Food waste in cities: an urban metabolism approach applied to Paris and Île-de-France

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Summary

Social metabolism is the social systems' throughput of energy and material, its application to cities is called urban metabolism. Quantifying and analysing socio-metabolic flows is crucial for sustainability policies seeking to reduce resource use and waste generation. Although it is a priority on the political agenda, the massive generation of food waste reported for high-income societies has been largely neglected in urban metabolism research. The aim of this interdisciplinary PhD thesis is to develop a method to quantitatively analyse urban societies' food metabolism and its determinants with respect to food waste.

The thesis' main focus is on characterizing and quantifying the urban food metabolism. This quantitative part looks at case studies of the French capital Paris and its neighbouring areas of the Île-de-France region, in the year 2014. Novelty lies in the development of an accounting tool, namely a hybrid method of material flow analysis and a food system approach, in the definition of the eating population (surprisingly smaller than the resident population) and in the consistent compilation of various data sets so far unused in urban metabolism studies. The results show that the urban food metabolism of Paris and its region is characterized by significant levels of food waste. 19% and 22% of food, excluding drink, ended up uneaten and turned to food waste in the food supply of the eating population in Paris Petite Couronne and Île-de-France, respectively. Moreover, little food waste was collected separately from other waste and recycled. The consumption stage alone accounts for a significant share of food waste from both in-home and out-of-home consumption. Part of this food waste could be avoided, as it initially was food that could have been saved and used for human consumption, had it been handled differently.

The urban metabolism becomes more legible when it is recognized as embedded in cultural practices and social institutions, another focus in this thesis. At the consumption stage, the literature review demonstrates that food waste is not only the result of individual action, but of practices shaped by broader societal processes, such as changing lifestyles and consumption norms in affluent societies. Inappropriately, current food waste reduction policies consider neither the systemic characteristics of the urban food metabolism, nor the interconnectedness between food and waste, nor yet the multiple determinants of food waste origin. Avenues for research include inquiry into how societies respond to the opportunity to reduce food waste, when the context is one of oversupply and perceived abundance of food, and a still largely invisible phenomenon of food waste. Cultural studies can help to understand how societies change their cultural practices and social institutions with a view to food waste reduction under a multi-faceted sustainability discourse.

Zusammenfassung

Städtischer Metabolismus, eine Form des gesellschaftlichen Metabolismus, bezeichnet die Gesamtheit der Energie- und Stoffströme, die durch das Wirken von Städten mobilisiert werden. Die Mengenbestimmung und Untersuchung dieser Ströme sind bedeutsam für die Erarbeitung von Strategien, die den Ressourcenverbrauch und die Abfallerzeugung senken sollen. Trotz seiner hohen Stellung auf der politischen Tagesordnung wurde das massive Wegwerfen von Essen, das insbesondere in den reichen Ländern dokumentiert ist, in Studien über städtischen Metabolismus bisher wenig beachtet. Ziel dieser interdisziplinären Dissertation ist es, eine Methode zur Mengenbestimmung des städtischen Lebensmittelmetabolismus zu entwickeln und verschiedene Faktoren zu untersuchen, die das Wegwerfen von Essen beeinflussen.

In der Dissertation wird zuerst der städtische Lebensmittelmetabolismus beschrieben und mengenmäßig bestimmt. Dieser quantitative Teil stützt sich auf eine Fallstudie über die französische Hauptstadt Paris und die umliegenden Gebiete innerhalb der Île-de-France Region im Jahr 2014. Es wurde eine hybride Methode zur Mengenbestimmung bestehend aus einer Stoffstromanalyse und des Ansatzes des Ernährungssystems entwickelt. Weiterhin wurde die essende Bevölkerung definiert und in der Größe bestimmt (niedriger als die ansässige Bevölkerung) und mehrer Datensätze zusammengetragen, die teils bisher noch nicht in Studien zum gesellschaftlichen Metabolismus verwendet wurden. Die Ergebnisse zeigen, wie groß der Strom der Lebensmittelabfälle ist. 19% und 22% der Menge an Lebensmitteln, ohne Getränke, zur Versorgung der essenden Bevölkerung in Paris Petite Couronne und Île-de-France sind Lebensmittelabfälle. Ein geringer Anteil wurde getrennt gesammelt und verwertet. Der häusliche und Außer-Haus-Verzehr allein trägt dazu bedeutend bei. Ein Teil dieser Abfälle, nämlich der aus weggeworfenem Essen, könnte vermieden werden, wenn Essen anders gehandhabt würde.

Das Verständnis des städtischen Metabolismus wird bereichert, wenn er eingebettet in kulturelle Praktiken und soziale Institutionen betrachtet wird, ein weiterer Aspekt dieser Dissertation. Der Literaturüberblick zeigt, dass das Wegwerfen von Essen zu Hause und außer Haus nicht alleine eine Folge individueller Handlungen ist, sondern von Praktiken unter dem Einfluss gesellschaftlicher Prozesse, wie Änderungen im Lebensstil und in den Konsummaßstäben wohlhabender Gesellschaften, ausgeht. Im Gegensatz dazu berücksichtigt Politik, die darauf abzielt, das Wegwerfen von Essen zu vermindern, weder die systemischen Züge des städtischen Lebensmittelmetabolismus, noch die Verknüpfung zwischen Essen und Abfall und auch nicht die zahlreichen Faktoren, die das Wegwerfen von Essen bedingen oder fördern. Forschungsbedarf besteht darin zu untersuchen, wie Gesellschaften der Einladung weniger Essen wegzuwerfen gegenüberstehen, wenn der Konsumkontext von Überversorgung und vermeintlichem Überfluss geprägt ist und das Wegwerfen von Essen weitestgehend unsichtbar bleibt. Der Beitrag der Kulturwissenschaft kann darin liegen zu verstehen, wie Gesellschaften ihre kulturellen Praktiken und sozialen Institutionen hinsichtlich des Wegwerfens von Essen und in Anbetracht von Nachhaltigkeit weiterentwickeln.

Résumé

Le métabolisme urbain désigne l'ensemble des flux d'énergie et de matières mis en jeu par le fonctionnement d'une ville ; il constitue une déclinaison localisée du métabolisme social. La quantification et l'analyse de ces flux sont cruciales pour la définition de politiques qui visent à réduire la consommation de ressources et la production des déchets. Malgré sa mise à l'agenda politique, la génération massive des pertes, gaspillages et déchets alimentaires, documentée en particulier dans les pays des Nords, n'a été analysée qu'à la marge dans les recherches sur le métabolisme urbain. L'objectif de cette thèse interdisciplinaire est de développer une méthode de quantification du métabolisme alimentaire urbain et d'analyser ses déterminants en lien avec les pertes, gaspillages et déchets alimentaires.

La thèse aborde en premier lieu la caractérisation et la quantification du métabolisme alimentaire urbain. Cette partie quantitative s'appuie sur une étude de cas de la capitale française, Paris, et des territoires adjacents de la région Île-de-France, en 2014. Elle repose sur le développement d'un outil de quantification hybride associant analyse de flux de matière (AFM) et analyse du système alimentaire, sur la définition de la population qui mange (inférieure en taille à la population résidente), et sur la compilation de plusieurs jeux de données, dont certains n'avaient pas été mobilisés à ce jour. Les résultats montrent l'importance du flux de déchets alimentaires. Une part de 19% et 22% des denrées alimentaires, hors boissons, qui approvisionnent la population qui mange à Paris Petite Couronne, d'une part, et en Île-de-France, d'autre part, n'est pas consommée et devient un déchet ; une faible partie est par ailleurs collectée séparément pour être recyclée. L'étape de la consommation seule, à domicile et hors foyer, y contribue de façon significative. Une partie de ces déchets alimentaires pourrait être évitée par la réduction des pertes et gaspillages et une meilleure gestion de la nourriture.

Le métabolisme urbain devient plus lisible lorsqu'on reconnait qu'il est intégré dans des pratiques culturelles et des institutions sociales, deuxième aspect abordé dans la thèse. La revue de la littérature montre qu'au stade de la consommation, les pertes et gaspillages ne sont pas seulement le résultat d'actions individuelles, mais de pratiques sous influence de processus sociaux plus larges, comme des changements de styles de vie et de normes de consommation dans des sociétés à revenu élevé. A l'opposé, les politiques de réduction des pertes et gaspillages ne tiennent compte ni des caractéristiques systémiques du métabolisme alimentaire urbain, ni de l'interconnexion entre nourriture et déchets, ni même des multiples déterminants à l'origine des pertes et gaspillages. Des pistes de recherche consistent à explorer la question de savoir comment les sociétés répondent à l'opportunité de réduire les pertes et gaspillages, lorsque le contexte est celui d'un sur-approvisionnement, d'une supposée abondance et d'un phénomène des pertes et gaspillages largement invisible. Les études culturelles peuvent aider à comprendre comment les sociétés font évoluer leurs pratiques culturelles et leurs institutions à l'égard de la réduction des pertes et gaspillages dans un contexte de transition socio-écologique.

Introduction

How large are the annual food inputs into a city? How much of this food is left over, discarded and turns to waste? How is the urban food supply chain structured and organized? How much food waste is generated at each stage in the supply chain? These are simple questions. One would expect that the answers would be known and the corresponding data and metrics would be available at city or metropolitan area levels, by local governments or public authorities –, especially since the governments of many cities worldwide have committed to developing sustainable food systems to make healthy and accessible food available to all, to protect biodiversity and the climate, and to cut down food waste. The media have aroused interest in urban innovation for future smart and sustainable cities, in areas ranging from urban agriculture to smart mobility or housing. One might expect that the basic characteristics to describe the food system of a city would be known, including the food requirements of the local population, for example, so that solutions may be customized and their impacts assessed.

Yet this is not the case. Surprisingly, there is no simple answer to our initial questions and no single data source is available where one can look up the figures of the amounts of food required, handled, eaten or discarded at the city scale. As a result, what and how much food gets consumed and what and how much gets wasted in cities is largely unknown.

Some aspects of urban food systems have been nevertheless instrumental for the development of cities and have consequently attracted the attention of researchers and policy makers early on. Cities' food supply is one example of an instrumental aspect, closely related to the urban phenomenon as such. In human history, the emergence of villages and later cities depended on their ability to organize their food supply and to rely on provisioning from their hinterland. The surrounding areas, both close and remote, have been key to their consumption of food, fuel, construction and other resources, of which the limited urban area can supply only a negligible part. After all, one of the characteristics of cities is that they do not produce their own means of subsistence (Ascher, 2001).

Van der Leeuw argues that the real driver of urbanization is information processing, whereas energy is the constraint (van der Leeuw, 2018). Information processing is largely enhanced through proximity between people and thus generates possibilities of organization to shape relations with the hinterland for food supply. Access to energy, innovation in new transport systems (ship, rail, road), and later, industrialization of agriculture, have been shown to be pivotal for urban growth (Rutter and Keirstead, 2012). As more food and feed could be produced and transported and transport distances lengthened, the size of the supplying hinterland grew larger. The whole food system became increasingly dependent on fossil fuels, putting more and more pressure on the planet's ecosystems.

At the same time, what cities discharged and how they organized their urban metabolism changed as well. As historians have shown, prior to the invention of chemical fertilizer, any type of used matter was redirected to other purposes, reused and recycled by the means of a dedicated system of collectors and traders. Excreta for example from humans and the many animals living in the city were collected for use as fertilizer for peri-urban market gardening. Not until the discovery of substitute sources of mineral fertilizer – and particularly that of the chemical process of nitrogen fixation by Fritz Haber and Carl Bosch at the turn to the 20th century, laying the ground for the industrial production of explosives and fertilizer – did excreta lose this function and become useless waste.

Previously unknown as a material category in a city's social organization, waste rapidly became a symptom of the consumption-oriented high-income societies of the 20th century, the origin of over-consumption of the planet's resources and a source of pollution in even the remotest places on earth, including water bodies, soil and the atmosphere (Monsaingeon, 2017). The waste debate has become a new focus of attention in the public arena, along with food waste, as it highlights the extreme characteristic of a society that disregards the fundamentally vital nature of food and considers everything as disposable.

Cities are instrumental in the transformation of societies, precisely because they concentrate populations and income, which are the drivers not only of societal pressure on the environment but also of innovation (Grubler et al., 2012). A city's food supply and disposal of waste account for an important part in society's overall pressure on the environment, as food systems have large implications in the ways in which land, water and energy are used. Profound changes in the way human societies manage their material and energy use are inevitable if their aim is to maintain planet earth in a habitable state for humans (Steffen et al., 2015). Humanity is however currently taking a different path, as the figures of the global ecological footprint illustrate. On 31 July 2019, humanity's demand for ecological resources and services consumed what Earth can regenerate in one year. Since the first calculations of the so-called Earth Overshoot Day in 1970, the trend shows a progressive shift of the date to earlier in the year. In 2020, when the Covid-19 pandemic hit the global population, the greatest ever single-year shift the other way could be seen, as the estimated date moved back, to August 22nd (Global Footprint Network, 2020). The size of the shift related to the drastic restrictions in the everyday movements and organization of daily life of a large share of the world's population gives a glimpse of the extent of efforts required to radically cut global material and energy use.

The Covid-19 pandemic not only showed that an almost complete standstill of large parts of the economy, such as tourism, the food service industry and culture, and a decrease of household consumption are insufficient to solve the global ecological crisis. COVID-19 has also revealed critical weaknesses and inequalities in people's access to essential goods and services, in both health and food systems (IPES-Food, 2020). Previously thought to be restricted to the context of low-income countries, questions of vulnerability and resilience emerged for food systems at a larger scale, at the forefront of society's fundamental concerns. In a much more sudden way than the ecological crisis but complementary to it, the Covid-19 pandemic has given some idea of opportunities in the transformation of food systems, through territorialization and a more prominent role for public authorities (Caron, 2020).

All in all, there is an overarching need to gain more knowledge, through quantitative and qualitative methods, about urban food systems. Their transformation as a contribution to more sustainable forms of human settlements can meaningfully support other efforts undertaken by societies to face sustainability and global change.

The scientific literature is characterized by a lack of analysis of cities' food systems seen through the lens of their resource and material use exchanged with the natural environment and regulated by society. Yet food systems are major contributors to the human-driven pressure on the planet. Food and feed for livestock constitute approximately one third of the overall material metabolism of industrial societies. The lack of knowledge about the biophysical dimension and its regulation in urban food systems, with special consideration for food waste, has been a motivation for this research.

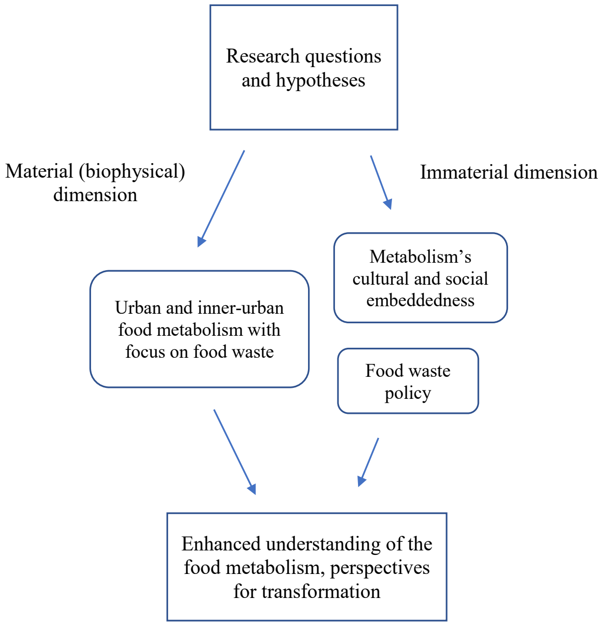
The social metabolism framework

To scientifically address human society's interaction with nature, societies' food use, like any other material use, can be expressed through the framework of social metabolism. Social metabolism refers to the way in which human societies organize their exchanges of energy and materials with their natural environment (Fischer-Kowalski and Hüttler, 1999). Humans socially organize the extraction of matter and energy from nature in order to sustain and reproduce themselves. Social metabolism borrows a concept from biology and applies it to the relations between human societies and nature. Rooted in the interdisciplinary fields of social ecology, industrial ecology and territorial ecology, and more broadly belonging to socio-ecological studies (Fischer-Kowalski and Haberl, 2007), social metabolism refers to the set of theories (Fischer-Kowalski and Weisz, 1999; Weisz et al., 2015) and methodological tools that allow the biophysical dimension of a society's functioning to be analysed through material and energy flows, similarly to the way economies can be described through monetary flows. In addition to flow analysis, social metabolism studies seek to gain knowledge about the actors, institutions, policies and techniques that shape the metabolism and explain why it is as it is. Thus, the social metabolism framework affords an enhanced understanding of both the material and the immaterial dimensions of societies' material metabolism (Barles, 2010; Haberl et al., 2016).

Using France's capital region of Paris Île-de-France as a case of a city's food metabolism, this study draws on the prosper urban metabolism research on food systems (Barles, 2010, 2009; Billen et al., 2009; G. Billen et al., 2012)[1] initiated in the French scientific community. As a central part in the operationalization of this research, I used a biophysical accounting method in the form of the standardized framework of material flow analysis, and developed a hybrid method by coupling it with a food system approach adapted to the purpose of this research. For policy and cultural and social embeddedness as the immaterial aspects of the metabolism, I used qualitative data. Thus altogether, data collection included a wide array of sources, the use of mass balances, scientific and grey literature, policy documents, and interviews with representatives of some selected sectors of the Paris Île-de-France food system (see Table A0.1 in Appendix to Introduction). The data collection process benefited from my participation, between October 2017 and April 2018, in the meetings of two working groups, one working on food waste and the other on organic recycling. These meetings were convened by the regional government of Île-de-France in the course of the preparation of a regional planning tool for waste management. Figure 1 shows how the different parts of this research are integrated within the overall research project.

[1] See Chapter 1 for a comprehensive review of this literature.

Figure 1. Scheme of integration



Source: author

Defining the scope of this study with the urban metabolism literature

Most of the urban metabolism literature has addressed nutrient flows with the goal of reducing waste flows (Barles, 2007; Esculier and Barles, 2020; Forkes, 2007; Svirejeva-Hopkins et al., 2011). Although the present research also looks at waste, the particular case of food waste is an opportunity to take a broader perspective on the use of food, prior to it becoming waste, and to analyse the individual stages of the urban food metabolism in a city. Hence, linear versus circular metabolism was not the focus of this research, and food waste management was beyond the scope the study. While a rough representation of the organic treatment technologies (composting and anaerobic digestion) of the separately collected food waste treated in Île-de-France is addressed, the destinations and technologies of food waste treatment elsewhere were not analysed within this research project.

The hinterland of the Paris Île-de-France food system has not played a role in this research. In contrast to previous work which provided evidence of the expansion and diversification of the supplying hinterland over time, for the food supply of the Île-de-France region (by

Chatzimpiros, 2011, and Bognon, 2014), and for the energy supply (by Kim, 2013), the equivalent absorbing hinterland of food waste components has not been examined. This is consistent with the fact that food waste management in general was not my focus.

While questions of waste management were clearly excluded from the beginning on of this doctoral thesis, others were planned to be part of it at an early stage. Early ambitions stemmed from a comparative study of the respective food metabolisms, taking as cases the European capital regions of Paris, Berlin or optionally, Vienna. It soon became clear however that the development of the method occupied much more place in this study than initially planned, and that as a result the comparative part had to be cancelled. The hybrid method developed in this research requires a considerable effort in data collection for the food metabolism study. Publicly accessible data sources were not enough to fill the data requirements. Interviews with representatives of some industries of the Paris Île-de-France food system helped to complete the data.

Furthermore, in the tradition of long-term socio-ecological studies, the evolution of the composition and quantity of food waste since the second half of the 20th century would have been interesting to study. Our assumption would have been that there is a link to the changing features of industrializing food systems, as the food industry and mass retail through supermarkets emerged. Unfortunately, the experience during this research has shown that industry-specific food waste data on the past are not easier to obtain than data on the present.

Synopsis of the manuscript

The manuscript is structured in six chapters and completed by the present Introduction and by the Conclusions. The structure of the manuscript reflects the interdisciplinary nature of this thesis. Chapter 1 presents a multidisciplinary body of literature, from science, policy and examples of the civil society movements which together show the importance of a socio-ecological transformation in food systems and cities with respect to sustainability and global change. Specifically, I derived my research question and the three propositions from the socio-metabolism literature of the closely connected fields of social ecology, industrial ecology, and territorial ecology.

Chapter 2 describes how I operationalized the concepts from the social metabolism framework to test the propositions and obtain empirical evidence in the form of quantified food and food waste flows, taking Paris Petite Couronne and Île-de-France as case areas. Operationalization of the social metabolism framework required to build an original method including a quantitative tool for the flow analysis, which was itself hybrid as it was combined with a food systems approach. This chapter lays the groundwork for the definition of food and food waste.

The following two chapters, Chapter 3 and Chapter 4, go deeper into operationalization by presenting the data sources and assumptions used for the quantification of the food metabolism. Both chapters present and discuss the results of the food flow analysis for the respective scales of analysis. Chapter 3 presents the analysis of food and food waste flows that enter and exit a city according to the main input and output flows but disregarding distinct food system sectors. Chapter 4 presents the analysis of inner-urban flows by using a sector-wise food system approach to see how food and food waste pass through the food supply chain within the city.

The findings presented in the respective chapters for distinct parts of the urban food system are integrated and discussed together in Chapter 5, which also presents the complete food flow results, visualized in the form of Sankey-diagrams (see A0.1 Appendix to Introduction). These diagrams are the most detailed quantitative representation of the inner-urban part of the urban food metabolism of Paris Île-de-France, structured according to the food system sectors. The transversal gaze on the urban food metabolism through a systems approach combined with a sector-wise approach enhance our understanding of the food waste phenomenon in cities. The second part of Chapter 5 adds aspects for understanding food waste by looking at the regulation of food waste flows through policy. A qualitative analysis of policy documents aimed at food waste reduction show how target, scale of intervention, and policy instruments at various and complementary administrative scales build a joint but complex policy framework. They also show where the priorities are set and action is taken.

Chapter 6 wraps up the study with a cultural and social perspective on food waste generation. In the Conclusions that follow, the first section is dedicated to a summary of the key results of this research as an empirical answer to the main propositions. A second part draws conclusions from this research with respect to the scientific interdisciplinary field of social ecology, industrial ecology, and territorial ecology, and establishes recommendations in terms of the method and data. Avenues for future research and recommendations for policy close the study.

Apart from editing this thesis manuscript, I presented results of this research at the annual conference of the Royal Geographic Society in August 2018, in Cardiff/Wales, and at the biannual conference of the socioeconomic metabolism (SEM) section of the International

Society of Industrial Ecologie (ISIE), in May 2019 in Berlin/Germany. Together with my supervisors, I published a review paper entitled "Are waste hierarchies effective in reducing environmental impacts from food waste? A systematic review for OECD countries" in the scientific journal *Resources, Conservation and Recycling*, in May 2020[2] (Redlingshöfer et al., 2020).

[2] Redlingshöfer, B., Barles, S., Weisz, H., 2020a. Are waste hierarchies effective in reducing environmental impacts from food waste? A systematic review for OECD countries. *Resour. Conserv. Recycl*. 156, 104723. https://doi.org/10.1016/j.resconrec.2020.104723

Chapter 1: Theoretical background

Food systems are an essential element of the social metabolism, by which human societies are connected to their natural environment. Food as such is always physical and material since it is composed of nutrients and water embedded in a matrix, produced through essential natural resources such as land, water and energy. The extent to which human societies have used natural resources to feed themselves has increased massively in the course of industrialization and makes further expansion a threat to the planet (Springmann et al., 2018). For the sake of cross-planetary equity, a socio-ecological transformation[3] of the industrial food metabolism can be an option but must be better understood.

Section 1.1 of this chapter presents a pluri-disciplinary body of literature, from science, policy and examples of civil society movements, at the interface of food systems and cities, taking sustainability and their socio-ecological transformation as a common denominator. It offers insights into the various aspects of a socio-ecological transformation – be it already underway or desired – of food systems embedded in an urban context. Such a broad perspective on the transformation of food systems in cities is key to understanding the role that possible options for transformation can play. Food waste reduction as one example of a transformation option that has received extensive media and policy attention in recent years is described within this larger context.

