onbegroeid) en duinen	Water	Moeras

Source: VITO - *(Poelmans et al., 2021)*

A4. Diets in Belgium optimized for GHG emissions



Source: WWF (te Pas et al., 2021)

A5. Monitoring consumption

Food balance sheets

The first alternative data source to track food consumption are food balance sheets (FBS), which provide food consumption information at national level. FBS are derived from official primary commodity production data, and primary and derived commodities trade data (FAO, 2018). FBS are not a direct source of food intake, but instead indicate how much food was available for consumption on the internal market of a country. Due to this any food waste will be reported as consumption, while any home-grown products are not accounted for. The data from FBS should be considered as 'apparent intake' and not 'actual intake'. Further, the data cannot be disaggregated across different population characteristics and is only available at national level. The main advantage of food balance sheets is that they can be compiled relatively inexpensively, yearly and are available for almost all countries (FAO, 2018). Additionally, FBS can be compiled for different principal products (e.g., grain/meat/fruit/…), however the final product in which it is consumed is unknown (e.g., bread). As an example, figure 41 shows the apparent consumption of meat, as compiled by Statistics Belgium.

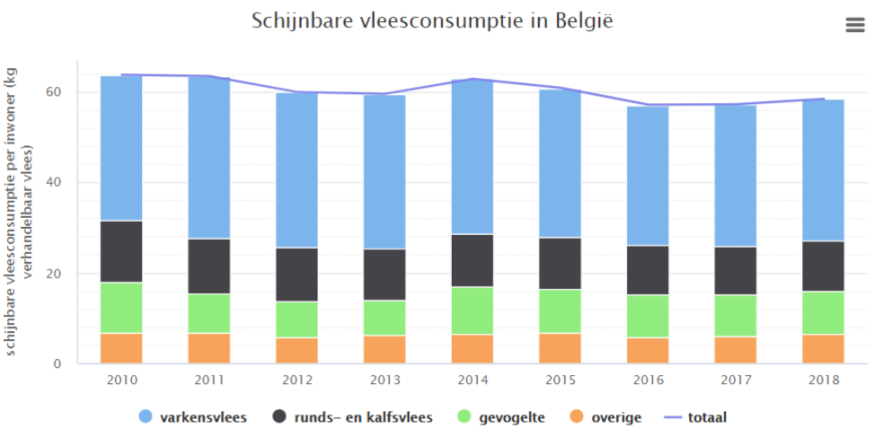


Figure 41 – Food balance sheet for meat, Belgium, 2010-2018
(source: Statistics Belgium)

Household consumption and expenditure survey

Another possible indirect source of consumption data are Household Consumption and Expenditure Surveys (HCES). Every other year the federal government of Belgium conducts a household budget survey, for which the data can be disaggregated to Flanders. Most EU member states also conduct household budget surveys according to the same methodology making comparisons possible. The data is available at household, not individual, level, meaning that the food distribution between household members is unknown, and is apparent consumption, meaning aspects like food waste and home grown products are not accounted for (FAO, 2018). Further, the data only covers products bought for at home consumption, meaning out-of-home consumption is not taken into account. At European level conversion factors are determined to convert the financial data from household budget surveys to estimated mass. Estimates for Belgium are available to policy research centre and shown in Figure 42.

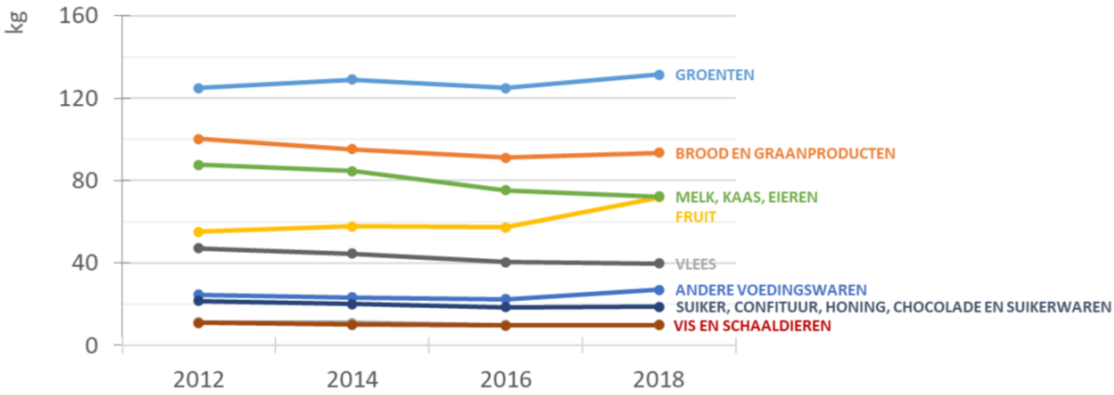


Figure 42 – Evolution in consumption based on household budget survey, Belgium, 2012-2018
(source: calculations of Policy Research Centre for CE based on household budget survey by Statbel)

Consumer panel

Inhouse food consumption of fresh products is tracked by GfK on behalf of VLAM, the agricultural marketing agency of Flanders. Their numbers are based on purchasing data, only giving an indication on 'apparent intake'. Further, it only considers inhouse consumption of fresh products, leaving out processed foods and consumption which occurs outside of the home (e.g., restaurants). Hence trends in consumption can also be explained by a shift to processed foods or an increase in out of home dining. The main advantage of this data source is that updates are made available every quarter. Figure 43 shows the evolution of at home consumption in Flanders as reported by VLAM.

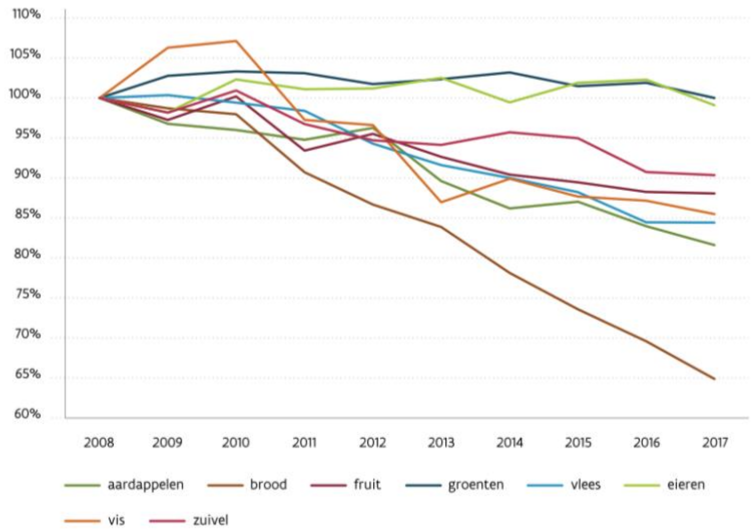


Figure 43 – Evolution in inhouse consumption of fresh foods in Flanders, 2008-2017
(source: GfK on behalf of VLAM, figure: (Platteau et al., 2018)*)*

Proxy indicators

Lastly, proxy indicators on consumption - like the number of vegetarians - are often used to say something about shifting diets as they are relatively easy and inexpensive to obtain. They however only provide limited information, as any efforts of consumers to reduce aspects like portion size are not reflected.

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