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[3] By socio-ecological transformation, I refer to a set of changes in the functioning of a system which are consistent with the socio-ecological transition. They may however not reach far enough, and be major changes, so as to initiate a new stage of functioning, as the term transition implies. Like transition, the transformation of an urban food system, analysed in this thesis through the urban food metabolism, must have as a target a functioning compatible with the one of the biosphere. The fact that today, the situation of urban food systems in the context of industrialized societies is far from this target, as outlined in this chapter, is the result of an increasing use of energy and material, driven by access to fossil energy (Krausmann et al., 2016). Yet this is not an inherent characteristic of urban food systems. It is the result of the social organization of the food system by all the actors involved, under the influence of economic, technical, social, cultural, and political factors. As a consequence, the transformation of urban food systems, for example through an increased supply of food produced according to the principles of agroecology, reduced food loss and waste, and a higher share of plant-based diets, is always a socio-ecological transformation. Its aim is to enhance food system sustainability.

The material implications of urban food consumption have been the topic of a growing body of empirical literature in the closely connected interdisciplinary fields of social, industrial and territorial ecology (see Section 1.2). The theoretical approach chosen in this research is anchored in these fields. They both offer joint concepts and tools to analyse interconnected society–nature relationships through their material dimension. The section illustrates through a non-exhaustive literature review how the concept of societies' metabolism is used to study food flows as the material expression of the relationship between human societies and nature.

The problem set in the societal and theoretical contexts leads to the definition of the research question and propositions in Section 1.3.

1.1. Urban food systems as a node of sustainability issues

Cities have recently displayed the ambition to engage in the sustainable transformation of their food systems[4] (Brand et al., 2019), as illustrated by the Milan Urban Food Policy Pact[5] and the flourishing individual urban food policy initiatives in many cities worldwide, often in industrialized countries. Morgan and Sonnino (2010) show that the initial motivation of the earliest cities to focus on food issues was related to residents' health and rising obesity rates[6]. They note that cities have become "an obesogenic environment due to the predominance of energy-dense foods on the one hand and the lack of opportunities for physical mobility on the other", and argue that "obesity is not so much an urban problem per se as a problem of poor people in an obesogenic urban environment" (Morgan and Sonnino, 2010: 210). Motivation for urban food policy then extended to

[4] The urban food system is understood here as a network of food-related activities driven by the urban demand for food and that hence includes activities which lie both within and outside of the boundaries of a city.

[5] The Milan Urban Food Policy Pact was launched by the Milan Municipality in 2015. It groups together cities worldwide around an agreement committed "to develop sustainable food systems that are inclusive, resilient, safe and diverse, that provide healthy and affordable food to all people in a human rights-based framework, that minimize waste and conserve biodiversity while adapting to and mitigating impacts of climate change" ("Milan Urban Food Policy Pact," n.d.).

[6] Morgan and Sonnino's (2010) analysis of the initial motivation for urban food policy seems to generalize for cities of Europe and North America, the most cited examples. Despite relatively close geographic and/or cultural proximity, it could be that motivations vary. The example of the origins of alternative systems of food distribution (community-supported agriculture or *Agriculture pour le maintien de l'agriculture paysanne* (Amap) in France, farmers markets, community gardens, etc.) has shown that food security was a strong motivation in North America, whereas in Great-Britain it was local and quality food and rewards producers, and in France and Italy, gastronomy, the Slow Food movement and lastly the conservation of a peasant farming model (Deverre and Lamine, 2010).

encompass the multiple dimensions of sustainability, including the environment and social equity concerns. Pivotal in sustaining recent trends of rapid urbanization and population growth of cities worldwide [7] (United Nations-Department of Economic and Social Affairs-Population Division, 2018), industrialized agri-food systems are criticized for their role in many adverse effects. While feeding a growing number of people, particularly due to high productivity rates in agricultural production, they have multiple negative effects on the health of populations and of the planet. The concept of One Health encapsulates the growing and partly interconnected nature of this reality [8]. Urban consumers in particular have concerns about the lack of transparency and ethics in complex supply networks. Partly because of geographical distance ("food miles") (Paxton, 1994), and partly because of relational distance due to intermediary operators (Torre and Rallet, 2005), there is an increasing disconnection between food production and consumption. This is but one illustration of the urban-rural divide (Francis et al., 2005). Food choices are becoming signs of a political engagement, especially in cities, towards alternative forms of practices in food systems. Taken together, questions about the long-term benefits and drawbacks of types of food systems and the related environmental, social and health burdens they require society to bear have become legitimate in the context of the current ecological and social crisis.

The problem setting of this research lies at the interface of two societal challenges addressed in the research literature: the sustainability challenge related to food systems, and the challenge of the reduction of material use (dematerialization) of cities. With its potential to contribute to the sustainable transformation of both food systems and cities, the reduction of food loss and waste in urban food systems appears as an important strategy.

1.1.1. Food system sustainability

[7] At the turn of the last millennium, 371 cities worldwide had 1 million inhabitants or more. This number had risen to 548 by 2018 and is projected to reach 706 in 2030.

[8] One Health, an approach launched by the WHO in the early millennium, addresses both infectious diseases and not non-communicable diseases, which are an equally big threat to humanity, if ever the two can be compared. One Health recognizes that human health is closely connected to the health of animals and the environment. Several factors have made the concept more important in recent years: growing human population expanding into new natural ecosystems, climate change and intensification of land use and agricultural systems, and trade and travel of humans, animals and goods. These factors have changed interactions between people, animals, plants, and our environment.

The complex organization human societies put into place to acquire and consume their food, termed food systems[9] (Malassis, 1996), is the result of a long-term evolution of human societies in interaction with nature. While the literature reports diversity in food systems globally and attempts to classify them, from domestic household and local systems to globalized agro-industrial systems (Colonna et al., 2013), the dominant industrialized food system is currently conquering large parts of the world. This is problematic as this food system relies to a large extent on globalized agro-chemical based chains of agricultural production, industrial processing of standardized farm commodities, and mass retail by a few global players, entailing not only easy access to food for an increasing share of the global population, but also massive negative effects (Rastoin and Ghersi, 2010).

Scientists, international organizations and NGOs are all expressing serious concern about the unsustainable nature of the dominant industrialized food system (Esnouf et al., 2013; IPES Food, 2015). "It is clear from the scientific literature that Western-style food systems, and of course their global extension, are not sustainable in terms of their consumption of resources, impacts on ecosystems and effects on health (overweight, obesity and associated pathologies)" (Esnouf et al., 2013: 445). Recent developments in several respects, from health to social, economic and environmental dimensions, suggest alarming consequences for the long-term well-being of human societies on earth. In fact, food is a node of these dimensions, which implies that improvements need to be achieved in an integrated way if undesirable trade-offs are to be avoided.

Health dimension

Food is a key to a healthy life, when it is balanced, varied, tasty and provided in sufficient quantities (FAO and WHO, 2019). Yet this type of diet is far from being the reality for many. In Europe, more than 50% of adults and one in three children aged 6–9 on average are overweight or obese (WHO, 2014). Worldwide, 1.9 billion adults are overweight or obese. In fact, unhealthy diets, overweight and obesity contribute to a large extent to non-communicable diseases, including heart diseases, type 2 diabetes and some cancers, together the leading cause of disability and death in Europe and a pressing issue

[9] A discussion about the relevance of the food system concept for this study can be found in Chapter 2, Section 2.1.3.

worldwide. Nutrition policies worldwide were developed with the aim to support healthy diets, which were thus given an unprecedented role in disease prevention (WHO, n.d.). Simultaneously, in some countries and among some vulnerable groups, under-nutrition remains a concern, although global food production provides enough food to feed the global population (Godfray et al., 2012). In 2017, worldwide, 821 million people did not have access to sufficient amounts of safe and nutritious food. 462 million adults were underweight (2014), and 155 million children under the age of 5 were under-nourished (2016) (Sundaram et al., 2016).

Popkin (2006) has shown how increasing consumption of animal foods, saturated fat, sugar and salt, in parallel with a decreasing consumption of vegetables, fruits and whole grains, are part of a nutrition transition that leads to the "degenerative disease" pattern. This pattern, one out of five classified by the author, characterizes the transition from the "receding famine pattern" that attended the second agricultural revolution and the industrial revolution[10]. The trend towards Western style diets worldwide is accelerating in developing countries, thus exposing a population already concerned by undernutrition to such changes (Popkin, 2002). The so-called "double burden of malnutrition" is characterized by the coexistence, within the family or for an individual, of undernutrition (protein, energy or micro-nutrient deficiencies) along with overweight, obesity or diet-related non-communicable diseases (Sundaram et al., 2016). The number of malnourished people is expected to rise with the population growing by 2 billion by 2050 (WHO, 2017).

Malnutrition is not only a consequence of insufficient food consumption; health status and hygiene are also responsible. Unsafe food for example creates a vicious cycle of disease and malnutrition, particularly affecting infants, young children, elderly and the

[10] Diet shifts referred to as "nutrition transitions" are predictable under the influence of modernization, urbanization, economic development, and increased wealth (Popkin, 2006). Five patterns can be distinguished in the course of the transition: i) Pattern 1, Hunter Gatherer; ii) Pattern 2, Early Agriculture; iii) Pattern 3, End of Famine; iv) Pattern 4, Overeating, Obesity-Related Diseases; and v) Pattern 5, Behavior Change. The last pattern, the youngest one, refers to individual or community behavior change to healthy diets as a response to increasing rates of obesity and obesity-related chronic diseases. A comparison can be drawn to the three socio-metabolic regimes – of fire, agrarian, and industrial – defined by Fischer-Kowalski and Haberl (2007). While the latter refer to the broad principles of the societal use of material and energy, the nutrition transition can be seen as a sub-form of the socio-metabolic regime peculiar to food, with the exception of the last two nutrition patterns: obesity and behavior change. Analogously, it would be worth debating whether one regime, the industrial regime, is enough to account for the evolution of societies' use of material and energy over the course of two centuries.

sick [11]. Whereas food safety is well managed in industrialized countries, new contaminants, such as pesticides used in agriculture, endocrine disrupters from packaging, or newly-formed products used in food processing or preparation raise new health concerns[12]. Food allergies are assumed to be on the rise in both developing and industrialized countries (Loh and Tang, 2018).

While food consumption has not ceased to be a matter of concern in industrialized countries, it is the nature of concern that has changed, from questions of availability towards questions of safety, purity, and transparency.

Social dimension

The social dimension of food has various facets. One is the unequal access to food. Because food is a primary need, it captures a large part of households' budget, to a greater or lesser degree. The reduction of social inequality in the access to food is an important aim for society, locally, nationally and globally, to move towards cohesiveness and stability.

Depending on wealth, the share of a household's budget spent on food decreases proportionally with the increase in income. Defined as a law by German economist Engel (1821–1896), this ratio is found not only between countries but also within a country. World Bank and the USDA data (Our world in data, 2015) show that in the least wealthy countries, in terms of GDP, between 30% and 50% of household budgets is spent on food (Nigeria, Pakistan, India for example), whereas in the most affluent countries that proportion is around 15%, in the case of Europe, and below 10% in English-speaking countries (USA, United Kingdom).

Within a country, food consumption indicates the social status of population groups. In France, food ranks third in household expenditure, on average, but for the least affluent households it ranks first (Demoly and Schweitzer, 2017). Results from the Household budget survey show for 2017 that households in the lowest income quintile used 18% of their budget for food (in-home consumption only, without alcohol), whereas households in the highest income quintile used 14%. Although this difference has decreased over time, from 17% in 1979 to 4% in 2017, absolute food expenditure is much higher in high

[11] https://www.who.int/news-room/fact-sheets/detail/food-safety
[12] https://www.who.int/news-room/fact-sheets/detail/pesticide-residues-in-food

income households. In 2011, households earning more than 3,500 € per month spent 2.6 times as much as households with less than 1,000 € (Laisney, 2013).

Some foods are truly social markers[13]. Results from the INSEE food survey carried out from 1967 to 1991, showed that food consumption is strongly dependent on the individuals' social class. Studies published in the early 1980s (Régnier et al., 2006) show that luxury products such as seafood, beef, fish, cheese and fresh fruits are significantly over-consumed by the upper social classes, whereas the lower classes over-consume bread, potatoes, pasta and substitutes such as margarine or horse meat. For some products, the consumption between the classes remains discriminating today. A higher consumption of fruits, vegetables and fish, associated with a healthy diet, still characterizes affluent households' food consumption.

The increase in overweight and obesity attracted attention to the social inequality in access to a healthy diet, which is significant. Food with a high energy density, an indicator that expresses the energy content per mass unit, is less expensive than a healthy diet, which explains that households with budget constraints tend to have a higher incidence of obesity. Results from the French OBEPI survey showed that in 2012, the proportion of obese adults was 1.7 times higher in households with a net income below 900 € than in the general population (25.6% vs 15%), and 3.65 times higher than in households with a net income of 5,300 € (Darmon, 2014). The impact of constrained budget on healthy food choices can be partly counteracted by knowledge, a robust food culture, and a social network, for example. However, they might not be enough when the available budget amounts to less than 3.5 € per person per day (Darmon, 2014).

Environmental dimension

The global food system is a major contributor to environmental impacts induced by human societies. Already a pressing issue today, the growing global population and related increase in the food demand will put additional pressure on the planet's ecosystem (Godfray et al., 2012; Smil, 2000; Springmann et al., 2018). At the same time, irreversible

[13] Chapter 6 traces the history of sociology's interest in food, gain insight into the cultural and social determinants of food consumption and the role that food waste plays in this literature. The sociology of consumption, in the footsteps of Halbwachs and Bourdieu was particularly interested in social distinction and the role that food plays, amongst other goods (music, clothing, etc.). This sociological tradition occupies an important place in the French sociology of food, as outlined in Chapter 6.

changes to the environment, notably climate change and biodiversity loss, might persistently threaten future food production, with geopolitical resource use conflicts and migration being possible consequences (Mbow et al., 2019). The global food system has a role in the crossing of the planetary boundary as suggested by Rockström (2009) and revised by Steffen (2015), illustrating the degree of implication of human-induced environmental change. The further a boundary for a particular function of the planet is transcended, the higher the risk of a regime shift that might bring the earth in a new state no longer considered a “safe operating space for humanity” (Steffen et al., 2015). Four functions – climate change, biosphere integrity (previously biodiversity loss), biogeochemical flows, and land-system change – have seen the suggested planetary boundaries transcended, with two of them, climate change and biosphere integrity, recognized to be of primary importance for the functioning of the earth system.

Ensuring food security for the global population while keeping environmental impacts within the planet’s boundaries is one of the major challenges of humanity for the 21st century. Food and feed imports, along with water and air pollution beyond local areas, mean that the implications of industrialized food systems are global. Changes in the food production and consumption patterns of industrialized countries are particularly effective insofar as two aspects of their food system have major environmental implications: industrialized agriculture and livestock systems for food production, and the composition of a Western-style diet with its high share of animal products (Tilman and Clark, 2014). Furthermore, the role of food waste as a contribution to industrialized countries’ already high level of food demand has been recognized more recently as an additional aspect (FAO, 2017). For example, a combination of demand-side changes in diet, with the reduction of food loss and waste, was found to make conversion to organic agriculture at global scale feasible and beneficial for many environmental indicators, while ensuring food supply[14] (Müller et al., 2017).

[14] The rationale of this study lies in the assumption that global food supply can be maintained after conversion to organic agriculture, despite lower yields requiring more land, due to demand-side changes. The modelling study (Müller et al., 2017) has shown that through a combination of reductions in food waste and in food-competing feed use from arable land, correspondingly reducing production and consumption of animal products, land use under organic agriculture remains below a reference scenario of non-organic agriculture, Western diet and average food waste. Other indicators such as greenhouse gas emissions also improve, but adequate nitrogen supply is a problem. The researchers highlight that besides focusing on food production, sustainable food systems need to address waste, crop–grass–livestock interdependencies, and human consumption.

Agricultural food production including livestock is the food system sector generating most impacts on the environment due to its close relation to land use. At global scale, more than 25% of all greenhouse gas emissions are attributable to food production, including fertilizer and manure use, livestock, and energy consumption by machines (Vermeulen et al., 2012). Pollution of land and water bodies due to nitrogen and phosphorous run-offs from fertilizers and manure (Bodirsky et al., 2014; Cordell and White, 2014), and biodiversity loss from land conversion and degradation (Newbold et al., 2015), are further adverse effects of industrialized agriculture.

In France, as an example of an industrialized country, agricultural food production is the primary emitting stage of greenhouse gases, with 109 Mt CO_2-eq, accounting for two thirds of the greenhouse gas emissions related to French food consumption[15] (Barbier et al., 2019). The latter amounted to 163 Mt CO_2-eq in 2012, that is 24% of the total greenhouse gas emissions of French households, estimated to amount to 671 Mt CO_2-eq.

At the level of food products, a review by Tilman and Clark (2014) shows that animal-based foods generate more greenhouse gases per mass unit, energy unit and serving, than plant-based foods. At the level of diets, higher consumption of animal-based foods was similarly associated with higher environmental impacts, whereas increased consumption of plant-based foods was associated with lower environmental impacts (Nelson et al., 2016). For this reason, the Western diet with its high proportion of meat, egg and dairy products generates particularly high amounts of greenhouse gases. 4.2 kg CO_2-eq/cap/day were associated with the average self-selected diet of French adults, typical of a Western diet (Vieux et al., 2012). The calculations of Rosi et al. (2017) indicate an omnivorous diet of 4.0 ± 1.0 CO_2-eq/cap/day; an ovo-lacto-vegetarian diet of 2.6 ± 0.6 CO_2-eq/cap/day; and vegan diet of 2.3 ± 0.5 kg CO_2- eq/cap/day. The growing literature summarized in the most recent IPCC report on food security (Mbow et al., 2019) confirms the benefits, in terms of greenhouse gas emissions, of alternative diets, with those having a lower share of animal products, meatless diets (vegetarian) and exclusively plant-based diets (vegan) in increasing priority. However, for the feasibility of diet change, nutritional quality and cultural and hedonic aspects are also important. In contrast to theoretical diets

[15] A consumption-based approach was used that includes emissions related to food and feed imports, and excludes emissions related to food and feed exports. Additionally, emissions related to the transport of commodities and for household shopping trips were included.

in modelling studies, self-selected and genuinely practised diets observed amongst the French population revealed diets that were both nutritionally satisfying and less greenhouse gas generating than the average French diet (Masset et al., 2014; Vieux et al., 2012). These diets were lower in energy intake and density and had a higher share of plant-based products. Combining four aspects that together define the sustainable character of diets – namely affordability, diet-related greenhouse gas emissions, nutritional adequacy, and acceptability –, Perignon et al. (2016) showed that moderate reductions in greenhouse gas emissions (≤30%) were compatible with nutritional adequacy and affordability, without adding a major shift of food groups compared to nutritional recommendations.

The literature addressing environmental impacts from food systems mostly covers greenhouse gas emissions and the related climate impacts. Methods and data to cover further impact categories at the level of diet are of lesser quality. Despite this apparent research gap, the available literature suggests overall environmental benefits of diets with reduced animal foods – where meat is the single most important category to reduce (Nelson et al., 2016) –,provided the diet remains close to physiological requirements, that is, avoids over-consumption (Serafini and Toti, 2016), and that the levels of food waste are low (Beretta et al., 2017; Birney et al., 2017; Grizzetti et al., 2013).

Beyond this background, industrial societies are assigned not only a moral role to play, as defended by a global environment and climate justice movement (Sikor and Newell, 2014; Temper, 2018), but also a role in ensuring the political stability on earth. They can do so by changing their highly impacting agricultural production system and diet, both of which have expanded across the planet. Clearly, the global population is not equally responsible for the current situation of the planet's ecosystem. Environmental change in a large part of the world is due to a few industrial countries' activities and adds to other factors compromising developing countries' potential to ensure their food security[16]. The worlds' poorest are those who already suffer from environmental change, partly aggravated by political instability and war, as regularly occurring episodes of famine in Sub-Saharan Africa and the fate of climate migrants (Vinke, 2019) illustrate. Their

[16] Other factors are largely society-driven, such as lack of development of domestic agriculture, market support structures, political instability and civil war, etc.

situation might worsen in the future, given the risk that the planet irreversibly turns to a different state from the one in which humanity has so far evolved.

Economic dimension

The global food system has not managed to get a large part of the world's population out of poverty. At global scale, the issue of under-nutrition has not been resolved; on the contrary, it grew to over a billion people in the 1990s, before declining again to reach 821 million in 2017 (FAO, 2018). Food security is not a problem of food availability, as many of the countries concerned, such as China and India, are large food exporting countries. Small-scale rural farmers are those predominantly concerned, due to limited access to land for production and to markets for selling their produce. In the wealthy industrialized countries, food insecurity has now become alarming as well, despite safety nets and food aid for the needy. Limited purchase capacity for part of the population and unequal access to employment reveal the vulnerability of economies worldwide.

Large sectors in the globalized food system – e.g. the food industry, and the retail and agro-chemical input industry – are in the hands of a small number of big international companies, driven by productivity gains at the expense of social, environmental and even nutritional aspects (Rastoin and Ghersi, 2010). In addition to concentration of market power, the growing presence and influence of financial entities in the global economy has transformed food systems and rural economies worldwide. Financialization is seen as a driver of change towards a globalized industrialized mass diet and investment in agro-industrial commodities, food, feed and fuel (Bjørkhaug et al., 2018). In this process, humans' fundamental need for food – reaffirmed by governments worldwide as a basic human right – is literally ignored. Speculation on the prices of agro-industrial commodities on financial markets is suspected of entailing price volatility, which would put tight household budgets under pressure.

Impacts from food systems occur at various scales, from local to global, driven through the globalized industrial food system. Increasing populations and pressure on resources, driven by the global food demand and non-food biomass use, has the potential to contribute to resource competition, tensions and even conflicts, as the increase of staple food prices[17] resulting in the 2007/2008 food crisis illustrates (Headey, 2011; Headey and Fan, 2010).

Some authors point towards the increasing instability in which food systems develop, with potential consequences on employment (Esnouf et al., 2013). When the liberalization of agricultural and trade policies implemented from the 1980s led to an oversupply of agricultural products and low prices, action was taken for mitigation, including keeping national stocks low. Market instability and fluctuating prices hit the most vulnerable communities and households hardest. Further instability must be expected from increasing variability in agricultural production as a consequence of climate change, and the related increase in the frequency and severity of climatic events, droughts and floods (IPCC, 2019).

Overall, the main economic issue of the global food system revolves around a fairer distribution of value creation and income amongst producers, and the participation of all, producers and consumers, to food system possibilities offered at local, regional and global scale.

1.1.2. Cities' material consumption

Urbanization is a global trend and has been so for millennia (van der Leeuw, 2018). Cities are the geographical location in which a growing share of the global population is concentrated. The urbanization level has almost doubled in the past 70 years, from 29% in 1950 (Satterthwaite et al., 2010) to 55% in 2018 (United Nations-Department of Economic and Social Affairs-Population Division, 2018). Since 2008, more than half of the world's population has been living in urban areas, and this proportion is expected to grow to two-thirds by 2050, according to the UN. Most of this population increase is expected to be concentrated in the megacities of Africa, Asia and South America, adding approximately 3 billion urban dwellers by 2050 (United Nations-Department of Economic and Social Affairs-Population Division, 2018).

[17] The steep increase in food prices in 2007-8 was at the origin of riots and protests in more than 60 countries, a third of which were middle- and high-income countries. In the aftermath of the events, food security was acknowledged to be a matter of national security, confirmed by the G8 countries at their meeting in Italy in April 2009, the first time such a meeting was devoted to agri-food issues.

While in the past century the human population grew by a factor of four, its material use multiplied by a factor of 8, raising the global use to 60 billion tons (Gt) per year in 2005 (Krausmann et al., 2009). Energy use in the same period rose by a factor of 10, 80% of which was sourced from fossil fuels, while biomass use remained stable (BP, n.d.; Smil, 2017). While cities offer livelihood to more and more people, they concentrate most of the global economy, with over 80% of the global GDP generated in 2007 (Dobbs et al., 2011) and almost 85% US GDP generated by 259 large US cities in 2010 (large cities of Western Europe contributed less than 65%) (Manyika et al., 2012). The remaining rural dwellers, that in 2007 made up 51% of the global population, are left with very few opportunities for income (Population Reference Bureau, 2017).

Income largely determines inequalities in material and energy use, which is why increasing pressure on the environment comes from urban areas. The more affluent a society is, the higher is its material and energy use. Increasing income and associated material- and energy-intense consumption patterns have been a more powerful driver of the global increase in greenhouse gas emissions than have growing populations and urbanization (Weisz & Steinberger, 2010). Urbanization alone is not to be held responsible for diet changes towards resource-intensive diets, with increased meat consumption as an important feature. While diets differ between rural and urban areas, and per capita meat consumption is higher in urban areas, a review by Stage et al. (2010) of the relation between urbanization and food prices (reported in Satterthwaite et al., 2010), suggests that higher urban incomes, not urbanization or urban living, are responsible for higher meat consumption. Meat consumption, in fact, is similarly high between rural and urban dwellers with high income.

Cities therefore have or could have a role to play in reducing societies' energy and material flows in the future. Urban-specific features such as urban form, that is, shape, size, density and configuration, as well as the building stock, were identified to impact emissions from transportation and housing (Weisz and Steinberger, 2010). Cities offer a potential for material and metal recycling through urban mining (Barles, 2017; Brunner, 2011), as they produce large amounts of used material that can be recovered to replace virgin material extraction. Metal ore recovery and the combined generation of heat from recycling plants for city needs were the first to receive attention in the first decade of the 21st century (Brunner, 2011; Graedel, 2011). Wallstein (2015) has extended the notion of urban mining to the recycling of discarded materials from the built environment and underground urban infrastructure (cables, pipes, etc.). He coined the term “urk world” to denote a subsurface urban realm of rejects, with “urk” from “urkopplad” meaning “disconnected” (Wallstein, 2015).

Urban sustainability includes the sustainable management of waste generated in cities. Besides bulk construction waste, household waste is the greater part of urban waste, with the characteristic of being composed of many different materials (Conseil Régional Ile-de-France, 2018). Strategies to reduce the environmental impact from waste can take many different forms of waste management, including sorting and recycling of different waste categories (metals, plastic, glass and organic material) or incineration with energy recovery of mixed waste. This has been extensively studied using life cycle assessment[18] (see Laurent et al., 2014a for a review of these studies). However, at the level of a city, or any geographic area for that matter, the study of environmental impacts from waste management requires us to consider absolute waste amounts, since total environmental impact is always the product of specific environmental impacts (e.g. impact per unit of mass) times total amount. The contribution of material flow analysis lies in quantifying the absolute amounts of waste per category, and usefully informs the question of an integrated management strategy for municipal solid waste (Padeyanda et al., 2016; Turner et al., 2016). For food waste in particular, which is the major part of household organic waste, waste management strategies following the "reduce, reuse, recycle" principle were scrutinized in a literature review, for environmental impact and further economic or social considerations (Redlingshöfer et al., 2020). One of the core insights of this study was that assessments of the “reduce” option in the form of food waste prevention, although confirmed as the option of highest priority, were under-represented in the reviewed literature. This result is consistent with that of authors who conclude that the difficulty of prioritizing waste prevention is twofold: for researchers, to analyse impacts from waste

[18] Life cycle assessments consider many different aspects of resource use and the environmental releases associated with the life cycle of a functional unit of a good or a service, from the extraction of materials to the manufacturing, distribution and use, up to the final disposal of waste (Curran, 2016). The definition of the functional unit is a crucial step in life cycle analysis. Whether it is defined as a mass unit for waste per waste category or for mixed waste, in neither case does it grasp the inter-connectedness of specific waste management strategies within one management system.

prevention (Laurent et al., 2014b; Yano and Sakai, 2016); and for policy makers, to implement waste prevention (Sakai et al., 2017; Van Ewijk and Stegemann, 2016).

Food is a concern for cities in terms of the management of sensitive resources (e.g. agricultural land, energy, water, nitrogen and phosphorous). Food is also a subject of heated debates in political and NGO movements. In industrialized societies, three consumption categories – food, transport, and housing – have the biggest life-cycle environmental impacts (Hertwich and Peters, 2009; Tukker et al., 2006), which is why they are of specific interest for urban sustainability. For food, most of the life cycle emissions occur elsewhere than in the city, notably upstream or downstream (Goldstein et al., 2017). However, this does not mean that cities have no role to play in mitigating impacts within their own territory; nor is it irrelevant for cities to promote options for change outside of their boundaries (Minx et al., 2013; Pichler et al., 2017). Reduction of the intensity of resource and material use – so-called dematerialization [19] – in the food sector can be achieved in various ways: through food consumption – e.g. a change to more plant-based diets and hence less livestock induced flows – or types of agriculture – e.g. change towards organic farming instead of farming with mineral fertilizer –, or the reduction of food loss and waste with impacts on resources along the entire food life cycle.

Both options – mitigating impacts within cities and promoting change outside of cities – are seen as stimulating by a scientific community of planners and social geographers who, since the early millennium, have put food issues on the agenda of a social science movement. In the aftermath of a series of developments and crises, including the 2007/20008 food crisis, the community was struck by the awareness that food production is no longer a guarantee to secure access to food, particularly for cities. They termed this the "new food equation" (Morgan and Sonnino, 2010). A dynamic food planning movement with a particular focus on "Feeding the cities" (Morgan, 2009) addressed the sustainability of food systems, and implicitly urban systems. Its focus was twofold: on urban agriculture; and on food policy and the role of public procurement in reshaping the

[19] Not to be confounded with the conversion of information stored on analogue mediums, notably paper, to digital format (servers, spreadsheets, database documents, multimedia files, etc.).

food system. Both fields were revealed as fertile areas of research to support social movements (Aubry and Daniel, 2017; Pourias et al., 2014).

The awareness that cities' food systems have long been ignored by planners has been brought into sharper focus by British architect and writer Carolyn Steel in her book *Hungry City* (Steel, 2008). Steel sees food planning as a means to reshape cities as 'it emerges as something with phenomenal power to transform not just landscapes, but political structures, public spaces, social relationships, cities' (Steel, 2008: 307).

The potential role of cities in reducing societal material and energy use has increasingly attracted the attention of researchers, governments, and international organizations (Swilling et al., 2018, 2013). Countless initiatives in the field of urban energy use, urban transport, urban agriculture, and sustainable and/or climate-smart cities have arisen for more than a decade. Eager to move on with sustainability policy at a faster pace than that adopted by national governments, city governments have built a range of national or international networks to share experiences and initiatives regarding energy consumption and the mitigation of greenhouse gas emissions. Some of the many examples include the Global Covenant of Mayors for Climate & Energy, C40, International Council for Local Environmental Initiatives (ICLEI), the Global Parliament of Mayors, and the Carbon Neutral Cities Network.

Concerning food, the Milan Urban Food Policy Pact has united more than 210 cities covering a population of more than 450 million inhabitants from across the world. This Pact, a voluntary framework for action to achieve more sustainable food systems, was launched by the Municipality of Milan on the occasion of the 2015 Expo "Feeding the Planet, Energy for Life". Additionally, more and more cities are engaging in partnerships with farmers and promoting local food systems favorable to healthy and sustainable food (Sustainable Food Places, Greenbelt Foundation). City governments and urban policy makers have rediscovered their potential role of using policy to support an efficient food system, with public procurement in school canteens as a prominent sector of engagement in many countries (Barling et al., 2013). This function was largely ignored in the recent past, for since the 1950s, driven by the industrialization of societies, "urban food supply has become a trade issue, left to the opaque management of private stakeholders and ad minima regulated by public authorities" (Bognon and Marty, 2015). Strong public intervention in food systems dates back to the era before the 1950s[20]. The obesity pandemic and serious public health concerns were eventually the trigger for cities, especially metropolises, to become more proactive in urban food policy. Today, many cities have fully-fledged food policy strategies but inadequate means to implement them.

1.1.3. The role of food waste reduction

Reducing food loss and waste[21] is seen as a promising way to foster the sustainability of food systems. Along with other strategies such as diet changes or improved agricultural management, its benefits are deemed a valuable contribution to the transformation of food systems. The broader aim is to make them more efficient and less resource intensive and climate-impacting, and furthermore to improve food security and nutrition (Foley et al., 2005; Foresight, 2011; Ingram et al., 2016). As these dimensions are all interlinked, a multidimensional and integrated global strategy for food systems is required. To improve the food security of a growing global population, constrained resources and climate change must be considered, while conserving the quality of ecosystems and biodiversity (Godfray et al., 2012). Food loss and waste act on food security by reducing global and local food availability, limiting food access due to increases in food prices and decreases of producer income, and affecting future food production due to unsustainable use of natural resources (HLPE, 2014). Besides political aims, there is a large moral and ethical-driven consensus that food loss and waste are incompatible with values of social justice and equity, thus generating tension fuelled by the stable number of food insecure people globally (Fleetwood, 2020).

To endorse the role that the reduction of food loss and waste reduction can play in supporting human well-being and prosperity, it received a dedicated target within the Sustainable Development Goals (SDGs) adopted by the United Nations Member States in 2015 under the 2030 Agenda for Sustainable Development. As part of Goal 12

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[20] Historians were interested in the regulation of food system activities by public authorities during specific periods in time, for example, Kaplan on whole grains – bread-baking in the 18th century (Kaplan, 1988) or Clement (1999) on food in general in the period from the 16th to the 19th century. Calame goes back up to two millennia, to earlier European civilizations, by studying the evolution of agricultural policy from a historical and agronomic perspective. For a long time, agricultural policy was food policy, in the sense that policy makers considered society as a whole, thus going far beyond the interests of farmers, in a long-term perspective of human history (Calame, 2008).

[21] Food loss and waste, synonymous with food waste in this study, refers to food that leaves the food supply chain and ends up uneaten. See Chapter 2.

"Sustainable consumption and production", target 12.3 aims to "by 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains" (United Nations, n.d.). Many other SDGs can also benefit from food loss and waste reduction, such as SDG 2 "Zero hunger", SDG 6 "Clean water and sanitation", SDG 11 "Sustainable cities and communities", SDG 13 "Climate action" and SDGs 14 and 15, "Life below water" and "Life on land", respectively.

Supporting evidence is strong. Food loss and waste was estimated to amount to 30% of the original global food production (Gustavsson et al., 2011). Globally, the stages from post-harvest up to but excluding retail account for a loss of 14% of food produced, according to estimates established with the recently developed Food Loss Index, one of two sub-indicators for SDG target 12.3 (FAO, 2019). Estimates of food waste at retail up to consumption were established with the Food Waste Index, the second 12.3 sub-indicator, and account for 17% of food produced at global scale (United Nations Environment Programme, 2021). Other studies for industrialized countries in particular, which tend to have the highest levels, have found food loss and waste to be less than 20% (Income Consulting AK2C, 2016; Stenmarck et al., 2016). As methodologies vary widely between the different estimates, comparison of the extent of food waste and its monitoring are challenging. To resolve a decade's debate, universal indicators were developed within work to monitor progress towards SDG target 12.3. By distinguishing sub-indicators, Food Loss Index and Food Waste Index, a standardized framework for food loss and waste measurement and monitoring to be used at national and global regional level have been finalized this year (2021), thus enabling a more robust assessment albeit one that is incomparable with previous assessments [22]. Their operationalization however is confronted with the same obstacles that researchers and practitioners in food supply chain analysis have experienced in previous attempts to quantify food loss and waste (Chaboud and Daviron, 2017; Corrado et al., 2019; Xue et al., 2017).

Irrespective of the exact amounts, impacts from food loss and waste are substantial. Globally, food crops produced but then lost or wasted account for 23-24% of total use of fresh water, fertilizers and cropland, which is an arable area the size of China (Kummu et al., 2012). Springmann et al. (2018) argue that halving food loss and waste until 2050

[22] Both sub-indicators, the Food Loss Index and the Food Waste Index, are presented on a distinct FAO webpage: http://www.fao.org/sustainable-development-goals/indicators/1231/en/

would reduce agriculture-driven environmental pressure by 6-16%, depending on the environmental dimension (greenhouse gas emissions, cropland use, water use, nitrogen and phosphorous application). In terms of calories, total food loss and waste accounts for 24% of the global production (Kummu et al., 2012). Not only energy but also many other nutrients are lost and wasted, while micronutrient deficiencies, such as for iron, iodine or vitamins, are still on the agenda of nutrition-related public health problems globally (*Glob. Nutr. Rep.*, 2018). Food loss and waste means financial losses to producers, business and consumers. Additionally, the economic value to society, defined in a study by ReFED (2016), covers impacts from food loss and waste more comprehensively. Defined as the aggregate financial benefit to society (consumers, businesses, governments, and other stakeholders) minus all investments and costs over ten years, it reflects the cost-effectiveness of different prevention and recycling solutions[23]. The study shows that overall, prevention of food loss and waste results in greater economic value per ton, while recycling is more scalable.

The reasons for food loss and waste are manifold and highly dependent on the product category (perishables are concerned more), the food system sector, and the geographical or industrialization context concerned, which makes them difficult to summarize. Overall, in industrialized countries most losses are in the retail and consumer stage, whereas in developing countries losses are highest in the immediate post-harvest stages (Parfitt et al., 2010). Poor management and infrastructure in storage and logistics, technical dysfunctions in processing, quality standards on markets, and consumers' lack of knowledge are amongst the main direct causes (Lipinski et al., 2013).

Due to the wide-reaching impacts in health, social, economic, and environmental terms, the reduction of food loss and waste is considered an important action for a socio-ecological transformation of food systems. Reducing food loss and waste in cities contributes to dematerialization, or the reduction of the high level of material

[23] For food waste, as for any other biomass, the term recycling denotes composting and anaerobic digestion processes that return nutrients and organic matter back to the soil and improve its quality. Haas et al. (2016) point out that strictly speaking, according to Circular Economy principles, these processes do not qualify as recycling since two preconditions are not met. First, a large part of the cycle lies outside of the socio-economic system and takes place in natural ecosystems. Second, it is not the main material component that is recycled. Food waste cannot be reprocessed back into food. Composting or anaerobic digestion yield products that must first return to the production of primary biomass. While we take note of these reservations, we still use the term recycling for biomass as it is commonly understood, both by the public and in the scientific discourse.

consumption that characterizes large Western cities. Yet the phenomenon has barely been addressed, although the literature suggests that food loss and waste in industrialized countries stems largely from activities close to the consumption stage. Seventy percent of food waste produced in the 28 EU member-states occurs at the retail and consumption stages of the food chain, including in-home and out of-home consumption (Stenmarck et al., 2016). Driven by urban concentration and related activities, this waste is primarily generated in cities (Guilbert and Redlingshöfer, 2018). Moreover, in most industrialized countries, food waste is managed in centralized waste management systems, often together with mixed household waste, with barely organized recovery of valuable organic matter and nutrients for use in agriculture. Hence, global biochemical cycles related to food production and consumption, above all the sensitive nitrogen and phosphorous cycles, are disrupted by cities, which adds even more pressure (Svirejeva-Hopkins et al., 2011). This comes from the fact that organic treatment infrastructure is often largely insufficient at this scale of cities, and future additional units are unavailable immediately, which raises the question of where currently collected bio-waste is being treated and where the output products (compost, digestate) end up spatially and in terms of destination and use. Research by Lehec (2018) has shown that decentralized composting sites in neighbourhoods, promoted by institutions at the state or the commune level, such as the City of Paris, are emerging as an option for the management of household food waste. Yet their technical performance suffers with their use as an educational tool. Weidner and Yang (2020) estimated the potential of integration of treated food waste into urban agriculture projects. These authors showed a moderate and large potential of integration for the cities of Glasgow and Lyon. Unlike more than a century ago, organic treatment of bio-waste and use of the output products in urban and peri-urban agriculture have become largely insignificant in food waste management nowadays. In his ongoing thesis project, Etienne Dufour is analysing the sociotechnical pathway of bio-geochemical policies in the Paris area from the end of World War II to the 1990s, to identify major disruptions and determinants.

For these reasons, cities are a relevant level of social organization to study human societies' food use and the role of food loss and waste in urban food systems. Cities have understood its importance, since many of them have developed food loss and waste reduction policies, either as a stand-alone policy, as part of integrated urban food policy, or as a contribution to waste policy and circular economy programmes[24].

1.2. The ecology of societies analysed through their relation to food

This section presents an overview of the theoretical foundations developed to study societies' interactions with nature, through a systemic approach derived from an analogy with the ecosystem concept. Organized in four sub-sections from a historical perspective (1.2.2), the scientific roots, the significant authors and publications, and the scientific debate about the theories and concepts are explored in the respective fields of urban, industrial, social, and territorial ecology. The focus is on the way cities and their particular features in their relationship with nature were conceived of in this literature. Social, industrial and territorial ecology, close to each other in their foundation and aims, were identified as a relevant theoretical framework for this research. This was due to the founders' shared conviction that the material and immaterial dimension of society's functioning need to be understood together.

1.2.1. From urban chemistry to social, industrial and territorial ecology

The history of urban metabolism studies is one of multiple branches and affiliations from various scientific fields (Barles, n.d.). Its early roots lie within the field of urban chemistry as it emerged in the late 19th century, before gaining momentum in the 1960s and 1970s within research in urban ecology and environmental engineering. Then already, early signs of man-made ecological disorders augured a much larger crisis and pushed researchers to develop new approaches. The beginning of urban ecology in the 1960s inspired by Odum's theory of the ecology initiated a new way to analyse the relationship between a city and the environment. The concept of urban metabolism examined a city's material and energy flows as an expression of the material relationship between the city

[24] The detailed analysis of food waste reduction initiatives presented in Chapter 5 shows how numerous they are and consideration they receive at various policy making levels. However, the general picture is one of poorly coordinated approaches to food waste reduction, between food policy and waste policy, and even within waste policy.

and its environment. It was later challenged by the social sciences for failing to consider the role of society as a determinant of its material flows. Their integration found expression respectively in the concept of social metabolism, according to social and industrial ecology, and that of territorial metabolism, according to territorial ecology, two parallel but hardly connected scientific dynamics.

Urban chemistry

In Europe, urban metabolism studies are rooted in 19th-century urban chemistry (Hamlin, 2007). With the population growth during the industrialization of society, chemists were concerned about meeting the increasing urban requirements of food while maintaining the soil fertility of agricultural land, a pre-condition for continuous prosperous growth of the cities. Late 19th-century agronomy was primarily preoccupied with soil fertility, as each harvest removed nutrients that needed to be restored to again enable food production in the following seasons. Manure from animal husbandry had been of primary interest for a long time, but its availability was limited. Excreta of the urban population together with other urban organic matter, most importantly manure from the many horses living in cities at the time, for traction (Barles 2005), was seen as a new additional source of fertilizer to be used in agriculture. By-products from slaughtered animals, organic mud produced on the street, and organic residues from households, for instance from food, were also considered. The quantification of the availability, collection and conversion potential of this material was therefore of great interest to urban chemists, and paved the way for urban metabolism approaches developed since the early 19th century. Through their work, European urban chemists – of whom the most renowned at the time were Jean-Baptiste Dumas, Jean-Baptiste Boussingault, and Justus von Liebig – supported material and nutrient exchange between the city and agriculture. Yet Liebig was also aware that fundamental nutrients would never return to agricultural soil in so far as food products from agriculture were consumed in distant cities [25] (Liebig, 1859). While favouring recycling, urban chemists were also concerned about the health impacts of material

[25] "This enormous drain of these matters [mineral substances], from the land to towns, has been going on for centuries, and is still going on year after year, without any part of the mineral elements thus removed from the land ever being restored to it; a very small proportion only is turned to account in the garden and fields in the more immediate vicinity of towns" (Liebig, 1859: 219).

exchange[26] (Keller, 2009). Though their concerns were diverse, they laid the ground for urban metabolism studies through the development of the first quantification approaches to food, nutrients and human excreta. It is noteworthy that, at that point, French urban chemists used the principle of metabolism but not the term, which appeared much later on in France (Barles, 2010). Theodor Weyl, another urban chemist, explicitly referred to the notion of the metabolism (Lederer and Kral, 2015) in his analysis of the food and nutrient supply and excreta of the city of Berlin, published in 1894 (Weyl, 1894). This study was recently pointed out by researchers as a little-known contribution to the history of urban metabolism studies (Lederer and Kral, 2015). The dynamic of city–agriculture material exchange based on urban chemistry came to an end when, in the early 20th century, Haber and Bosch invented a process of synthetic chemistry to produce nitrogen fertilizer from the unlimited nitrogen stock in the air, and when fossil phosphates and potash mines were discovered. From then on, the possibility to access non-organic sources of nutrients was seen as a liberation from agriculture's steady concern to access limited organic fertilizer from biogeochemical cycles. As industrial fertilizer production promised unlimited growth, the recycling of urban organic matter for agriculture, along with the practical and scientific knowledge on how to use it, were forgotten. Instead of efficient sorting, collection and recycling, waste and wastewater were destined to undifferentiated elimination in centralized infrastructures of large technical systems, termed "all-to-sewer" or "*tout à l'égout*" in French, in the case of wastewater (Coutard, 2010; Esculier, 2018). The situation of centralized elimination to the sewerage system, like curbside bin collection for solid waste, still prevails today as the reference situation, while sorting and recycling appear as innovative solutions – the exact opposite compared to the late 19th-century urban context.

[26] With urbanization and a growing urban population in cities in the 18th and 19th century, increasing requirements for water and energy, and for the management of waste water and solid waste, led to their re-organization through "large technical systems", that is, infrastructure for the centralized management of large urban services (Coutard, 2010). Technical, economic, and political reasons were powerful drivers for the dissemination of these systems in cities in Europe, North America and Japan in the 19th century, but environmental and hygiene factors also interfered. The density of the urban population brought along occasional epidemics, described from 1832 onwards, with a cholera epidemic, which made poor hygiene one of the nuisances of life in cities, next to violence, crime and riots (de Swaan, 1995, cited in Coutard, 2010: 104). The supposed relationship between epidemics and filth of any kind led to the construction, from the turn of the 19th century, of water supplying systems used to efficiently clean the alleys, lanes and later streets of North-American cities. Large collection, evacuation and treatment systems for any urban residues in liquid and solid form completed the supply infrastructure and took part in their progressive devalorisation, thus conferring on them the status of waste (Barles, 2005).

Urban ecology, urban metabolism

Abel Wolman's founding article "The metabolism of cities", published in the *Scientific American* in 1965 (Wolman, 1965), was at the origin of a new approach to the concept of urban metabolism, in the United States in the 1960s. Time was favorable for such change as ecology as a scientific discipline had begun to be understood in a wider sense than previously, including the impact of human activities on the environment, as the ten-year International Biological Program (IBP) launched in 1964 illustrates[27]. The programme was assigned new objectives to include the effect of changes in the natural environment on biological communities and on the conservation and growth of natural resources for human benefit. Inspired by this emerging scientific ecology, Wolman defined metabolic needs, the metabolic cycle and urban metabolic problems of cities, taking a hypothetic city of a million inhabitants (Wolman, 1965). Using an input-output balance approach, he illustrated the requirements in tons per day of water, food and fuels on one hand, and the restitution of metabolic products, which were sewage, refuse and air pollutants, on the other. He drew attention to three main concerns, of growing importance with escalating populations in cities: water supply, efficient wastewater management, and the control of air pollution from fossil fuel combustion (Wolman, 1965). Drawing on these concerns, ecologist Eugene Odum described cities' heterotrophic functioning that required high external energy inputs (Odum, 1975), and later even saw cities as parasites (Odum 1989). Odum looked at ecosystems as organisms, as by Hausladen (2014: 114) pointed out. With reference to the definition of living systems by Maturana and Varela (1975), this implies that both are built from a subsystem of components and organs, respectively, which together form a whole and self-produce as "autopoietic" systems. This step, theorized by Wolman (1965), likened the metabolism of an ecosystem to that of an organism.

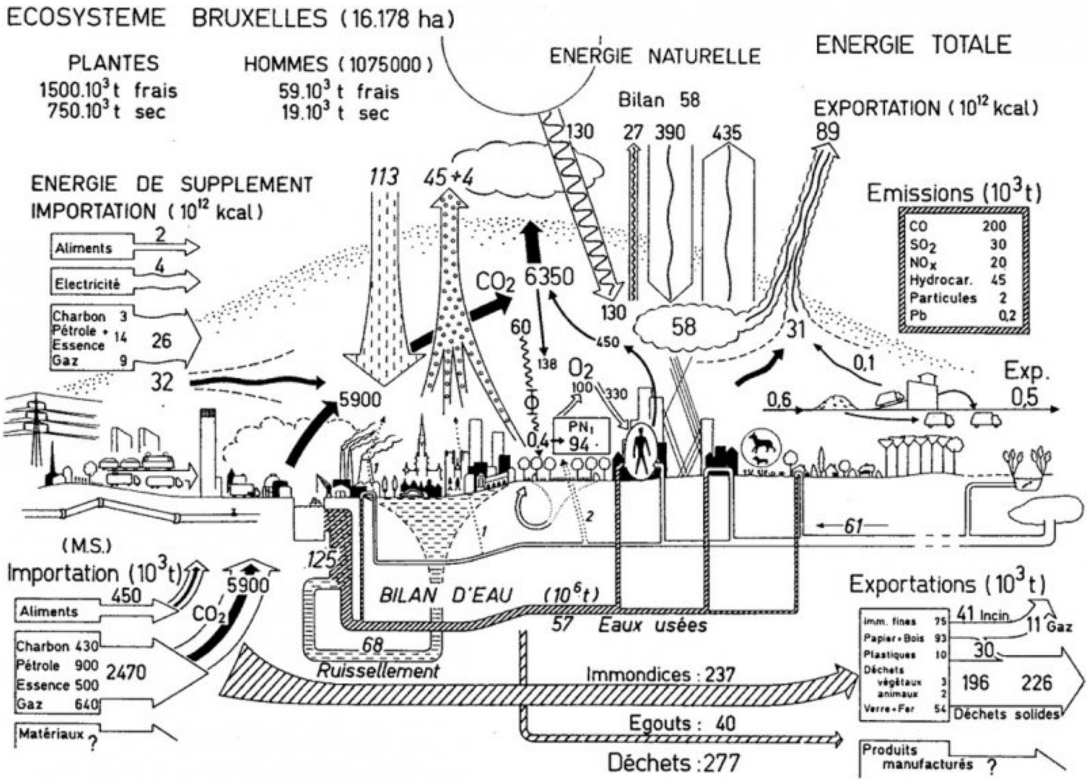
The use of the term metabolism for ecosystems or social systems has generated much controversial debate (Fischer-Kowalski, 1998). Metabolism understood as requiring material inputs from the environment and returning them to the environment in a modified form fits well in ecology, as it does in biology, from which it stems. However, Fischer-Kowalski (1998) pointed out that materials used to maintain living systems that do not

[27] A description of the programme and its history is available at the following website (accessed on January 6th, 2021): http://www.nasonline.org/about-nas/history/archives/collections/ibp-1964-1974-1.html

pass through cells and organs (e.g. housing), or simply surplus material remaining unused, would never be considered as part of the metabolism from a biological perspective. In an ecosystem perspective, it would be necessary to do so as the overall material and energy throughput of an ecosystem may be a useful information for ecologists. Therefore, "the concept of metabolism needs to be expanded to encompass material and energetic flows and transformations associated with "living things" but extending beyond the anabolism and catabolism of cells" (Fischer-Kowalski, 1998: 63). This difference is all the more meaningful as modern industrialized societies have high volumes of material input, despite large variations explained by economic structure, income and lifestyle (Weisz and Steinberger, 2010). These societies additionally have surplus material flows in their system that end up unused and turn to waste, as revealed for example for food, clothing and personal care products (Agence du don en nature et al., 2014; Stenmarck et al., 2016).

Inspired by Eugene Odum's ecosystem theory (Odum, 1953), urban ecology emerged in Europe as an ecology of the city, *urbs* in Latin, and referred to a city as an ecosystem, as did Belgian ecologist Paul Duvigneaud. Closely following in Odum's footsteps, Duvigneaud extensively covered the city as an ecosystem in his seminal article '*Synthèse écologique*' (Duvigneaud, 1974). In 1974 he published a study of the urban ecosystem of the city of Brussels, showing a detailed analysis of the material and energy flows of the city (Figure 2). Unlike Wolman's work, his analysis included a twofold expression of material flows, where relevant: both mass and energy units. This was the case of food and fuels, for which the proportion of each became visible. While fuels produced ten times more energy than food (electricity played a minor role), the proportion in terms of mass was only a factor of five. Massive fuel use was already driving industrial cities in the 1970s.

Figure 2. The urban ecosystem of Brussels in 1974



Source: Duvigneaud and Denaeyer-De Smet (1977)

Besides Duvigneaud's influence in the emerging urban ecology, he played an important role in the implementation of international environmental research programmes, which in turn benefited the emerging field. Advocacy from him and some other participants at the International Symposium on the Urban Ecosystem, held in Brussels in 1974, led to the integration of urban ecology in the UNESCO Man and Biosphere (MAB) programme (Numata, 1975) launched in 1971 (Celecia, 2000), and to a cooperative study of large cities within the programme. Under project number 11 dedicated to "Ecological aspects of urban systems with particular emphasis on energy utilization", the programme gave rise to detailed metabolism studies of the cities of Rome, Barcelona and Hong Kong (Boyden et al., 1981).

An echo of early work in urban ecology, with its naturalistic heritage, was found throughout the international community, particularly in France (Beaucire, 1985; Mirenowicz, 1982). Despite the initial dynamic, the field suffered under severe criticism. For example, some urban ecologists had in mind to make ecology a stand-alone science that would include the social sciences, which caused them to be the target of fierce objections. Urban ecologists' view on the urban metabolism being determined by energy and seen as a parasite was not universally shared either, as it excluded any action with the aim to mitigate cities' environmental impact (Barles, 2010). Such criticism hindered further development.

Metabolism studies in urban ecology had a strong focus on issues of water and energy supply, and pollution-related aspects. In the words of Wolman (1965), "the metabolic cycle is not completed until the wastes and residues of daily life have been removed and disposed of with a minimum of nuisance and hazard…Casual methods that once appeared satisfactory for the disposal of wastes no longer seem acceptable" (1965: 156). Concerns referred to the treatment of waste that needed for man to become self-evident as "his planet cannot assimilate without limit the untreated wastes of his civilization" (1965: 156). Solid waste received little attention in these studies and was not considered in any detail.

Industrial metabolism, industrial ecology, industrial symbiosis

A parallel movement to urban ecology originated in the late 1960s in the United States where, at the time, environmental issues were generally seen as political issues (Fischer-Kowalski & Hüttler, 1999). Forerunners in economics and physics emphasized the need to consider increasing environmental pollution and material consumption as physical problems to growing national economies (Kneese et al., 1970; Ayres and Kneese, 1968; Boulding, 1966). Their concern was an economic one: the use of priceless environmental goods such as air and water through the economy drives allocation at the expense of those goods and makes them scarce (Ayres and Kneese, 1969). Externalities – a term used by economists to describe negative environmental impacts – must be compensated for, argued Ayres and Kneese, since economics ignores the fact that physical production and consumption processes obey the fundamental law of the conservation of mass (Ayres and Kneese, 1969). These considerations gave rise to an initial wave of research on society's metabolism, with a first material flow analysis of the United States for the years 1963 to '65 carried out by Ayres and Kneese (1969). At the beginning of the 1970s, other authors followed these lines of work about the physical basis of industrialized societies (Georgescu-Roegen, 1971). In one of the most popular and memorable studies, entitled "The limits to growth" (Meadows et al., 1972) and commissioned by the Club of Rome, a team of scientists concluded from modelling that the physical limits of planet Earth would impose limits to industrial growth within a century – a declaration that fuelled huge controversy among scientists, scholars, and the general public.

In Europe, a first study of the ecosystem of Belgium followed, in 1983, by Billen and colleagues (Billen et al., 1983). These metabolism studies have in common that they addressed the flows of materials and energy in modern industrial society through the chain of extraction, production, consumption, and disposal, which made many authors prefer the term industrial metabolism, later coined by Ayres and colleagues (Ayres, 1989; Ayres and Simonis, 1994).Material flow analysis (MFA) as a biophysical accounting method grew into a central role in social metabolism studies as it provides a simple representation of the material dimensions of metabolic flows needed to maintain and reproduce human societies.

A turn from the metabolism of industrial societies to the metabolism of industries and to the scientific discipline of industrial ecology was taken in the course of the 1980s. The World Commission on Environment and Development (WCED) introduced the concept of sustainable development via the so-called Brundtland Report also entitled "Our Common Future" (1987)[28]. Amongst many other objectives like poverty reduction, gender equity, and wealth redistribution, the report highlighted the crucial need for a new paradigm to balance ecology and economy. Natural scientists and engineers applied the ecosystem concept to industrial systems, not to society as a whole, and developed strategies of the optimization of material and energy flows. Robert Frosch and Nicholas Gallopoulos made these ideas popular through an article entitled "Strategies for manufacturing" published in a special issue of *Scientific American* (Frosch and Gallopoulos, 1989). The authors described the perspective of an industrial ecosystem, in which the use of energy and materials is optimized, wastes and pollution are minimized, and companies become more viable and competitive. They advanced the idea that "waste from one industrial process can serve as the raw materials for another, thereby reducing the impact of industry on the environment" (Frosch and Gallopoulos, 1989). Without using these terms, they advocated a shift from linear to circular models of industrial activity in which waste was recycled and used as input to another activity, therefore

[28] https://sustainabledevelopment.un.org/milestones/wced

reducing virgin material use. Circular models of material flows are at the core of several close concepts, such as industrial symbiosis and circular economy, that emerged at the time. Consumer waste was also included because, as the authors argued, the bulk of it consists of organic materials and plastics that "could relatively easily be composted, recycled or burned to produce energy but instead are stored in landfills" – an idea that has been implemented only partially for more than 30 years[29].

In 1994, the U.S. American National Academy of Engineering defined industrial ecology "as the study of the flows of materials and energy in industrial and consumer activities, of the effects of these flows on the environment, and of the influences of economic, political, regulatory, and social factors on the flow, use and transformation of resources" (National Academy of Engineering, 1994: v). This broad definition had the advantage of leaving room for various scientific disciplines and questions on all aspects of a society's metabolism.

In the following years, industrial ecology gave rise to a growing scientific production and substantially progressed in the development of material flow analysis[30] as a central tool in early metabolism studies[31]. The discipline's institutionalization advanced with the founding of the *Journal of Industrial Ecology* at the MIT in 1997 and of the *International Society for Industrial Ecology* (ISIE) in 2000. The concept of industrial symbiosis emerged from efforts towards resource savings in the industry sector, defined as the physical exchange of material and energy between clusters of firms which traditionally act separately (Chertow, 2007, 2000). It further strengthened the positioning of industrial ecology as an engineers' and natural scientists' field. The main characteristics of industrial ecology as a discipline are the biological analogy (metabolism), the use of a

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[29] Recent global data show that recycling rates of municipal household waste in big industrial countries reached a maximum of 53%, in the case of Norway, in 2007, and low levels of only 19% and 29% in Japan and the EU27 respectively (Tisserant et al., 2017). Rates of landfilled waste remained high (up to 55%) in many industrial countries. For the remaining proportion of waste, energy and nutrients are recovered, mostly through incineration. The relatively high levels of landfilled waste suggest that the direction advanced by Frosch and Gallopoulos (1989) therefore is still relevant, even if, today, importance is given to material recycling and closed material cycles (European Commission, 2008; Hotta, 2013). Incineration, on the other hand, makes closed material cycles impossible.

[30] See Chapter 2 for a short history of material flow analysis as a method of metabolism studies.

[31] Next to Material flow analysis, Life-Cycle Analysis (LCA) as a tool was developed and standardized during the 1980s and '90s in an effort to assess the environmental impact of products throughout their life cycle. In Europe, the Society of Environmental Toxicology and Chemistry (SETAC) developed a standard for LCAs, fueled by the increasing demand of governments and firms to assess the environmental dimension of production activities.

system's perspectives (industrial ecosystem), the role of technology leading to ecoefficiency and dematerialization, and the role of companies as the objects of study and change. Technology was regarded as a way to make the industrial system more compatible with the growing demand for "sustainable development" (Allenby 1999).

As the increasing focus on technology in industrial production was starting to narrow the boundaries of industrial ecology as a scientific discipline in the eyes of many, criticism became audible. Ongoing epistemological debate about the relevance of using analogies from biology and ecology (Ehrenfeld, 2004), the poor contribution of the social sciences to the understanding of the determinants of flows (Boons and Howard-Grenville, 2009), and the growing disconnection of the consumption stage from scientific production in industrial ecology (Hertwich, 2005) were some of the main points of criticism.

Concerns about the health and environmental consequences related to waste and emissions had already been expressed by Kneese, Ayres and colleagues (Ayres and Kneese, 1968; Kneese et al., 1970). Alerts about consequences for the climate of one big waste stream, carbon dioxide emissions, into the atmosphere were being ignored by policy makers until the Kyoto protocol was finally adopted, more than twenty years later[32] (Fischer-Kowalski, 1998). As Fischer-Kowalski pointed out, this research community was clear-sighted enough to see that "a reduction of residuals [waste] can be achieved only through a reduction of inputs" (Fischer-Kowalski, 1998: 72). This was subsequently reflected in policies of resource and material efficiency and strategies of "decoupling" with the aim to support input reduction in industry without jeopardizing economic output (OECD, 2016). Frosch and Gallopoulos' popular concept of waste as an input to industry (Frosch and Gallopoulos, 1989), an idea later taken up and developed through the industrial symbiosis concept and more generally towards closed-loop material flows was seen as one solution to overcome physical constraints to continuous economic growth. This viewpoint contrasts somewhat with the urban ecology literature where concerns about waste became concerns of the treatment and destination of waste (Wolman, 1965). One reason is that in urban ecology studies, the waste in cities was largely human or

[32] The Kyoto Protocol is an international agreement anchored within the United Nations Framework Convention on Climate Change. It committed industrialized countries and economies in transition to limit and reduce greenhouse gases (GHG) emissions in accordance with agreed individual targets. Adopted in 1997, it was the first international agreement with the aim of climate protection https://unfccc.int/kyoto_protocol.

animal waste or waste from related human activities, and therefore was considered ineluctable fate.

As regards MFA, it took a few more years before, from the 1990s on, a large academic network, the ConAccount network (1996), made MFA a fast-growing field of research (Bringezu and Moriguchi, 2002). It was subsequently recognized as a section in its own right, called socio-economic metabolism (SEM), of the International Society of Industrial Ecology[33]. The rise of political interest played a role in the method that was further gaining ground. Policy-oriented analysis of economy-environment interactions such as those informed by MFA were badly needed as international organizations and national governments committed to resource-efficiency policies and dematerialization strategies(von Weizsäcker et al., 1997), and required that this indicator to be quantifiable. MFA was developed in this context. Today, MFA is recognized as having achieved maturity in its application to European or global flow accounting, due to extensive work on data compilations (Fischer-Kowalski et al. 2011). MFA indicators have been increasingly used in national policies directed at reducing environmental pressures and impacts of their economies. In 2001, Eurostat, the European Union's statistics agency, implemented MFA in a statistical accounting framework called Economy-wide Material Flow Accounts (EW-MFA) (Eurostat, 2001), implemented in the European Statistical System and conceptually embedded in the System of Environmental Economic Accounting. National and supranational economies, however, are not the only field of application for MFA. Following the MFA typology in Bringezu and Moriguchi (2002), the method is being widely applied to analyse the material throughput of firms, economic sectors and regions. It is available to a large academic community (Krausmann et al., 2015).

[33] ConAccount stands for "Coordination of Regional and National Material Flow Accounting for Environmental Sustainability". Coordinated by the Wuppertal Institute for Climate, Environment and Energy in close cooperation with the Institute for Interdisciplinary Research and Continuing Education (IFF) in Vienna, the Centre of Environmental Science of Leiden University (CML), and Statistics Sweden. It started in May 1996 as an EU funded network of institutions with the aim to develop regional and national material and substance flow accounting (MSFA) in the EU (https://cordis.europa.eu/project/rcn/39994/results/it). In summer 2008, the International Society of Industrial Ecology (ISIE) formally integrated the ConAccount network as a section under the name of socio-economic metabolism (SEM).

Cities attracted little attention in the early years of industrial ecology as the methods were generally poorly spatialized (Barles, 2010). Baccini and Brunner (1991) placed urban systems, next to terrestrial and aquatic ecosystems, within the anthroposphere. But while these authors acknowledged the consumption of large amounts of material, energy and space in modern urban areas, as places of high concentrations of population and wealth, they applied the metabolism concept to regional areas rather than specifically urban ones [34]. The topics covered were not typically urban, in the sense of using urban infrastructure or defined by urban form or density; instead they focused on human settlements in a geographic area. They showed the benefits of applying material flow analysis to demonstrate the material implications of four main activities of human societies, which were defined as "to nourish", "to clean", "to reside and work" and "to transport and communicate", and how they were organized in a fictive region called "METALAND". Weisz and Steinberger (Weisz and Steinberger, 2010) have proven the usefulness of urban metabolism studies to analyse the role of urban system-specific parameters, including urban form, urban building stock and urban consumption patterns for reducing energy and material flows in cities.

In 2007, a special issue [35] of the *Journal of Industrial Ecology* was dedicated to cities, covering empirical research about mobility, construction and urbanization, and examining urban management and policies; yet food consumption was not addressed. When cities became increasingly acknowledged as the origin of societies' environmental impact, while also holding potential solutions to it (Weisz and Steinberger, 2010), the situation gradually changed towards rich scientific production with empirical work for cities throughout the world. Several review articles and reports cover the state of the art of urban metabolism studies at different times and in relation to various topics, such as articles on urban planning and design by Kennedy et al. (2011), research methodologies by Zhang et al. (2013), food consumption by Goldstein et al. (2017), and waste by Ramus and Obersteiner (2016).

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[34] Some years later, Baccini and Bader published a textbook for students, in German, entitled *Regionaler Stoffwechsel* (regional metabolism). The authors presented ways to analyse – using material flow analysis –, and evaluate metabolic processes, and partly also how to control them, at the level of regions, establishing links with policy and planning (Baccini and Bader, 1996).

[35] Journal of Industrial Ecology, Volume 11, Issue 2, Pages: iv, 1-154, published in April 2007, available at the following link: https://onlinelibrary.wiley.com/toc/15309290/2007/11/2

Studies on the food metabolism in urban areas studies are of particular interest for this research, which is why a dedicated section reviews the main references from the literature (see 1.2.3).

Society's metabolism in social, industrial and territorial ecology

Whereas industrial ecologists anchored the field in a technical conception of solutions for sustainability, mainly of business, emerging interdisciplinary scientific communities placed social systems, such as a country, the global community or a city, at the centre of their research. They shared with industrial ecology the systems approach, accounting tools for material and energy flows [36], and the acknowledgement that human and social factors determine interaction with the environment. These communities gave rise to two similar movements, the Vienna School for Social Ecology in Austria, and the territorial ecology (*écologie territoriale)* movement in France.

Social ecology[37], which has its early roots in the 1980s in Austria, studies the interaction between social and natural systems[38]. Society-nature interaction is based on mutual dependencies – which is why they are seen as co-evolutionary – of symbolic/cultural and biophysical processes relevant for societal dynamics. The Vienna Social Ecology school around Marina Fischer-Kowalski, Helga Weisz, Helmut Haberl and colleagues developed a socio-ecological theory and a conceptual model to explain society-nature interaction (Fischer-Kowalski and Haberl, 2007; Fischer-Kowalski and Weisz, 1999). According to the model (Figure 2), human society is a hybrid of the material and symbolic realms (Fischer-Kowalski and Weisz, 1999). Its bio-physical structures (population, livestock, artefacts etc.) are part of the material world.

Two concepts, social metabolism and colonization of natural systems, constitute the core of socio-ecological theory. They draw on various scientific traditions, such as biology,

[36] The Vienna Social ecologists were strongly involved in the development of material flow accounts to be applied to nations within the ConAccount network.

[37] Vienna Social Ecology movement differs in its aim and roots from the Vermont Social Ecology movement, which is placed close to eco-activism and teaching in environmental ethics.

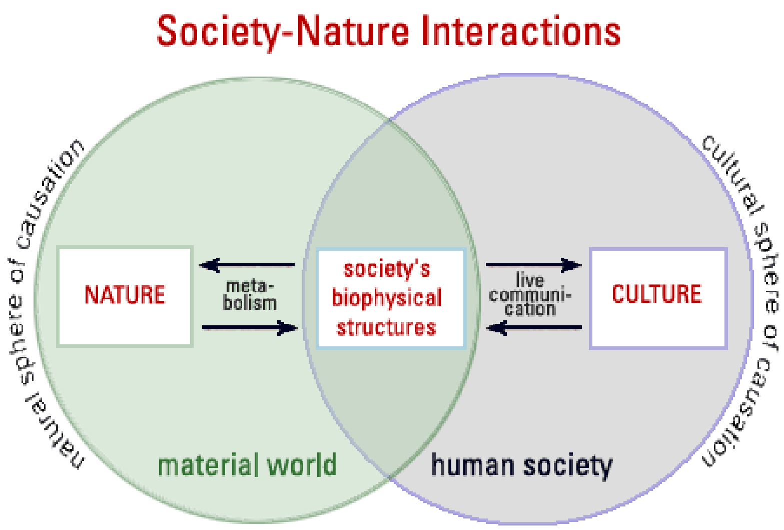
[38] For an overview of the history of the conceptual foundations, and the empirical work on the core concepts and perspectives for social ecology, see the compendium *Social Ecology: Society-nature relations across time and space* edited by part of the Vienna Institute for Social Ecology, with contributions from scientists trained there or otherwise collaborating (Haberl et al., 2016).

sociology, economics, technical sciences, history, geography and cultural anthropology, to offer a coherent perspective on the society-nature relationship.

Social metabolism is considered a key process in society-nature interactions (Figure 3), as it links society to its natural environment through the exchange of material and energy flows. Social metabolism refers to the socially organized co-evolution of society and nature occurs as society intervenes in nature through so-called practices (labour, technology and capital), and conversely, through its bio-physical structures, is subject to the physical forces of nature.

The other key process in society-nature interaction in social ecology is the colonization of natural processes, that is “the intended and sustained transformation of natural processes by means of organized social interventions, for the purpose of improving their utility for society” (Fischer-Kowalski and Weisz, 1999). Land use receives particular attention as it is a key element of society-nature interactions and a driver of global environmental change, considering that resources essential to society (e.g. food, feed, fibres, energy, including the provision of clean water and air) are provided from terrestrial eco-systems through land use.

Figure 3. The conceptual model of society-nature interaction developed by the Vienna Social Ecology school



Source: elaborated after Fischer-Kowalski and Haberl (2007) and Fischer-Kowalski and Weisz (1999); retrieved from https://boku.ac.at/en/wiso/sec/research/soziale-oekologie

In social ecology, society or social metabolism is often analysed from a long-term perspective, sometimes over centuries and millennia, as society-nature interactions can have long-term effects in the future just as they can have their origin in the past. The social organization of material and energy extraction, transformation, use and restitution to the environment reveals how societies shape their environment, impacting the availability of resources and the type and degree of pollution. Drawing on types of social organization in humankind's history, structured by historian Sieferle (1997), three socio-ecological regimes can be distinguished, namely the hunting and gathering mode, the agrarian mode and the industrial mode. The main differentiating element is the source of energy and the dominant technology a society uses to convert energy, according to Sieferle (1997). Whereas Paleolithic hunters and gatherers relied "passively" on solar energy, as they collected biomass for mostly food and fuel, agrarian populations which started to settle in the Neolithic relied "actively" on solar energy, as they cleared areas from the natural vegetation and monopolized solar energy for edible plants (that they then had to store and preserve as a consequence of the newly adopted sedentary life style) (Fischer-Kowalski and Weisz, 2016). Both regimes relied on solar energy and therefore have a strong relation to land as a resource for the access to renewable biomass. With the industrial regime however, which started in the 17th century in the UK, fossil-fuel-based energy became available, and in unprecedented amounts. In social ecology, the shift from local, solar- and biomass-based energy provision to the use of fossil energy carriers changed the energy and material use by up to two orders of magnitude (Krausmann et al., 2016). While for most of the time of human history, the endosomatic metabolism that directly sustains human organisms determined their material needs, for which renewable biomass was the most important material, the metabolism of industrial societies is predominantly exosomatic (Lotka, 1956). Material and energy are extracted to produce and reproduce population, buildings, built infrastructure, animal livestock and all goods and services used by human societies. Because material and energy are available in limited amounts and are unevenly located and unequally distributed amongst and within societies, Georgescu-Roegen argued that the exometabolic evolution pushes societies to transgress the planet's limits, and results in human problems of social unrest associated with societies' limited and unequal access to resources (Georgescu-Roegen, 1977). The sustainability challenge, in both environmental and social terms, consists in reducing the exosomatic metabolism while maintaining its function for human well-being.

In line with the research purpose and scope of social ecology, food production and land use are important research topics due to the vital function of food for human societies and the strong and multiform pressure on the environment from land use (Foley et al., 2005). Understanding the socially organized use of land, water, energy and other limited resources for food production is of crucial importance in the light of a growing world population facing the biophysical limitations of planet Earth. Although macro-scale, from national to global, primes in social ecological research, urban systems are being acknowledged as a relevant level to study effects from the physical concentration of demand on material flows and on the spatial relation to a city's hinterland. Combined approaches to urban planning can help to reduce material and energy consumption through appropriate spatial structures (Weisz and Steinberger, 2010).

The francophone studies of territorial ecology build on the achievements of industrial ecology and on urban ecology, as developed since the 1960s in the course of Odum's ecosystem theory. Territorial ecology analyses society-nature interactions through the study of the material and energy metabolism, an aim that it shares with the sister field social ecology. However, it pays specific attention to the spatial context and the local socio-ecosystem or anthroposystem (Leveque Leeuw 2003). It therefore adds to the understanding of particular patterns in the socio-ecological functioning of a *territoire* (socio-ecological regime) in consideration of the local particularities – beyond the three global regimes (foraging, agrarian and industrial) – which define the history of society-nature interactions in a long-term perspective. Territorial ecology is interested in both the material and the immaterial dimension of local socio-ecosystems. It uses the conventional methods of industrial ecology, first and foremost, to analyse material and energy flows in the material dimension. In parallel, it considers the social dynamics of the stakeholders in place, their system of interaction and governance, and the determinants of the local activities related to issues of sustainability. Barles (2010) defines territorial ecology as "an industrial ecology that is considered in a spatial context and that takes into account the stakeholders, and more generally, the agents involved in material flows, questions their management methods and considers the economic and social consequences of these flows". In this sense, beyond the characterization of the territorial metabolism, studies in territorial ecology open perspectives for change. The joint definition of industrial and territorial ecology is common in France as well (Buclet, 2011), where it underpins the epistemological roots in industrial ecology as an internationally acknowledged field of various developments. Debates about these multiple definitions, their aims and scope, what they share and what differentiates them, are ongoing in the francophone academic landscape.

The origins of the field lie in a French academic movement committed to the institutionalization of industrial ecology in France from the 2000s onwards. Dominique Bourg founded the centre for interdisciplinary research and studies on sustainable development (*Centre de recherches et d'études interdisciplinaires sur le développement durable*, CREIDD) at the Technical University of Troyes (UTT), where his successor was Nicolas Buclet. He anchored industrial ecology in the francophone scientific landscape. The first Chair of Industrial Ecology was founded at the UTT in 2005. The research project CONFLUENT (2009-2013), acronym for knowledge of urban flows, environmental imprint[39] and sustainable governance, under the coordination of Sabine Barles, and its specific interest in sustainability in urban areas, can be seen as the starting point of territorial ecology in France, federating contributions from various fields such as industrial ecology, urban planning, urban engineering, urban biogeochemistry, and ecological economics.

While not being conceptually limited to urban areas, studies of the urban metabolism have proved to be particularly insightful for the further conceptual development of territorial ecology. Cities have particular features with respect to their interaction with the environment as they source most of the material and energy to satisfy their high level of requirements from outside of the city boundaries. The industrialization and urbanization processes, characteristic of Europe's history over the past two centuries, shaped cities' metabolism. Large, linear and originating from outside of a city, or as Barles (2015) put

[39] Imprint is a less common term than footprint in societies' metabolism studies, but both mean the same thing, that is, a common measure to capture the resource consumption and environmental impacts associated with the production, processing, distribution, and waste generation of a material demand from society. Several indicators have been developed to characterize a city's or other units of human activities' environmental imprint, such as the ecological footprint (Wackernagel and Rees, 1996), the water footprint (Hoekstra and Chapagain, 2006), and the nitrogen footprint. With regard to urban food consumption, the term "a city's foodprint", in analogy to footprint, has been used by some (Billen et al. 2008; Chatzimpiros and Barles 2013).

it, externalized, linear and intense, the cities' metabolism progressively took form. Under the influence of globalizing economies, supplying areas diversify and their distances to urban consumption increase, leading to a globalized urban metabolism (Gilles Billen et al., 2012). An international workshop was organized in September 2009 in Paris, to gather and discuss work on the relationship between large Western cities and their surrounding territories over a long historical time period. The proceedings were compiled in a special issue of the scientific journal *Regional Environmental Change*[40].

Territorial ecology, closely connected to industrial ecology on the one hand, has borrowed from urban ecology, on the other hand, the systems approach that connects input and output flows of the city, usually considered separately in research and policy about the urban environment (Buclet et al., 2019). Compared to urban ecologists' negative view of the city as a parasite and a source of pollution, it sees the city as a provider of many resources, notably used construction material for recycling or, in the tradition of 19th century urban chemists, human excreta for fertilizer use in agriculture (Barles, 2007, 2005; Esculier, 2018).

Territorial ecology has much in common with social ecology: metabolism as the core concept to study society-nature interaction through the analysis of material and energy flows; interest in industrial and pre-industrial societies and in the events that shape their evolution; places with actors involved in metabolism governance; and the importance of producing knowledge and advancing in the theoretical foundations that place the analytical perspective above a normative or operational one. In my understanding, differences lie in the empirical dimensions of metabolism studies, although they are not exclusive. National and global scales of analysis which are prominent in social ecology versus the urban and wider territorial scale, including rural places, set an example for empirical work in territorial ecology. The reference to a *territoire* as "a social and a lived place, including political and ideological dimensions of space", as defined by Barreteau et al. (2016), is well understood in the francophone scientific community close to the regional sciences and social geography, and justifies the use of the French term. In the Anglo-Saxon community, territory refers to administrative boundaries. Social ecology,

[40] Regional Environmental Change, 2012, volume 12, issue 2
https://link.springer.com/journal/10113/12/2/page/1

on the other hand, refers directly to actors and stakeholders of a place and less to the place itself.

1.2.2. Urban metabolism studies on food

The review is structured according to different angles chosen, within the urban food metabolism, to study cities' interactions with the environment. The examples quoted amply refer to a flourishing field of studies carried out in France over more than a decade within several research programs, such as the interdisciplinary research program on water and the environment of the river Seine basin[41] (PIREN Seine), and the interdisciplinary research programme on City and Environment (PIRVE), as well as the research project CONFLUENT (see section Territorial Ecology). Other studies complete the overview to illustrate additional angles. These studies are good examples of the diversity of the angles, methodological approaches, or focus on food categories. Taken altogether, the literature on urban food metabolism can be divided into four thematic sections: i) food supply, consumption and excretion; ii) resource use and losses in agriculture related to urban demand; iii) land use, environmental footprint studies, "food print", supplying areas and supplying distance, self-sufficiency; and iv) multiscale approach to a city.

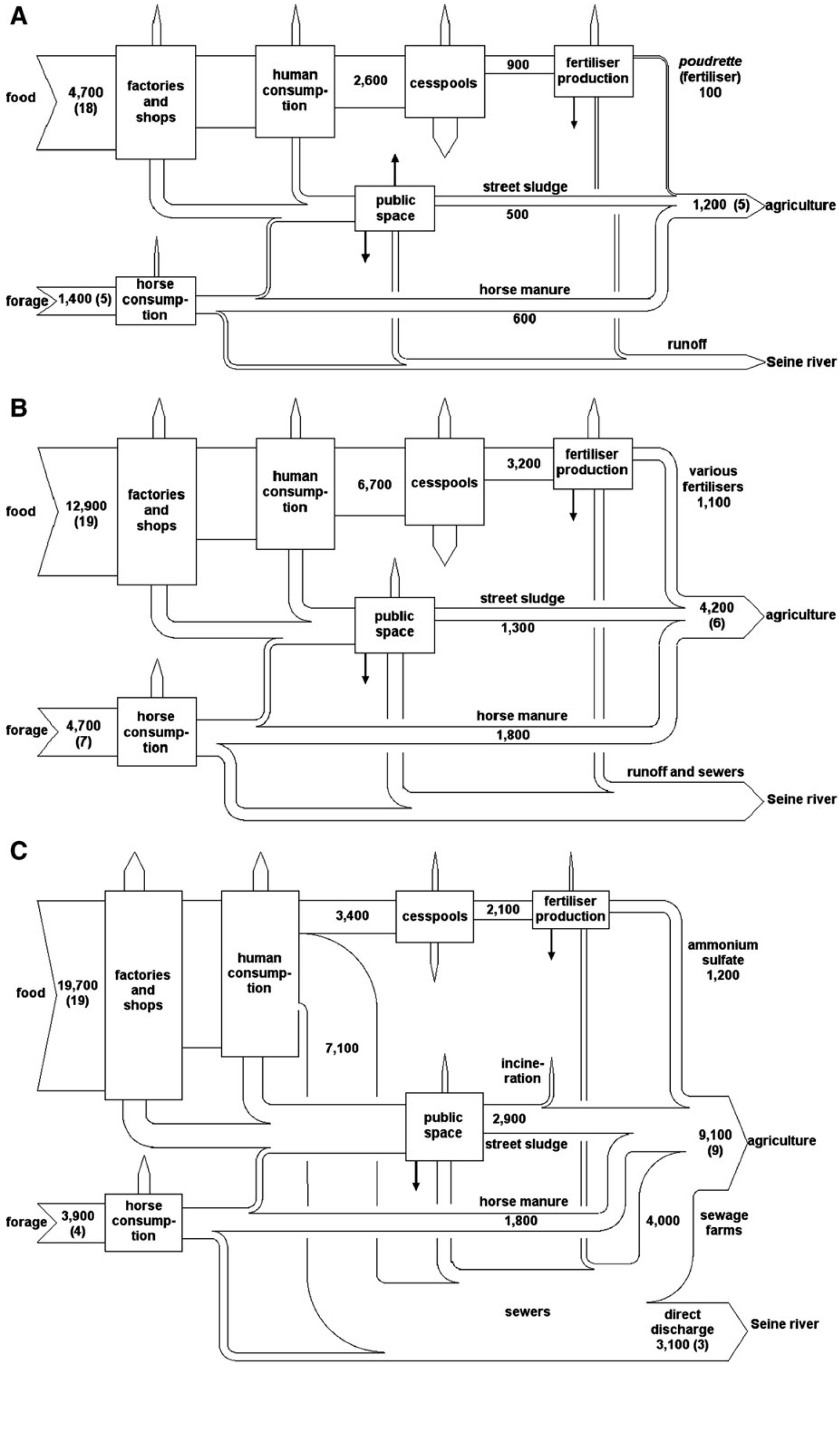
Food supply, consumption and excretion

The studies in this section originate in concerns about the environmental impacts of nitrogen and phosphorous emissions. Several studies analysed a city's food supply over time. Barles (2007) has shown that in the period between 1801 and 1914, the fivefold increase in the population of the city of Paris, from 500,000 to 2,900,000 inhabitants [42], and the threefold increase in the number of horses, entailed an increased demand for food and feed (Figure 3). Due to concerns about the availability of fertilizer for rural agricultural production, the share of street sludge and horse manure redirected to agriculture increased from 10% to over 40% over half of a century (Figure 4). In the course of the urbanization and population growth studied here up to the early 20th century,

[41] The Paris capital region is situated in the Seine basin, which explains why the urban area of Paris was commonly used as a case study.
[42] From the early 19th century on and over one century, not only did the population of the city of Paris increase, the suburbs also came into existence. By 1911, an additional population of 1,300,000 inhabitants lived in the Seine department outside of Paris, as the census figures quoted by Dupeux (1981) and by Barles (2007) indicate.

cities and their supplying hinterland – a term used to describe the surrounding rural territories shaped by urban demand (Gilles Billen et al., 2012) – were connected to each other through inversely directed nitrogen flows: food supply flowed in one direction, and human and animal waste in the other direction. The spread of the industrial Haber-Bosch process made urban nitrogen sources obsolete and led to a steep decline in the reuse of urban nitrogen from food, down to 10% in the mid-20th century (Figure 5) (Esculier and Barles, 2020).

Figure 4. Circulation of dietary nitrogen, Paris, tN/year, (gN/cap/day)



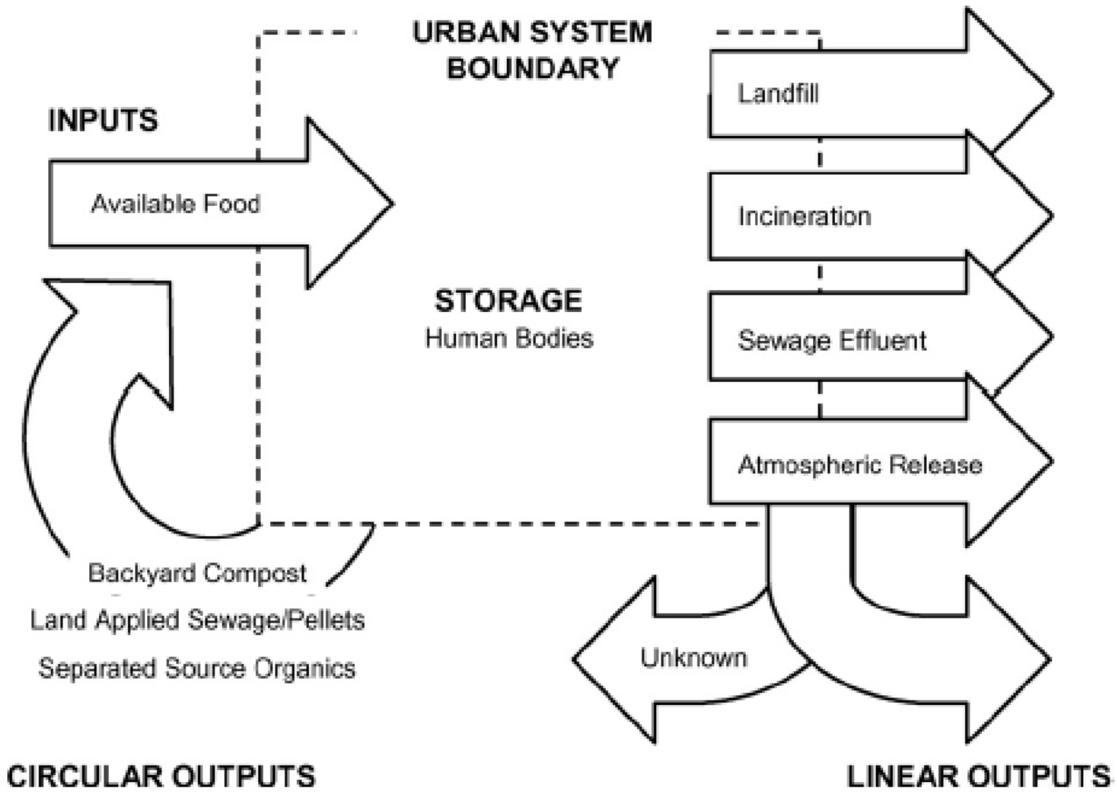
Source : Barles (2007); Comments on the figure: A. 1817: 716,000 inhabitants, 16,500 horses. B. 1869: 1,841,000 inhabitants, 50,000 horses. C. 1913: 2,893,000 inhabitants, 55,000 horses.

Figure 5. Nitrogen recycling rate of the Paris conurbation, 1860s to 1960s, %

Source: Esculier and Barles (2020)

Forkes (2007) suggested a simple conceptual mass balance model (Figure 6) with a focus on linear and circular food output flows. The results of the model applied to the contemporary city of Toronto underlined the largely linear nature of the urban food metabolism, expressed in nitrogen flows. Circular output represented below 5% of total urban output of dietary nitrogen in 2001.

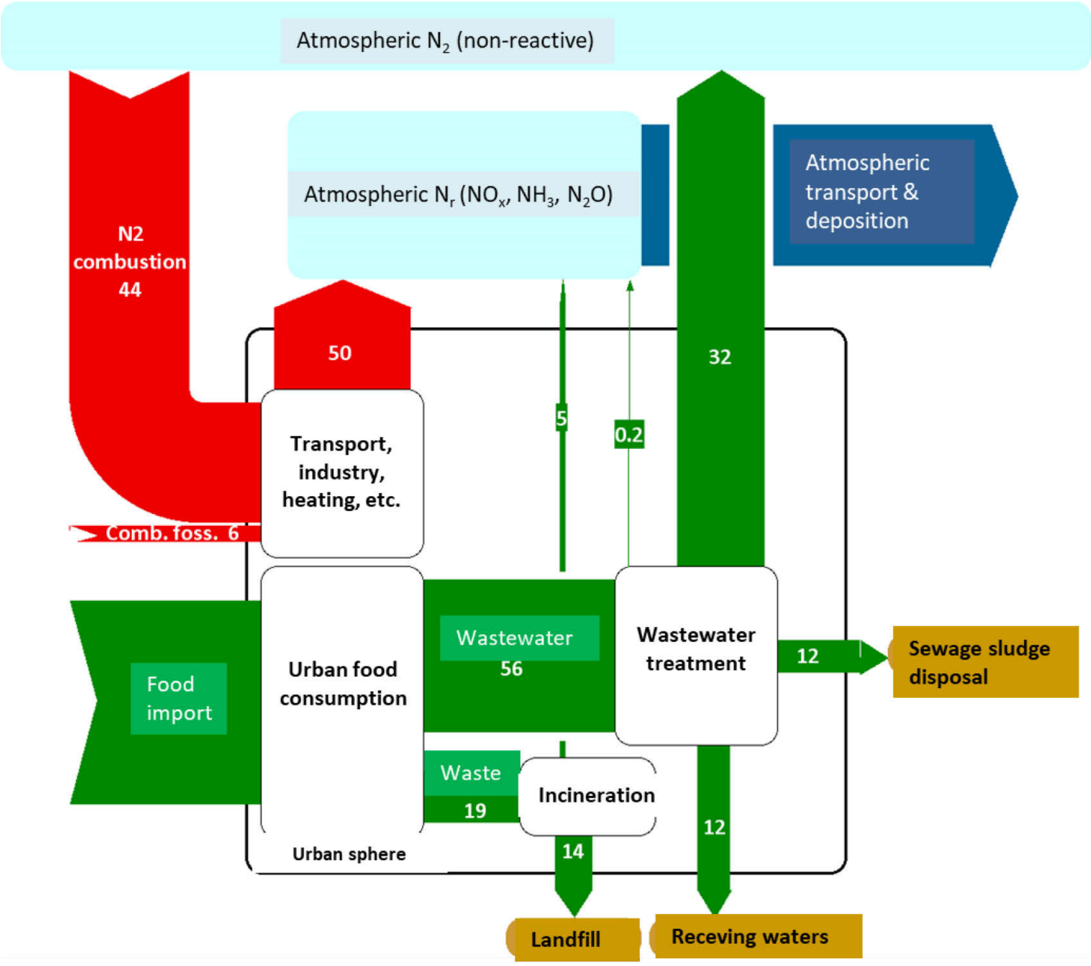
Figure 6. Nitrogen balance model components



Source : Forkes (2007)

The study by Svirejeva-Hopkins et al. (Svirejeva-Hopkins et al., 2011), using Paris metropolitan area as a case for the year 2006, obtained similar results. The study included non-food and non-feed nitrogen sources. The results showed massive nitrogen losses to the air and the water system, causing pollution. Nitrogen is furthermore stored in landfill or spread as sewage sludge, neither of which are options for reintroducing nitrogen into the food system and enhancing circularity. Hence, the food metabolism of Paris metropolitan area, expressed in nitrogen flows, is characterized as exclusively linear (Figure 7).

Figure 7. Nitrogen balance, Paris metropolitan area, 2006, Gg N/y



Source: adapted by Barles from Svirejeva-Hopkins, et al. (Svirejeva-Hopkins et al., 2011)

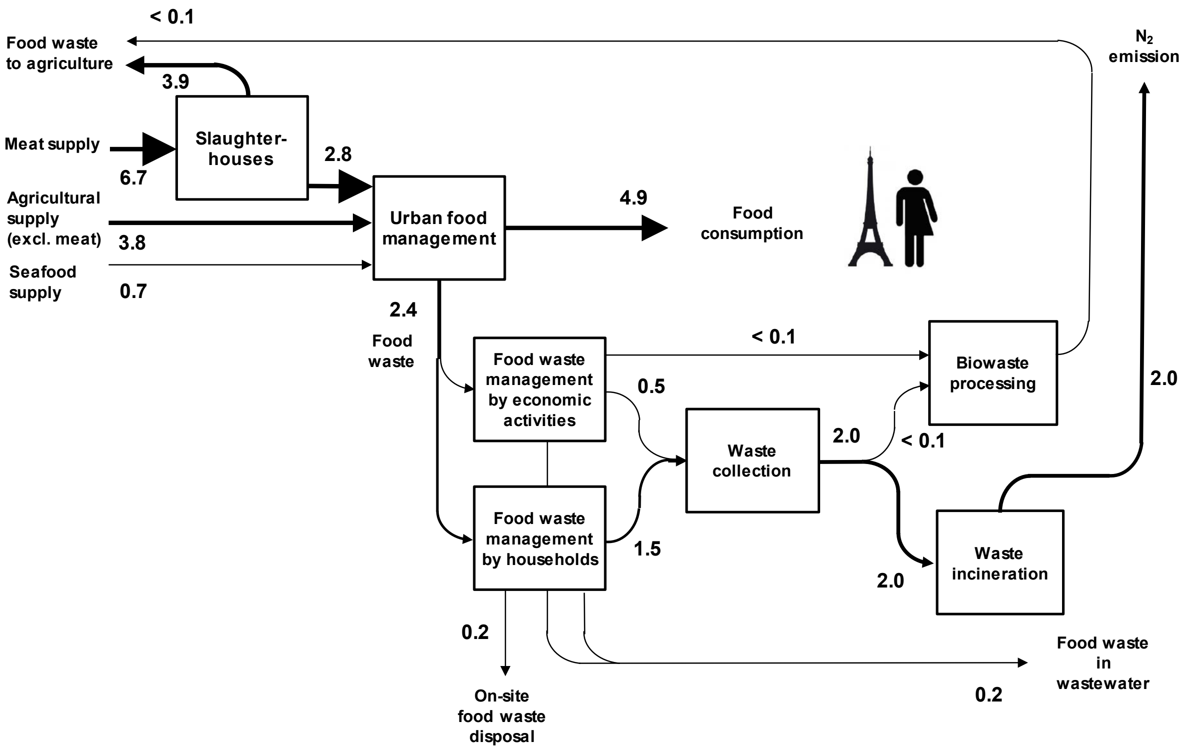
Conceptually, a city's food metabolism was further developed for the stages of excretion and waste. Using Paris urban area again as a case study in his doctoral thesis, Esculier (2018) characterized the extended and newly termed agro-food-excretion system, and calculated dietary nitrogen and phosphorous flows circulating within. Results show that most metabolic output from human digestion of food end up in urine and feces and are directed to the wastewater system, as low nitrogen and phosphorous recycling rates illustrate. Food waste is predominantly incinerated. Negligible quantities of nitrogen in its reactive – and therefore polluting – form (Figure 8) and phosphorous are released into the environment, but relevant reuse for their fertilizing properties is not being achieved[43].

In a study of the food-related phosphorous flows for an average inhabitant of the Swedish city Linköping, from 1870 until 2000, Schmid-Neset et al. (2008) have shown profound changes in their intensity and nature, driven by increased phosphorous input through chemical fertilizer, diets heavier in animal products, and higher phosphorous outflow to the wastewater system. Phosphorus recovery could contribute about one quarter of the current need for phosphorus in fertilizer for the average diet, and an even larger proportion for a meatless diet (Schmid Neset et al., 2010).

Nitrogen and phosphorous flows illustrate the linear nature of the food metabolism of Paris, as an example of a large Western city. Organic recycling through composting and anaerobic digestion has played no role for the destination and fate of food waste. Legally required for bio-waste, of which food waste is a small percentage, organic recycling was only starting to be implemented at the time of this study and is expected to grow steadily for at least a decade[44]. Once converted, the output products, compost and digestate, are highly valuable for the generation of soil organic matter and for their nutrient properties for agricultural production. For this reason, it is relevant to study the urban food metabolism from the angle of post-consumption destination and fate of food, and of the relevant part of the system.

[43] Changes in the socio-ecological regimes of societies based on solar energy, to societies based on fossil fuel, imply the release of reactive nitrogen into the atmosphere (cf. social ecology, Chapter 1, definition of food, Chapter 2). Incineration returns nitrogen back to the atmosphere, but releases its non-reactive and unpolluting form (N_2) which is unavailable and irrelevant as a nutrient for food production unless it is transformed into a reactive form. Phosphorous stays in the bottom ash and is fixed in clinker, mostly used for construction.
[44] See Chapter 5, policy analysis.

Figure 8. Nitrogen flows associated with food waste of one inhabitant of Paris megacity for one year (in kgN/cap/y)



Source: Esculier (2018)

The selection of studies demonstrated that urbanization leads to increasing amounts of nutrients in the urban cycle, situated far from the areas of agricultural production where they are required. Urban sewers can be seen as nutrient mines, an opportunity for “reverse nutrient mining” (Forkes, 2007). For phosphorous, however, impurities in sewage sludge require caution and have driven the development of phosphorous recovery technologies rather than the expansion of sewage sludge use in agriculture.

The increasing distance to agricultural areas does not fulfill conditions for urban nutrients to contribute to a closed nutrient cycle connecting urban and rural areas. Aside from consumer aspirations to reconnect, localizing agriculture close to cities has the potential to close nutrient cycles and inversely reconnect production and consumption.

Resource use, environmental footprint studies, "food print"

While nitrogen losses occur massively from wastewater and, to a lesser extent, from solid waste in the city, other food-related nitrogen flows occur far from cities. A large proportion of the nitrogen applied as fertilizer to agricultural areas is lost to the environment where it contributes to the nitrogen cascade, defined as "the consequential transfer of nitrogen through environmental systems and which results in environmental change as nitrogen moves through or is temporally stored within each system" (Galloway et al., 2003). Although nitrogen losses in agriculture occur geographically distant from the city, there is a causal relationship through urban demand. The losses can therefore be attributed to urban demand by using consumption-based indicators. One example of a consumption-based indicator for food system-relevant substance flows is the nitrogen footprint, defined as an indicator to connect nitrogen flows and losses in production systems to the consumption of dietary nitrogen, through foodstuffs. Chatzimpiros and Barles (2013) have calculated nitrogen footprints specifically for the consumption of animal foods (beef, pork and fresh milk), for France. Nitrogen footprints represented 35%, 53% and 48% of total nitrogen use in beef, pork and fresh milk, respectively, and were mostly due to crop production to feed livestock (Chatzimpiros and Barles, 2013).

A review paper by Goldstein et al. (2017) provides the full picture of published metabolism studies on the environmental footprint of urban food demand ("foodprint"). The study reviewed 43 UM assessments covering 100 cities and a total of 132 "foodprints" in terms of mass, carbon footprint, and ecological footprint, an indicator which Rees and Wackernagel (2008) define as the requirements of biologically productive land to support a population's resource use. Besides providing a useful benchmark for foodprint indicators for cities worldwide, the study showed large deviations based on wealth, culture, and urban form. The mass foodprint was primarily linear. The generation of organic waste from the urban system was amongst those indicators that had a strong, positive correlation to wealth. Goldstein et al. (2017) concluded that much of the foodprint is embodied within food imports, but cities can nevertheless act on it through improved nutrient recycling and food waste avoidance.

Land use, supplying areas and supplying distance, self-sufficiency

Urban food (and feed) demand have a causal relationship not only with nitrogen flows in agricultural areas, but also with the use of other resources, such as land and water. However, the rural area required to supply a city, also called the foodprint [45], depends not only on the urban but also on the local demand and hence, on the surplus production available for export. Billen and colleagues (Billen et al., 2009) showed that in the case of Paris, the balance between the increase of urban population – from several thousand inhabitants in the early 11th century to just under 5 million in the Paris conurbation in mid-20th century – and the increase in rural productivity did not significantly change over several centuries. The production area, located primarily in the Seine watershed surrounding the city, consequently remained nearly equal in size. By contrast, during the second half of the twentieth century, the Paris foodprint declined in size, despite the population doubling to close to 10 million inhabitants by the end of the century. The uncoupling of urban food consumption, food supply and land use, unprecedented in human history, was achieved through land-independent access to synthetically processed nitrogen which likewise raised rural productivity to unprecedented levels.

Further studies analysed changes, over time, in the supplying areas and supply distances for various food categories feeding the urban population. They characterized the relationship between the consumption area and supplying area, and the degree to which these areas were interconnected. Billen et al. (2012), for example, analysed the supplying areas and distance of fruits and vegetables, cereals and animal foods supplied to Paris at the end of the 19th century and in 2006. The results differ for the three categories of food. For cereals, the supply area remained the central area of the Paris basin, an area which gradually turned to intensive cereal production. Livestock moved to regions located west and north of Paris, which supplied the predominant share of animal foods. For fruits and vegetables, Paris still depends for about half of its fruit and vegetable supply on a close hinterland (less than 200 km from Paris), but on long-distance supply for the other half of it.

[45] Food-print defined by Billen et al. and ecological footprint by Rees and Wackernagel are both spatial indicators of a society's metabolism, with one important difference. The food-print indicator refers to the geographical supplying areas for the main supplies used by a population, whereas the ecological footprint informs about the virtual requirement of biologically productive land.

Another set of studies with a similar aim, to study supplying areas of urban food, but with a slightly different approach, focused on the contribution of local peri-urban agriculture and analysed the agri-food system with a territorial delimitation. Agricultural areas close to cities in most countries are increasingly threatened with growing urbanization, urban sprawl and the extension of peri-urban areas. Furthermore, as Gilles Billen et al. (2009) have shown for the Paris region, the local contribution to urban food consumption decreased in the course of industrialization, and specialization in an export-oriented agriculture increased in the second half of the 20th century. Tedesco et al. (2017), for example, used a nitrogen flow analysis to study the agri-food system of a peri-urban area close to Paris. Their findings show local production and consumption to be largely disconnected, with only 8% of the urban demand being sourced locally, within the territorial limits. In this study, food consumption was modeled under consideration of the resident and temporary population, i.e. workers, due to important economic activities in the area.

Varying approaches to scale

The question of which scale of a city to choose – city centre, with suburbs, larger metropolitan area –has been prevalent in part of the literature. Barles (Barles, 2009) carried out a material flow analysis at city scale using a standardized method designed for use at national scale[46] in the case of Paris. Apart from testing whether the method was appropriate to apply at this scale, the aim was to see the effects of a multiscale approach on the results of material metabolism, by distinguishing between Paris, its suburbs, and the region (Barles, 2009). This study covered all relevant material categories, not only food or feed, and calculated a set of indicators developed with the method and useful for the interpretation of the results and comparison with results from other studies. Besides the stated feasibility for the method, Barles (Barles, 2009) concluded on the complementary role of the three scales in the different functions fulfilled in the urban food system. Her results show that Paris, as the dense centre, exports all of its waste to the other parts of the region and concentrates food consumption, while the agricultural and urban sprawl area consumes high levels of construction materials and fuel. Local per

[46] The EUROSTAT Economy-wide material flow accounting method was developed by a group of researchers under the coordination of Eurostat. A detailed description of the method is available in Chapter 2.

capita food consumption was equal at the different scales analysed in the study, with the exception of Paris, where per capita food consumption was twice as high as in the surrounding *départements*. Reasons advanced to explain the difference referred to a substantial addition to the eating population of other populations, through employment and tourism, which affected population-based consumption indicators. However, in contrast to the legally resident population, available through official statistics, the eating population is not known.

While the question of scale is relevant for input and output flows, due to complementary functions, inner-system flows are also to be considered. Lack of knowledge about the circulation of material within cities ("black box") has led Zhang et al. (2013) to propose an urban metabolic network system to analyse the input, recycling, transformation, and output within a city, tested for different food waste treatment scenarios by Tseng et al. (2015). Codoban and Kennedy (Codoban and Kennedy, 2008) analysed the urban metabolism of different neighbourhoods. Amongst other material and energy flows, they identified food and solid and liquid food waste flows for households, as one component of cities analysed at infra-urban scale.

1.3. Problem statement

Sustainability issues related to food systems have so far received very little attention regarding cities, despite the fact that cities concentrate a population's food demand and therefore concentrate food-related issues. The urban dimension of food systems is poorly represented in the scientific literature.

As the urban metabolism literature has shown, the rare studies about urban food systems were carried out at macro level and focused on nutrients. Micro-level analysis covering food system activity sectors and the food metabolism have remained under-researched. However, a focus on food, not nutrients, is crucial to any perspective on a socio-ecological transformation of food systems, for food is more to human societies than just a source of nutrients. The cultural social dimension of food strongly shapes human societies' organization and their use of food. Sector-wise organization of the food system contributes additional pieces of understanding of the urban food metabolism. A holistic understanding of the various dimensions of food consumption and their organization in cities is fundamental for a socio-ecological transformation of the urban food system.

Additionally, food waste has barely been studied at the level of cities. Analysed at other scales, such as at national scale, results cannot directly feed into the analysis of cities without accounting for city-specific features, for example the concentration of a population, of its food consumption, and of consumption-related activities. Quantifying food waste in cities is particularly insightful when the food system sectors generating it are distinguished, both of which are a prerequisite for any further step to elaborate targeted reduction strategies.

Because of the various sectors that compose the food system in cities and because food waste data is scarce, a method has to be developed to characterize and quantify food and food waste flows. A sector-wise analysis of the food system in terms of food waste has the advantage of revealing under-researched inner-urban flows of food and food waste, and showing how they pass between the food system sectors and interconnect them with one another.

The prism of the food system sectors' role in the urban food metabolism is useful to develop our understanding of the immaterial dimensions of material flows, such as their cultural, social, or political determinants and the cultural and social embeddedness of the metabolism. The same prism is also beneficial when it comes to examining the means that are employed to achieve food waste reduction, through policy action, for example. Knowledge of both the material and immaterial dimensions of the urban food metabolism is crucial from the perspective of socio-ecological transformation towards a more sustainable food system.

Given the research gap in the urban metabolism literature that consists of a lack of micro-level analysis of cities' food systems –, specifically with regard to food waste –, and the challenge of making the material use of urban food systems less intense, less linear and less externalized, there is an overarching need to gain more knowledge about urban food systems. This can be done by means of quantitative and qualitative methods.

1.4. Research question and propositions

The premises from the previous section lay the ground for the main research question: **How can the material dimension of food systems in cities be characterized and quantified using a socio-metabolic approach?**

In addition to substantial methodological points to resolve, I specifically address a policy perspective on food waste, to understand how food waste is perceived and to develop strategies of food waste prevention. I also look at how the urban food metabolism is culturally and socially embedded and what this means for a policy of food waste reduction.

This focal question includes two sub-questions:

- Given the lack of data on the material dimension of food, which methods and data can be used to characterize and quantify the urban metabolism related to food and food waste from a perspective of social, industrial and territorial ecology? Since food involves many different food system sectors within a city, how can the inner-urban food and food waste flows be addressed?
- How is the urban food metabolism culturally and socially embedded and what does this mean for a food waste reduction policy? What are learnings from a policy perspective about the immaterial dimension of the urban food metabolism?

Three propositions build the structure of the thesis. Proposition 1 directly follows from the research question about ways to analyse the material dimension of urban food systems, and suggests that Western cities' food metabolism is intense, linear and externalized. Two further propositions emerged from methodological work to test Proposition 1. Proposition 2 posits the usefulness of opening the black box of inner-urban flows, to deepen the understanding of the food metabolism. Proposition 3 suggests that, in an urban system, there is a difference between the resident population and the eating population, that this difference affects total food consumption, and that this is relevant to the analysis of the urban food metabolism.

Proposition 1: *With regard to food, Western cities exemplify the intense, linear, and externalized metabolism that characterizes the relationship between industrial societies and their environment.*

Due to the concentration of the population and its related food consumption, there is a spatial separation between food system activities close to consumption and land-based agricultural food production. The spatial separation between food production and consumption, together with industrialized and specialized food system sectors, are closely linked to cities' intense, linear and externalized material metabolism. We assume that cities make an intense use of food, that they manage food in a linear way, and that they externalize both food supply and its end of life, as either food waste or human excreta.

Questions of the intensity of the food metabolism involve food waste. In the context of industrialized societies, sectors close to consumption are much more concerned by food waste than those close to production. We assume that cities are places where levels of food waste are particularly high, despite the exclusion of food waste from activities that are located outside of the urban system.

Proposition 2: *Opening the "black box" of the urban system and analysing inner-urban food flows help to understand the overall food metabolism of a society.*

A sector-wise approach applied to the city is key to understanding how food moves across the urban food system and which changes in its material dimension have implications in its relationship to the environment. In which sectors and how does the transformation of food take place? What is the situation of food waste in terms of food system sectors, quantities generated, composition, and destination? The sectors and activities close to consumption are particularly relevant. When food is wasted close to consumption, the associated life-cycle environmental impacts are particularly high as they combine with those from the previous stages.

With the novel method developed in this work, a sector-wise analysis that opens the urban system "black box" informs investigations of how food moves from one activity sector to another and interconnects them, according to a food system approach. A sector-wise approach to food flows is valuable for scrutinizing current policy action aimed at food waste reduction, and, more broadly, food policy. Additionally, it enhances our understanding of the immaterial dimension of material flows, since their "embeddedness" in a context of social, cultural and political determinants of the organization of food flows can be analysed in connection with the food system sectors. A food system approach provides the framework for this analysis.

Proposition 3: *In an urban system, there is a difference between the resident population and the eating population which directly affects total urban food demand.*

Cities are places of concentration of employment and tourism that attract an additional population of commuters, tourists and excursionists. Even though it is not resident, the additional population consumes food and has part in the urban food demand and all activities of a city's food system. My hypothesis is that there is a difference between the resident and the eating population of a city, due to a city's appeal with regard to employment and tourism. The difference is reflected in total urban food demand and has implications for the organization of the urban food system, such as the role that out-of-home consumption plays in the system.

To respond to the research question and empirically test the three propositions, this work analysed the urban and inner-urban food metabolism of a large Western city, with particular attention paid to the analysis of urban food waste.

Chapter 2: Concepts and methods for analysing a city's food metabolism

This chapter introduces the methods and approaches that are combined to analyse a city's food metabolism by paying particular attention to food waste. Focusing on food waste requires that different food-related sectors and activities be accounted for, as they all contribute to the generation of food waste but present their own specific causes and solutions. This is why a food system approach is used in combination with material flow analysis, a method widely used in social metabolism studies (see background, Chapter 1). While material flow analysis is designed to reflect the material relationship between a society and its environment, here in the form of food, the cultural and social dimension of this relationship is important to consider. It is referred to again in Chapter 6 dedicated to the cultural and social embeddedness of the food metabolism, as it contributes to shaping the food metabolism. This is why this chapter introduces food from a material and a social perspective, followed by a short presentation of the recently emerging notion of food waste. The chapter ends with an outline of the case study of Paris Île-de-France, used to test the hybrid material flow analysis and food system method.

2.1. Notions related to food systems

2.1.1. Material, and cultural and social dimensions of food

Their interaction

Food is what people eat. Food is a means of subsisting, a minimum to support life. A strong physical or material component characterizes the definition of food since food provides people with energy and nutrients which are fundamental to ensuring human bodily functions, and hence provide feelings of well-being, comfort and security. The bodily need is such a fundamental one that it has driven humans, as individuals and as societies as a whole, to continuously care for food, every day, and to put their work power into the organization of its supply. Max Weber (1980) cited in Barlösius (2005) sees the instinct-driven search for food as the origin of the development of rational economic activity. Societies can develop when they have sufficient access to food. The rise of agricultural production, which is now the predominant form of food procurement in most societies in the world, must be seen from this perspective of continuous concern to access food[47].

The way in which humankind, as an omnivorous species, experiences the fulfillment of its dietary needs cannot be reduced to purely biological, technical or even utilitarian considerations (Poulain, 2017). Whereas some biological requirements exist, humans' choice of food from a wide range of possibilities, their likes and dislikes, and the way they cultivate, prepare and to eat are largely determined by social and cultural factors. This does not mean however that social and cultural factors are more flexible than biological ones. Food, chosen and accepted as such, is a "natural product culturally constructed and valued, transformed and consumed according to a strongly socialized use protocol" (Poulain, 2017: 11). Both physical and cultural dimensions characterize the human relationship to food, though not juxtaposed but in interaction and co-determination, otherwise called biocultural co-evolution (Fischler, 2001). The question of whether food cultures are primarily determined by "culture" or by "nature" has stimulated an area of intense research in cultural anthropology (see also Chapter 6). Societies, not necessarily individual members, have a degree of freedom to express food cultures including values, identity, norms and regulation systems across the stages from "farm to fork" (see 1.3.5). This freedom has found multiple forms of expression in food cultures across societies worldwide.

Supply, preparation, distribution, intake and disposal of food have always been organized and regulated by the community (Barlösius, 1999; Simmel, 1957). The cultural and social organization of societies is strongly structured by food. How societies organize themselves for all these processes reflects general principles of their functioning, with their hierarchies, social groups, and power relations. Eating and food are a "total social fact", as Marcel Mauss (1925) put it, for they reflect the entire society and its institutions, in analogy to a society *"en miniature"* (Barlösius, 2005).

[47] Today, agriculture – including crops and livestock – provides the predominant share of the human diet worldwide. Wild animals (game, fishery) and wild plants play a minor role, except for fishery, with large differences according to regions (FAO, 2018). Fishing was always the predominant source for fish for human food consumption, until the rapid growth of aquaculture in recent decades exceeded fishery for the first time. The share of aquaculture products in total food fish consumption was 51% in 2015 compared with 6% in 1966. Not only did aquaculture allow for increased fish consumption, it also diversified the supply, especially for species such as shrimps, salmon, bivalves, tilapia, carp and catfish (including Pangasius spp.) (FAO, 2018). These data do not consider fish captured for the fishmeal required for aquaculture and for other non-food uses. Considering total production, fishery is still ahead of aquaculture.

According to Simmel (1957), a natural bodily need, such as the need for food, translates into social action in the organization of food, culminating into the sharing of the meal. Each meal then builds a bridge between nature and society, as it translates the bodily need into a "social issue" (Barlösius, 2008: 49).

Changes over time

The meaning that food has for people has changed over time. Major changes in the diet occurred with the introduction of techniques, in the anthropological sense. Diet changed first in the Paleolithic era, when humans made use of fire for cooking – or better, grilling – food they previously ate raw (Lenton et al., 2016). This may date back to as early as 1.9 million years ago, detectable through physical changes in the body of early Homo erectus (Wrangham et al., 1999). Thermal processes can make more energy available from food (e.g. starch in tubers), increase nutrient absorption and digestion (e.g. through softening structure and fibers), and increase food diversity through detoxification (Gowlett, 2016). Later again, diet changed when humans settled, about 10,000 B.C.E., and moved from a hunting-gathering scheme to an agrarian one, involving plant breeding, farming and the domestication of animals as new techniques. Gradually, new resources again became food, such as cultivated cereals and dairy from livestock, both of which were virtually unavailable in a hunting-gathering scheme (Birlouez, 2019a; Flandrin and Montanari, 1996). In the industrial regime, major changes in the consumption of food originated in technically novel processes which accompanied the steep rise of the food industry from the early 20th century on. New preservation techniques, use of the cold chain, stabilization through additives, fractioning and reformulation of ingredients were involved to transform agricultural raw material into stable, standardized and microbiologically safe food products.

Food can lose its status over time. In Europe, the decrease in the consumption of parts of slaughtered animals, such as inner organs, is an example. Some staple foods or vegetables which were common meal ingredients in former times and became the main ingredient in times of hunger and war (cabbage, roots, etc.)[48] were later rejected by the generation that had suffered. Some animals have disappeared from diets. Horse meat is an example. With the change to recreational uses of horses, an increasing majority of people refuse to eat horse

[48] Some of them are now again being cultivated and marketed as "forgotten" or ancient vegetables, e.g. rutabaga, topinambour, and various varieties of cabbages. It needed a new generation free from the old associations to give these products a new chance.

meat[49]. Access to a new resource opens a possibility for humans to consider it as food. But humans are actually far from eating everything that is biologically useable by their organism, and biological needs alone never explain "why we eat what we eat" (Fischler 2001). Food items must be culturally accepted and approved as edible[50]. Culture explains that there are such big differences in what food is to people. While there is large consensus amongst food cultures worldwide about the edibility of chicken, there is by far less of it for the consumption of dog and rat, as Abrams (1987) found in a cross-cultural survey. Differences exist even in Europe, where horse, rabbit, snail and frog legs are part of the food culture of only France and Italy.

Whereas food, by definition, is culturally accepted and therefore edible, parts of foods can be considered inedible. Inedibility is determined partly but not only by biological possibilities; once again, culture and associated representations play a large part. In the European context, some parts such as egg shells, peelings of pineapple or orange, bones, fruit pits, coffee ground or tea bags are commonly considered as inedible (Östergren et al., 2014) and removed during the processing, preparing, cooking or eating of food[51]. For other parts, opinions vary about their inedibility, beyond personal taste. In the United Kingdom, Nicholes et al. (2019) surveyed people's view on the edibility of food parts that where considered ambiguous by the authors. They showed for a range of food parts that responses differed widely; many people always at them and many others never did. They also found a systematic difference between the perception of edibility and reported own consumption. Many respondents who ate certain foods perceived specific parts (e.g. carrot skin, outer cabbage leaves, cabbage stems) to be edible, yet reported that they hardly ever ate those parts themselves. Overall, in European food cultures there is no guideline about which parts belong to the group of inedible parts. This had implications later in this study when the composition of food waste was analysed with respect to the question of which parts were initially edible and which ones were not.

[49] In France, horse meat has had a changing status over the past centuries. It was forbidden for consumption up to the 1860s at a time when horses were crucial for traction and riding. In other times, horse meat was eaten but was never a first choice. At best it was recovered from old or injured animals, especially in difficult times (Toussaint-Samat, 2013). Today in France, horse meat still has a niche market with 17KT of carcass equivalents consumed annually, which is marginal compared to the consumption of pork, poultry and beef, with 1,580, 1,686 and 2,106 KT, respectively (Agreste, 2015).

[50] Terminology in French can vary between *comestible*, *consommable*, *mangeable*, etc. Barlösius (1999) sees the distinction between edible and inedible as one of the three institutions found universally across food cultures.

[51] While inedible, humankind found processing and preparation or extraction techniques to render them edible. Examples are broth made from bones, and candied orange peel. Renewed interest in these techniques is evidenced in the media and the food service sector, where "nose-to-tail eating" (Henderson, 2004), zero waste cooking, or slow food are reported or promoted.

The perception of when food is no longer good to eat has changed over time. Apart from hunger, food poisoning has been one of humans' fears, as omnivorous eaters. The natural rejection of bitter-tasting foods is seen as a means of protection against poison from organic decay, which often has a bitter taste (Fischler, 2001). But historians (Ferrières, 2015; Walter et al., 2006) have described multiple strategies used by populations to preserve foodstuffs – even if those methods are inadequate by today's standards. Ferrières (2015) showed how peasant populations in France managed health risks from the consumption of ergot-contaminated rye[52]. Aware of the neurological disorders caused by its consumption, those to whom the knowledge had been passed down from their ancestors diluted contaminated with uncontaminated rye in proportions which they considered an acceptable health risk. While access to food and its safety were of utmost importance, other qualities became more prominent when the situation allowed for food preferences or even refusal of food. Birlouez (2019b) has described the diversity of expectations regarding food, in terms of taste, nutrition, means of social distinction and conveyer of symbols, and how they changed over the ages. Recently, in the past two to three decades, confidence-inspiring items (e.g. labels, brands, official denominations) have become important in consumers' minds, following scandals or media coverage (e.g. mad cow disease, pesticide contamination, horse lasagna) often related to industrialized agricultural production and the processing industry. It has been in times of oversupply and abundance, once the vital need of subsistence is fulfilled, that food choices have been made with consideration for more diverse criteria. Throughout human history, prosperous and lean times have in many ways determined what food is to people, how it is treated, and when it is considered to be edible or not.

A food approach in social metabolism studies, as in this study, must necessarily integrate the physical material and cultural social dimensions of food, as together they shape society's metabolism. The quantification itself, however, relies on the physical material dimension.

Food in metabolic studies

In social metabolic studies, food is primarily considered in its physical material expression. EU law has a pragmatic view on the question of what food is and refers to a use-oriented definition

[52] Ergot is the dried sclerotium of the fungus *Claviceps purpurea.* It attacks rye and other grass by replacing the seed of the grass. Ergot which contains medicinally acting alkaloids contaminates harvested rye the consumption of which in excessive amounts can cause the disease known as ergotism ("ergot," 2003). Ergotism is a neurological disorder found in rural populations up to the 19th century. Caballero et al. (2003) reported that in some areas of France, ergots accounted for as much as 25% of the rye while 2% is enough to cause an epidemic. According to the same authors, about 8,000 people died between 1770 and 1771, in one district alone in France. Today, a strict food safety regulation in Europe and in other countries limits the contamination.

of food, but does not further qualify food. Regulation No 178-2002 defines food as “any substance or product, whether processed, partially processed or unprocessed, intended to be, or reasonably expected to be ingested by humans. ‘Food’ includes drink, chewing gum and any substance, including water, intentionally incorporated into the food during its manufacture, preparation or treatment (European Commission, 2002).”

Food, in this study, covers all forms of items from basic commodities provided by agriculture and livestock to processed end-products and prepared meals. The many forms in which food is handled in societies in recent history is due to the high degree of specialization of activities and their concentration in dedicated sectors forming a network called a food system (see 1.3.5).

In social metabolism studies, food is usually understood in the wider sense of biomass. Human societies extract or cultivate biomass for various purposes: food, feed, construction material, energy, and components for industry. While most biomass products supplied to an urban system are known for one predominant use and were easy to identify as food in this study, some products are used for multiple purposes. Non-food uses such as feed and increasingly biofuel for cereals and oil crops are salient examples (Fine et al., 2015; Juin, 2015). To quantify the supply of food in the strict sense, I diminished it in the case of cereals by estimated quantities used for livestock in the urban system. Oil crops were entirely classified as food. Pet food was not considered in this study. Once manufactured, it is not classified as food even though it is derived from the same basic food commodities as food for human consumption.

In this study, food and drink are analysed separately when it comes to their disposal, as different means and infrastructure are used. Food to be disposed of is most often handled through a centralized solid waste management system that includes the collection of waste bins and the treatment of their contents[53]. Drink is handled through the wastewater system, with disposal directly through the sewer system and treatment in wastewater treatment units. There are presumably exceptions to this rule, with liquid or saucy food, and meals being disposed of through the wastewater system. In line with the research aim of this study, food and drink flows were quantified separately in order to connect them to the respective treatment systems: solid waste and the wastewater systems.

[53] Other forms of disposal are feeding to pets and home or neighborhood composting, with the latter having increasingly been developed. Home or neighborhood composting is seen as one option for reducing the organic part of household waste bins, next to the separate collection by the public service. By 2025, all households in France must have an option available for the recycling of their bio-waste (*LOI n° 2015-992 du 17 août 2015 relative à la transition énergétique pour la croissance verte*).

The distinction between food and drink seems to be conventional with respect to food intake techniques referring to "eat" and "drink". This is how both categories are used in this study. Drink was used for liquids, hot or cold, which are drunk from a recipient, including milk and juices. All other items were considered as food, even when liquid and eaten with a spoon, for example. Common language found in dictionaries does not entirely reflect this nuance. The Merriam Webster dictionary for example defines food as a nutriment in solid form[54]. This definition overlooks the fact that food can be liquid and be eaten with a spoon, not drunk. Drink[55] is defined as a liquid suitable for swallowing, that does not need to be chewed.

In a subsequent step of my analysis, food flows of the urban system were analysed across the main food system sectors, according to the most common food and drink categories. The data sources used in this study, described in Chapter 3, all have their own nomenclature of goods, in line with the initial purpose of that source but hindering comparison across different data sources. For example, member states of the European Union must obey European harmonized methodology guidelines including nomenclature, such as the Standard Goods Nomenclature for Transport Statistics (NST) for transport surveys, or the Classification of Individual Consumption by Purpose (COICOP) for Household budget surveys[56], to ensure comparability of results between member states. For the purpose of this cross-sector food flow analysis, a transversal food and drink nomenclature (see Appendix to Chapter 3, Table A3.2) served to restructure the results from the various data sources (see Chapters 3 and 4). The transversal nomenclature includes the nomenclatures of the various data sources used for food flow quantification.

Tap water is a particular case in these considerations about food. Water is vital to any life on earth. The drinking water directive, Council Directive 98/83/EC of 3 November 1998[57], concerns the quality of water intended for human consumption. In Europe, the predominant supply of water comes from distribution systems installed in housing areas that were developed since the industrial revolution and generalized during the 20th century. Tap water in households

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[54] The solidity of food does not seem to be related to water content nor physical structure or matrix. Fruits and vegetables often have a water content of over 85%, similar to plain yoghourt, but different matrices. Oil contains no water at all but is liquid. They all count as food and are characterized as solid. However, in my research, I assumed that some food products are disposed of through the sewage system when their physical structure is close to liquid.

[55] "Drink." Merriam-Webster.com Dictionary, Merriam-Webster, https://www.merriam-webster.com/dictionary/drink. Accessed 22 Apr. 2020

[56] As recommended by the European Commission in a report entitled "Household Budget Surveys in the EU Methodology and recommendations for harmonization" (European Commission, 2003).

[57] https://ec.europa.eu/environment/water/water-drink/legislation_en.html

has many uses: apart from ingestion in meals (e.g. in soup, pasta, rice, sauces, etc.) prepared in the home and as drink, it is used for food preparation (e.g. washing of fruits and vegetables), for personal hygiene, laundry, dish washing, garden watering, and so forth. The INCA 3 survey (Anses, 2017) shows that adults aged 18-79 drink on average a daily 477 grams of tap water, next to 425 grams of bottled water. They also drink 486 grams of hot drinks (coffee, tea), usually prepared with tap water. Tap water use as hot and cold drinks, with less than one liter per day, made up a very small share (less than 1%) of average total tap water consumption of 144.6 l/cap/day in France in 2014 (Eau de France, 2017). Food purchase and food intake data were consolidated by considering tap water use to drink as a complement to purchased drinks. Tap water added to the preparation of meals was not accounted for in this study.

In this study, food is considered together with drink in their multiple forms used for human consumption. The quantification of food flows across the food-related sectors was achieved, in the course of this work, through the integration of the various classification systems into one system.

2.1.2. Food waste as an incompatible feature of sustainable societies

Food that leaves the food supply chain and ends up uneaten has commonly been termed “food waste”. However, terminology and definitions have been a subject of intense debate in the literature for the past decade (Chaboud and Daviron, 2017; Hanson, 2017; Hanson et al., 2016). This period has been characterized by shifting political concepts and a steep increase in the number of scientific publications, which sometimes make comparison and interpretation difficult. Inconsistency in the concepts and data make it challenging to integrate food waste in the analysis framework of this study and to account for it appropriately.

Broadly, two approaches to food waste have prevailed in the debate in recent years. In a food security approach, irrespective of its causes and its management, food waste is understood as food that ends up uneaten. The term “food loss”, sometimes referred to as “post-harvest losses”, is often used for situations in the agricultural, transport, storage, and manufacturing stages (Gustavsson et al., 2011)[58]. In this approach, the aim is to maintain food available for human consumption. Food waste reduction has the potential to increase food availability, which in turn supports food security. The food security approach has mainly been supported by the FAO

[58] The combined form “food loss and waste” (and not “food loss and food waste”) is used in parallel by consortia such as the Food Loss and Waste Protocol (Hanson et al., 2016) and the FAO (2014) in its early work, based on the FAO reference study from (Gustavsson et al., 2011).

(2014) and national governments, as in France[59]. In a resource efficiency approach, food waste is food that ends up as waste. The aim is to prevent food from ending up as waste and to support the conditions of food being eaten or being directed to other uses, such as animal feed or material for the bio-sourced economy. This conception refers to strategies, such as circular economy, to increase efficiency in the resource and material use of the economy. The research project FUSIONS suggested a definition according to the resource efficiency approach[60] and prepared its introduction to EU law (Östergren et al., 2014). Accordingly, food waste is food that has become waste (European Comission, 2018 Article 3); waste is "any substance or object which the holder discards or intends or is required to discard" (European Commission, 2008 Article 3.1). The definition applies to any stage of the food supply chain, except for agricultural production.

Inarguably, in the resource efficiency approach the decision not to consider productive non-food uses as food waste legitimizes any use for feed or industrial purposes, although resource input and emissions for the initial supply of high-quality food items are incommensurably high. For that reason, referring to a resource efficient approach is objectionable. A waste-centred approach would be a more appropriate term. Furthermore, in a context where access to food has again become a source of tension (e.g. food crises in 2007-2008 and in 2010-2012), the fact of downgrading food to non-food uses is criticized. From this perspective, the distinction between "edible" food waste (or wasted food) and "inedible" food waste is important as it calls for different waste-reduction strategies. Wasted food could have been eaten instead of being discarded and wasted, for example meal leftovers or food beyond expiration date, and for that reason, wastage could have been prevented or reduced at source. Hence, wasted food is avoidable. Contrastingly, inedible parts are parts of food that are not eaten. They are intrinsically part of food, such as vegetable peelings, bones, and so on, and for that reason are unavoidable (see 1.3.3 for a discussion of inedibility). Food waste reduction related to inedible parts refers to reuse or recycling.

Whereas when the food waste topic first rose to public awareness in around 2008, different definitions coexisted in the two approaches, they are now tending to converge. Following the

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[59] In French, the term *gaspillage alimentaire* is commonly used for food waste. In contrast, food waste according to the resource efficiency approach is termed *déchets alimentaire*s in French. Equally in the FAO definition aligned to SDG goal 12, *gaspillage alimentaire* would apply to food loss and waste in the conceptual framework whereas *déchets alimentaires* would apply to food loss and waste in the operational framework.

[60] The debate about the food waste definition was intense and protracted amongst the project participants. In the end, the definition retained was a result of a political decision and was not obtained upon consensus of the project participants.

United Nations' Sustainable Development Goals, including target 12.3 aimed at food loss and waste reduction, a new definition of food loss and waste emanated from previous discussions. This new definition, hosted by the FAO and the UNEP, distinguishes between "food loss" and "food waste" and specifies that non-food utilization is not loss or waste. It can be seen as a compromise of previous contrasting approaches[61]. The operational definition includes the following:

"Food losses are all the crop and livestock human-edible commodity quantities that, directly or indirectly, completely exit the post-harvest/slaughter production/supply chain by being discarded, incinerated or otherwise, and do not re-enter in any other utilization (such as animal feed, industrial use, etc.), up to, and excluding, the retail level.

Food waste : The food and associated inedible parts removed from the human food supply chain at the following stages of the food chain: manufacturing of food products, food retail and wholesale, out-of-home consumption and in-home consumption" (O'Connor, 2019).

What the coexistence of definitions will continue to look like at an operational level remains to be seen. France, for example, recently laid down in law a food security-oriented definition for food waste[62], initially elaborated in 2012, in the early phase of France's political engagement on the topic. Yet, as an EU member state, France is required to monitor food waste according to EU waste law and to report the data (Framework Directive 851/2018). It remains to be seen how food waste monitoring for both approaches simultaneously will be handled without adding confusion.

Regardless of one or the other approach to food waste, material flow analysis requires that outputs be exhaustively covered and balanced with input flows, irrespective of the food waste definition to which they refer. Therefore, a first step in this study consisted in quantifying how much food ended up uneaten in the urban system, irrespective of its destination as waste or as input to reuse, or the recycling options. The quantity of discarded food gives a rough picture of the efficiency with which an urban system feeds its population. A second step consisted in

[61] The turn in the position of the FAO is remarkable. An earlier definition illustrated that the FAO was a fervent proponent of the food security approach (FAO, 2014).

[62] Law No. 2020-105 from February 10th 2020 regarding the fight against waste and a circular economy (*LOI n° 2020-105 du 10 février 2020 relative à la lutte contre le gaspillage et à l'économie circulaire*): "any food item destined for human consumption which is lost, discarded or spoiled at any stage of the food cycle constitutes food waste" (« *Toute nourriture destinée à la consommation humaine qui, à une étape de la chaîne alimentaire, est perdue, jetée ou dégradée constitue le gaspillage alimentaire.* »)

analysing the destinations of discarded food. This analysis allows for insight into an urban system's organization and management with respect to environmental challenges, such as climate change mitigation and resource efficiency. For methodological reasons, productive non-food uses of food are not only within the scope of material flow analysis, but must be connected to food waste analysis, although current positions tend not to consider them as food waste (European Comission, 2018; O'Connor, 2019)[63].

In this study, I referred to food waste for almost all situations where food leaves the food supply chain or is discarded and ends up uneaten, except for the agricultural production stage where the term food loss is used. Following advice from Oldfield et al. (2018), I distinguish, where possible and relevant, between wasted food and inedible parts [64] (called "food residues" by the authors) as they require different action (see 1.3.4). Together, wasted food and inedible parts build food waste in this study. Any uses of wasted food or of inedible parts are designated as food waste, except for uses as animal feed or industrial uses.

2.1.3. The food system as a network of sectors and activities

In the French literature, the concept of food system originated in the work of economist Louis Malassis. A food system represents the way humans organize themselves to obtain and to consume their food[65] (Malassis, 1996). Method, organization, acquisition and consumption are the key elements in this short definition. Referring to Malassis' pioneering work, Rastoin et al. (2010:19) developed the concept further and defined a food system as "an interdependent network of actors (companies, financial institutions, public and private organizations) localized in a given geographical area (region, state, multinational region), participating directly or indirectly in the creation of a flow of goods and services geared towards satisfying the food needs of one or more groups of consumers, both locally and outside the area considered".

This definition suggested by the French scientific community is close to the accepted meaning of food systems in the English-language literature. Goodmann speaks of food systems as "all processes involved in feeding a population, and encompassing the input required and output

[63] http://www.fao.org/food-loss-and-food-waste/en/
[64] Inedible parts have a floating status in the FAO / UNEP definition. For reasons of data constraints and measurability, the food loss operational framework differs from the conceptual framework with respect to the inclusion of inedible parts (FAO, 2019). The food waste operational framework is currently under construction.
[65] Malassis' definition of a food system is "the way in which humans organize themselves to obtain and consume their food" (Malassis, 1996:1).

generated at each step. A food system operates within, and is influenced by, the social, political, economic and environmental context" (Goodman, 1997).

The distinction of food system sectors and their associated activities is structuring for this urban food metabolism study. Food loss and waste is generated in all of these sectors, but to varying degrees and for different reasons (see Chapter 1 for background). Reduction options must be tailored accordingly. For this reason, a sector-wise analysis of food and food waste flows should yield important insights. At a minimum, a food system covers production, processing, distribution, preparation and consumption (FAO, 2019). According to the type of food system, of which Colonna et al. (2013) distinguish five, other sectors or activities can be included. In agri-industrial food systems, the specification of import and export can add valuable information for the urban metabolism analysis. Domestic food systems have many food-related activities concentrated in a few sectors, especially in the household. Food consumption can be distinguished between the food service sector supporting out-of-home consumption, and households for in-home consumption. A more detailed description of each sector follows in the respective sections in Chapter 3 and Chapter 4.

Other terms describe the activities and sectors involved in supplying or demanding food. The food chain connects all processes and flows, from agricultural production to food consumption. Speaking of a supply chain puts emphasis on the organization of processes and flows from the perspective of the demand-side, for example from a company (Davis and Goldberg, 1957). A value chain, according to Porter (2011), has a focus on value-creating activities. Applied to whole industries, not companies, it is called industry value chain. Commodity chain analysis, or *approche filière* in French, covers the sequence of operations from agricultural raw materials to a consumer end product, and traces the associated physical and monetary flows (Tallec and Bockel, 2005). This notion places emphasis on processes and actors which directly handle the food item, excluding supporting activities such as agricultural input.

Commodity chain approach or *approche filière* usually ends with the stages handled by economic actors and ignores the domestic realm. The consumption stage though, with activities of food acquisition, food preparation and meal intake handled by households, can determine activities further upstream and stimulate change or innovation. This is how researchers in agroecology use the food system approach (Francis et al., 2003; Kemp et al., 1998). They analyse how changes in consumer-related activities can initiate or support solutions or innovations in agricultural practices. As an example, the literature reports experiments with innovative bread-baking techniques that use low-protein wheat which requires lower nitrogen fertilization, implying less water pollution.

In this study, the food system concept was used with its focus on the role of a network of actors for organizing the system, on the system's purpose of feeding a population and on the importance it gives to the domestic realm as a participating sector. The following sectors of a food system were retained for the analysis of food flows: agricultural production, import–export, food processing, distribution, food service, households, and waste disposal and management.

2.2. Material flow analysis

2.2.1. Reference methods and application to urban systems

For this study, I tested MFA in the case of an urban system for which the research aim consisted in characterizing and quantifying inner-urban food and food waste flows. There are some particularities of the application of MFA to urban systems.

The Eurostat methodological guide (Eurostat, 2001: 73) defines MFA as "an evaluation method which assesses the efficiency of use of materials using information from material flow accounting. Material flow analysis helps to identify waste of natural resources and other materials in the economy which would otherwise go unnoticed in conventional economic monitoring systems."

Irrespective of the scale of a system under study, there are established methodologies to carry out MFA. Two approaches can be broadly distinguished: a bottom-up approach and a top-down approach. The difference lies mainly in the way systems under study are described, which stems from their anchorage in different scientific communities. The bottom-up approach to MFA is based on the analysis of processes inside a system under study, where outputs are calculated from the inputs and transfer coefficients that characterize those processes (Brunner, Rechberger 2003). It was developed by a group of environmental engineers around Peter Bacchini and Paul Brunner, later joined by Helmut Rechberger, and yielded a flexible method applicable to small-scale and simple systems, such as those found in resource and waste management. The top-down approach is anchored in a more social science-oriented community, developed to respond to policy-oriented analysis of economy-environment interactions and therefore designed to address material flows to and from the system, but not within it. Although different in purpose and design, conceptually both MFA approaches are based on the physical principle, called mass balance principle, that matter can neither be created nor destroyed in any physical transformation process. This principle is an extension of the law of the conservation of matter from the French chemist Antoine Laurent Lavoisier (*loi de Lavoisier*) stating that "nothing is lost, nothing is created, everything is transformed" (*"rien ne se perd, rien ne se crée, tout se transforme")*[66]. Hence, material inputs into a system must always equal material outputs minus net additions to internal stocks (Fischer-Kowalski et al. 2011).

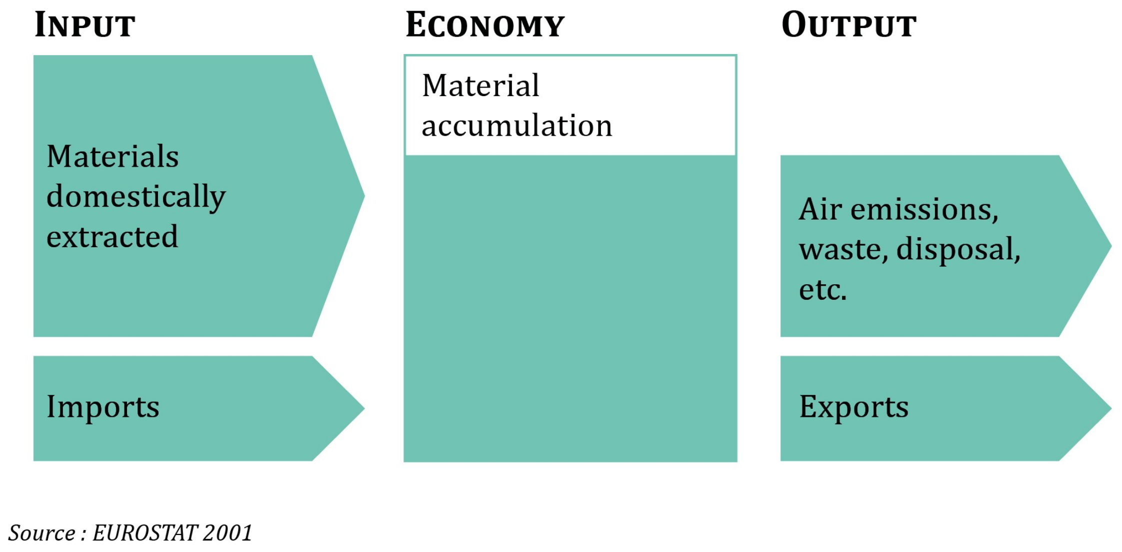
In Brunner and Rechberger's bottom-up approach to MFA that followed the work of Baccini and Brunner (1991), different processes inside the system under study are analysed in detail. According to their Practical Handbook of Material flow analysis (Brunner, Rechberger 2003), material flow analysis is a systematic assessment of the flows and stocks of materials within a system defined in space and time. The main processes are pre-defined according to a set of needs – "to nourish, to clean, to reside and work, to transport and communicate" – and gradually split down into smaller processes. A process is defined as "the transformation, transport, or storage of materials" (Brunner, Rechberger 2003: 37). But the processes can be more detailed, as shown by Schmid-Neset et al. (2008), for example. In their analysis of phosphorous flows related to the food production and consumption of Linköping, Sweden, this study distinguished six different processes in the system: animal production of food; plant production of food; household processing of food; industrial processing of food; consumption of food; and waste handling. The bottom-up approach requires technical knowledge of the processes, data sources and coefficients, and factors of material transformation throughout the processes, in order to properly represent and characterize the material flows within the system. The more the processes are detailed, the more work is required to comprehensively characterize them.

In a top-down approach, the processes between input and output flows are invisible and are handled as a "black box" (Eurostat, 2001). Input and output flows of a system are connected, without looking at the processes in-between. Data on the input and output flows of countries are widely reported in ideally periodically updated physical statistics, such as agricultural statistics, trade statistics, mining statistics, et cetera. The EUROSTAT methodology for

[66] The original wording in Lavoisier's text is the following « *car rien ne se crée, ni dans les opérations de l'art, ni celles de la nature, et l'on peut poser en principe que dans toute opération, il y a une égale quantité de matière avant et après l'opération ; que la qualité et la quantité des principes est la même, et qu'il n'y a que des changements, des modifications* » (Lavoisier, 1789:140-141). In English (my own translation), this reads: "nothing is created, neither through human skill, nor in nature, and one can state as a principle that there is an equal quantity of matter before and after any operation; that the quality and the quantity of the principles is the same, and that there is only change, modification".

economy-wide material flow accounts is the most prominent and most robust framework for carrying out MFA following a top-down approach, initially developed for application at national scale (Figure 9).

Figure 9. Basic Material flow analysis model



Source: EUROSTAT 2001

Barles (2009) adapted the EUROSTAT methodology for use at regional and urban scale, taking the city of Paris, together with its dense suburbs, and the Île-de-France region as a case study. Data availability, a precondition for the top-down approach, was deemed satisfying at this scale (Barles, 2009). Its application at the city level, in the case of Paris, was largely facilitated by the fact that Paris is both a municipality and a French *département*[67]. However, Barles (2009) considered it necessary to adapt the method to the particularities of urban systems. Unlike nations, urban populations export most of their waste, both liquid and solid, to wastewater treatment plants, sanitary landfills, and waste incinerators, which are often located at some

[67] In France, a *département* is an autonomous local authority, with an elected deliberating body and executive. The *département* has wide-reaching competencies: social action, construction and maintenance of secondary schools, rural reparcelling, organization of school transport, etc. Since 2011, there are 101 *département* including 5 overseas *département*. A *département* belongs to one and only one region and comprises several municipalities. (INSEE, definitions).

distance from the city. The Eurostat method distinguishes waste flows treated within the urban system and waste flows treated beyond it. To account for the impact of exported waste, Barles (2009) defined two local indicators to complete the set of existing ones: corrected domestic material consumption (DMC_{corr}) and local and exported flows to nature (LEPO). These adjustments are important for this study as they directly concern the analysis of food and food waste flows. Applied to this study, LEPO is equivalent to food waste. DMC_{corr} is calculated according to the formula given by Barles (2009): corrected domestic material consumption is equivalent to direct material input, minus imported waste, minus exports except wastes. Other indicators used in the Eurostat method are also relevant for this study and are translated accordingly: direct material input is equivalent to local agricultural production, food imports and tap water to drink, summarized as "input flows". Direct material output is equivalent to food intake, food exports and food waste, summarized as output flows. Further details about the application of the Eurostat method to this study are provided in Chapter 3.

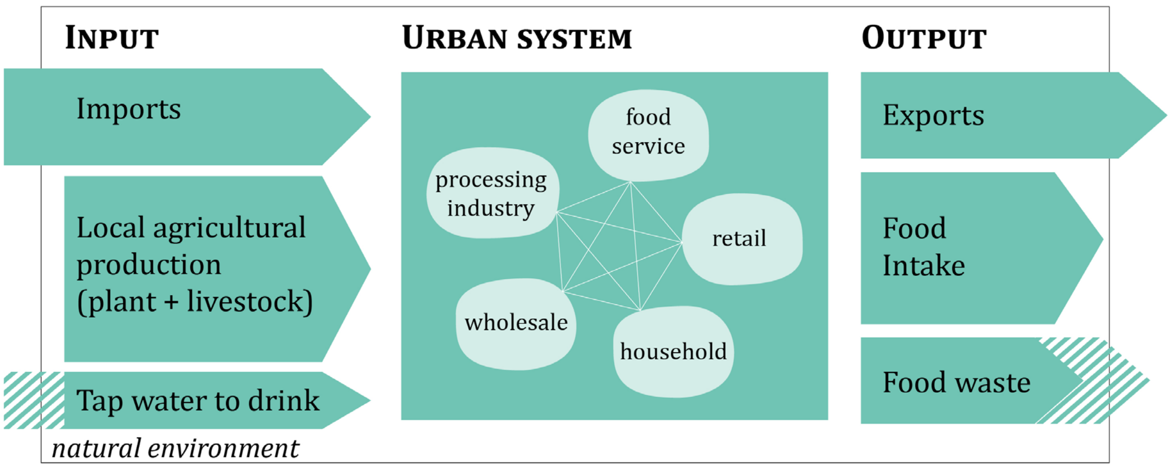
Both the bottom-up and the top-down approach have pros and cons with respect to the research aim of this study. The bottom-up approach represents a systematic in-depth analysis applicable to small systems and scales and to specific material types. But the definition of predefined needs, as suggested by Brunner and Rechberger (2003), seems arbitrary. These authors see the management of waste as part of a distinct need ("to clean") and not connected to the process chain allowing "to nourish", whereas in a food system approach, waste is part of the interconnected web of food-related activities and sectors. Brunner and Rechberger's interpretation of needs seems driven by a technical-engineering view and does not necessarily match with an understanding of needs in their social and cultural dimension. The appeal of the Eurostat method is its simplified analysis framework and the use of aggregated data sources for input and output flows. Whereas the method is useful for analysing input and output flows of a system, it is not designed for analysing inner-system flows. Input from a complementary approach is necessary to address them.

2.2.2. A hybrid method: material flow analysis and the food system approach

The hybrid method in this study is based on a combined use of the Eurostat European-wide MFA and a food system approach. The food system approach serves in a more straightforward manner the purpose of characterizing the urban system than Brunner and Rechberger's bottom-up approach. Taking into account that the system under analysis is urban, I use the term "local material extraction" instead of "domestic material extraction", and "urban system" instead of "economy". The terms "environment" and "hinterland" remain unchanged.

Where the Eurostat MFA ignores the processes between input and output flows, the food system approach fills the gap. According to the Eurostat method, the environment within the urban system is distinct from the environment outside of the urban system. Making this distinction enables us to differentiate local material extraction and restitution from material extraction and restitution performed beyond the environmental boundary of the urban system. This is important. While the scientific literature about supplying areas of urban food consumption has increased in recent years (see Chapter 1 for background), the subject of returning waste to the environment has so far not been of much interest to researchers. This is why the food flow analysis in this study contributed a spatial dimension to the results by identifying the areas to which food waste is eventually returned for waste treatment. Figure 10 shows the conceptual model of the hybrid MFA–food system method

Figure 10. Conceptual model of the hybrid MFA–food system method

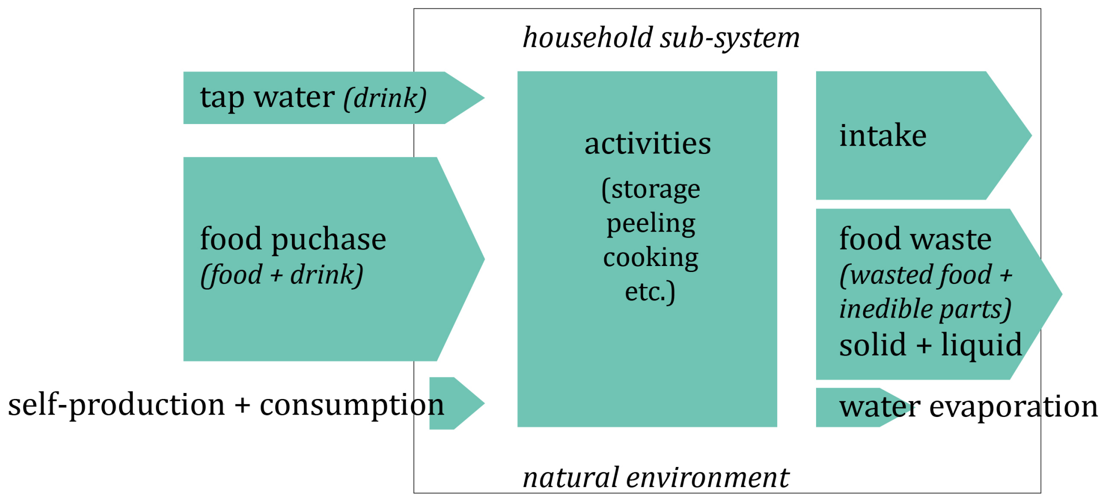


Source: author

In a material perspective, each food system component can be seen as a sub-system of the urban system, with material input and output that follows the same principle of conservation of mass and transformation of matter.

As an example, households shown as a sub-system present the following details[68]. Households' food purchases can be seen as input, food intake and food waste can be seen as output, with storage and food preparation processes in-between (Figure 11). Tap water used for drinking is part of our analysis and is shown separately. Following a mass balance approach, the difference between purchase and intake can be used as a gross estimate of food waste (wasted food and food residues), additionally influenced by water variations during cooking and food preparation. The extent to which water variations accompany food transformation (e.g. at processing or cooking) have however hardly been described (Caldeira et al., 2019), especially for situations where the huge diversity of processed foods is aggregated into a few food categories.

Figure 11. Food flows in the household sub-system



Source: author; tap water added at cooking (e.g. pasta, rice) is not considered. Only tap water used to drink is added to food and drink purchases. No material accumulation is considered. Excreta from food and drink digestion (water and carbon dioxide from fat and carbohydrates, urea from proteins and peptides) are released into the environment. In the flow diagrams, once digested, food and drink still appear as food flows in order to follow the material balance principle.

The sub-systems analysed separately and reconnected at the urban system level provide the framework for the insights that are hidden in a top-down approach to MFA. Given that the sub-

[68] The approach in this study is different from Brunner and Rechberger's (2001) model of food flows in private households (Brunner, Rechberger, 2003: 190). These authors quantify food flows in both fresh weight and dry matter and phosphorous flows, and include the human body and human waste into the empiric example.

systems compose the urban system and that the mass balance principle of Lavoisier (1789) is applied, there can be no difference in the material flows.

I drew on the work of Barles (2009) who adapted the Eurostat MFA method to use at urban and regional scale. In line with the research aim of this study, I followed Barles' suggestion to distinguish between exported waste and other exports. Doing so allows us to assess the extent to which cities relocate or delegate the treatment of their waste to distant sites, beyond the urban system. Four additional adjustments of the Eurostat methodology were furthermore necessary.

First, for the purpose of this research, the definition of food is distinct from the definition of food as a component of biomass in MFA. The Eurostat MFA standard defines "biomass" from different compartments of a territory: agriculture, forests, fishing, hunting and other activities (honey, gathering of mushrooms, berries, herbs etc.). Biomass from agriculture means plant production, whether the plants are used for food or for non-food purposes. Food from livestock, such as meat, milk or eggs, however is not considered biomass in the Eurostat method (livestock is a human activity and part of the biomass transforming economy). The distinction is particularly relevant in data sources that are organized to reflect a wider set of goods, and not food in particular, such as transport or waste statistics. Whereas products from livestock are not part of domestically extracted biomass in the Eurostat MFA, they are accounted for as food and as part of the urban system's food supply, through imports or local production. This methodological adjustment is important, otherwise a significant food flow would be missed at the level of food, when the analysis was narrowed down to the MFA food components[69]. This means that I applied a different system boundary between the socio-economic system and its local environment. A consequence is that comparisons to national MFAs are not possible.

Second, I simplified the mass balance. Working at the level of food, I account for the flows where food or parts of food are identified as food. Food can have undergone chemical, physical or biological transformation, in the course of food processing, preparation or cooking. Once eaten, digested and biochemically transformed, there is no more food at the material level; there are only food metabolites or excreta, which are not part of the analysis. This implies that food flows are accounted for from the moment where food is produced until the moment where food is eaten or directed away from being eaten. By-products directed to non-food use and inedible parts in food waste are accounted for. Ancillary resource flows at farm stage used in food

[69] In 2011, livestock products made up 24% of the human diet in Europe in terms of calories and 57% in terms of protein, according to the statistics of FAOSTAT cited in Dumont et al. (2016).

production (e.g. nitrogen fertilizer) and chemically degraded food metabolites (e.g. urea from the protein metabolism) are not accounted for. As a consequence, the representation of the urban food metabolism remains unbalanced, with some flows beginning or ending within the system.

Third, I quantified food flows in mass of fresh weight, which implies that water variations throughout the processes were part of the food flows and part of the changing material flows in all the urban system components. When food goes through various processing steps (in industry or with artisans, for example), the water added or removed is not reported separately. Varying water content along processing can be significant. In the bread supply chain, the water content varies from 13% in flour to 45% in dough and to 27% in baked break[70]. Cooking triples the mass of dried pasta or rice. Conversion factors are generally available, at least for the main food products, to trace primary products from agriculture throughout processing, as in the case of wheat to bread baking. Yet the information about the processing status of food is insufficient for a given processing step. The decision to retain fresh weight, and not dry matter, implies that the principle of conservation of matter cannot be applied in this research due to a lack of information about water variations throughout the processes.

Summary of the principles of food flow quantification:

- All food flows are expressed in mass of fresh weight. This implies that the principle of conservation of matter cannot be followed, due to a lack of information about the variation of water throughout the processes.
- Only food flows, and tap water used as drink at consumption stage in households, are accounted for, whereas ancillary material flows involved in the food system are excluded: packaging, agricultural input (fertilizer, pesticides, etc.), non-food uses of agricultural biomass, water and energy carriers.
- The territorial principle applies: flows accounted for are local flows and defined by the physical boundaries of the system under study. In contrast to the resident principle, the flows generated by the activities of non-residents, e.g. tourists and commuters, are part of the analysis.
- Input flows relate to imports, local agricultural production, including livestock[71] and crops, and supply of tap water to drink.

[70] https://ciqual.anses.fr/; boulangerienet.fr
[71] Quantities of feed to local livestock were subtracted on the input side to avoid double counting. Given the small size of local livestock in this case study, double counting feed would not have been a big problem.

- Output flows relate to food intake, exports and food waste. The common feature is that this food has not passed the human metabolism. Metabolites such as carbon dioxide, water or urea, obtained from food through human metabolic processes, or carrying materials such as urine and feces, are not part of output flows.
- For food waste at household stage, wasted food and inedible parts are differentiated.

2.2.3. The eating population as a link between the urban system and the food system

Wherever people spend time, they eat: at home, at work, during vacation and leisure activities. No single data source captures the number of people, residents and non-residents who are effectively present in a given area at a given time or time period. We therefore do not know how much food is eaten in that area over a given time. A city's food metabolism reflects not only the food turnover related to the resident population, but also any additional population of visitors and commuters. Moreover, the resident population may be gone part of the time on vacation or business trips, and eat food elsewhere. A comprehensive eating population concept is needed to estimate the total food intake related to an urban system.

Authors like Barles (2009) and Goldstein et al. (2017) have acknowledged that the food metabolism remains under-estimated when only "households" (residents) are considered. But examples of studies which effectively integrated non-residents quantitatively are rare. In a recent urban metabolism study on Indian cities, Boyer et al. (2019) calculated a community-wide food use consisting of food used by residents, by visitors and, for some cities, by industry (material input to food factories)[72]. The technical literature on urban infrastructure uses a concept similar to the capacity of a wastewater treatment system that has a defined carrying capacity and must be tailored to the present population. The population equivalent expresses the urban wastewater load that can be carried by a treatment system[73]. By analogy, in 2005, the tourism department of the French Ministry of Transport, Infrastructure, Tourism and the Sea developed the concept of a "present population" (*population présente*) following considerations

[72] The authors looked at the expenditure data for processed food of residents versus the industries in those cities, and saw that local consumption was very low in comparison to the flow through the industry. Regional input-output data would provide a precise picture of the flow of local industry to local consumption. However, in the case of India, there are no sub regional input-output tables available (personal communication, D. Boyer, November 5th, 2019).

[73] Population equivalent (in waste-water monitoring and treatment) refers to the amount of oxygen-demanding substances whose oxygen consumption during biodegradation equals the average oxygen demand (BOD) of the waste water produced by one person. For practical calculations, it is assumed that one unit equals 54 grams of BOD per 24 hours (United Nations, 1997).

about the size and organization of public service and infrastructure in areas of high levels of tourism in 2005 (Armand et al., 2005). For the management of public services, as much as for the case of sudden health risks, the administration must have the means to serve both residents and non-residents, which requires an estimation of their numbers.

In line with these references, I calculated the eating population for one year. The eating population totals the number of "permanent eating equivalents" per type of population (residents and non-residents). One permanent eating equivalent, or "PEEQ" (pronounce \ˈpē - kyü\), is a theoretical person who is present in a given area and takes all of his or her meals there on 365 days per year.

In this study, four parameters determine the estimated annual food intake of a population in a given area: population size; average time spent per year; share of daily food intake; and average daily food intake. The time spent there per year (number of days spent per year) varies between these populations and positively influences food intake. Conversely, the time spent elsewhere negatively influences annual food intake in the given area. Next to the time spent per year, the share of daily food intake plays a role in the case of commuters who come to work and have part of their meals in the given area, or who leave the area and have part of their meals elsewhere.

In terms of population, the eating population can be distinguished between residents and non-residents. Residents either live in ordinary households[74] or they do not, according to the INSEE definition of an ordinary household (for the purposes of census surveys) (INSEE, n.d.). When they do not live in ordinary households, they are mariners, homeless individuals, or people who live in mobile dwellings or in collective dwellings (young workers' hostels, retirement homes, student halls of residence, prisons, etc.). Non-residents are tourists, commuters and excursionists who come either for the day (commuters, excursionists) or for at least one overnight stay (tourists)[75].

[74] A household (or "ordinary household") as defined for the census survey describes all the persons sharing the same main residence, without these persons necessarily being blood-related. A household can be constituted by a single person. There is equality between the number of households and the number of main residence (INSEE, n.d.).

[75] A commuter is someone who regularly travels between work and home, located in different municipalities (INSEE, n.d.). Both excursionists and tourists are visitors traveling to a place that is different and far from their home, without further specification (IAU île-de-France, 2014). According to the World Tourism Organization (2019), tourists are defined as visitors staying overnight away from their home. Excursionists travel back and forth in the same day. The difference between commuters and excursionists is vague. Depending on the survey,

Table 1 provides an overview of the different population types considered for the eating population.

Table 1. Different population types considered for the eating population

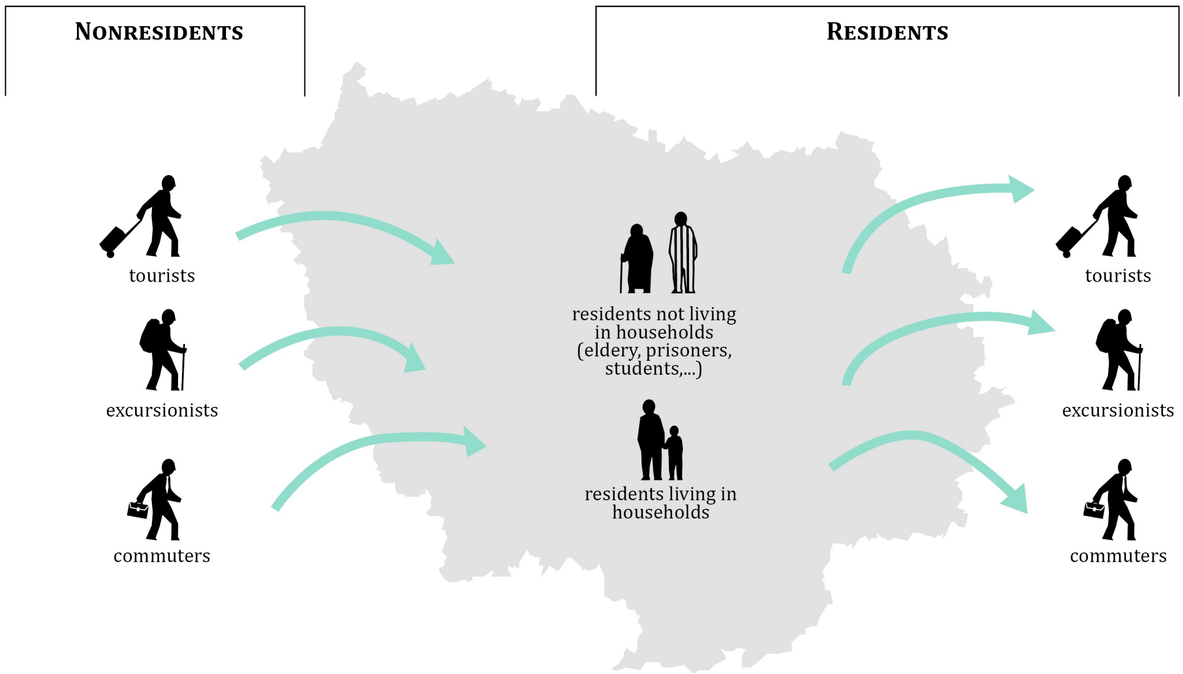
Eating population	
Residents	Non-residents

- living in ordinary households
- living elsewhere than in ordinary households, that is in
  o retirement homes
  o prisons
  o student halls of residence
  o young workers' hostels
  o homeless and others
	- tourists
	- commuters
	- excursionists

In turn, the resident population is also tourist, commuter and excursionist part of the year. Whereas non-residents join a given area for some time and add to the eating population, residents leave the area for some time and reduce the eating population. Figure 12 shows the movements per population type.

excursions involve a defined distance and exclude trips of commuters traveling shorter distances (IAU île-de-France, 2014).

Figure 12. Movements of population types to and away from the urban system



Source: author

Permanent eating equivalents (PEEQs) and, by extension, the eating population are accounted for as individuals and expressed in dimensionless numbers. The annual food intake is expressed in tons per year. We calculated PEEQs, eating population and annual food intake according to the following formula:

i = population type

PEEQ (i) = population (i) * average time spent per year (i) (d) / 365 d

Eating population = sum [PEEQ (i)]

Annual food intake (T/y) = PEEQ (i) x share of daily food intake (i) x daily food intake (i) (g/d) x 365 d x 10^6

Average time spent per year is reported in days (d), and daily food intake in grams per day (g/d). The formulae apply to all population types (i) except for excursionists and tourists. For them, not the population size but the total number of trips per year (excursionists) and the total number of overnight stays (tourists) are reported in the data sources I had available (see 3.1.3). Total number of trips or overnight stays divided by 365 days are equivalent to the number of permanent eaters (PEEQ). All data sources that inform the relevant parameters for the calculation of the annual food intake of the eating population are specified in Chapter 3, along with the calculation steps.

2.3. The study area: Paris Petite Couronne and Île-de-France

Drawing on the prospering urban metabolism research on food systems (Barles, 2010, 2009; Billen et al., 2009; G. Billen et al., 2012; Bognon, 2014; Chatzimpiros and Barles, 2010; Esculier et al., 2017)[76], this study focuses on Paris Petite Couronne and its region Île-de-France as a study area for a city's food metabolism.

Analysing the food metabolism of a city implies that I define what a city is. The term city is commonly used to denote a place of human settlement, often historically anchored, where a group of people live on the food production provided by others. The term is used more in common language than in administrative documents. There is indeed no universal definition of a city. There are various concepts concerning the city, used in a country's classification system and based on different criteria (population, employment, continuity of built zones, etc.) and methods (census, land occupation, etc.), which inform various policy issues. A threshold of number of inhabitants is often used in combination with other criteria. In France, land occupation in addition to demography is used to define the urban unit as a physical concept. The urban unit is a municipality, the smallest administrative division in France, or a group of municipalities which includes a continuously built up zone (no cut of more than 200 meters between two buildings) and at least 2,000 inhabitants (INSEE, n.d.). The concept of urban unit is used for policies of planning and monitoring urbanization. The concept of urban area, a functional concept, introduces criteria of occupation and occupational mobility of residents to the urban centre. INSEE (n.d.) has defined an urban area or a "big urban area" as a group of adjacent municipalities, without pockets of clear land, encompassing an urban centre (urban unit) providing at least 10,000 jobs, and rural districts or urban units (urban periphery) in which at least 40% of the employed resident population works in the urban centre or in the municipalities attracted by this centre. Based on occupational mobility, this concept is used to describe the influence of cities beyond the areas that are defined by their physical limits of built zones. INSEE census data show that 78% of the French population lives in a big urban area and 59% lives in an urban centre (INSEE, 2016). A complementary concept is the "living zone" which sheds light on the distribution and access to everyday services and facilities. The living zone is the smallest territory in which residents have access to facilities and everyday services (INSEE, n.d.). The definition of "living zones" facilitates the understanding of the structuring of the landscape of metropolitan France. The classification of territorial units for statistics,

[76] See Chapter 1 for a comprehensive review of this literature.

abbreviated NUTS (from the French version Nomenclature des Unités Territoriales Statistiques) completes this overview. It is a geographical classification subdividing the economic territory of the European Union (EU) into regions at three different levels. NUTS serves as a reference for the collection of regional statistics, for the socio-economic analyses of the regions, and for the definition of the regional policies of the EU (INSEE, n.d.). Acknowledging the diversity of concepts to describe a city means admitting that there a different perspective on the analysis of underlying issues. Retaining one or the other concept has implications for the geographic boundaries, which are set accordingly and obviously entail that the population encompassed varies in size. The debate about how to define a city's geographical limits is not a subject that contributes to this study. However, population size is an important parameter, as food consumption depends directly on it.

In this study, a city is defined by a functional approach focusing on the function of food supply. According to Ascher (2001), a city does not produce its own means of subsistence[77]; it depends entirely on supply areas, and the more inhabitants it has, the bigger the areas. Extended supply areas, increasing agricultural yields, and large-scale efficient transport systems made it possible for cities to grow by developing trade and markets for their food supply and distribution (Billen et al., 2009). While Paris Petite Couronne is classified as a city, according to Ascher (2001), as it has very little farm land and almost entirely subsists on food imports from elsewhere, the situation is different for the Île-de-France region, an important area of agricultural production which partly serves the Île-de France food supply. Although not qualifying as a city according to Ascher, retaining Île-de France for comparison with Paris Petite Couronne allows for insights into their respective metabolic profiles as regards food flows and, in particular, the change that occurs in the metabolism due to the presence of partly rural areas.

Paris Petite Couronne (PPC)[78], including Paris and the neighbouring *départements*[79], Hauts-de-Seine (92), Seine-Saint-Denis (93) and Val-de-Marne (94), is the dense urban centre of the Île-de-France region. It is also the centre of the urban unit of Paris which totals 10,706,072 inhabitants (2015), classified by its population size as megacity (United Nations-Department of

[77] "Cities can be defined as groupings of populations which do not produce their own means of subsistence. Hence, from the outset, cities require a technical, social and spatial division of production, and involve different types of trade" (Ascher, 2001: 13) ». Own translation from the original text: « *On peut définir les villes comme des regroupements de populations ne produisant pas elles-mêmes leurs moyens de subsistance alimentaire. L'existence des villes suppose donc, dès leur origine, une division technique, sociale et spatiale de la production, et implique des échanges de natures diverses* (Ascher, 2001, p. 13) ».

[78] Paris and its dense suburban rim, called the *Petite Couronne*, which includes three administrative *départements* (*Hauts-de-Seine, Seine-Saint-Denis, Val-de-Marne*), together constitute *Paris Petite Couronne.*

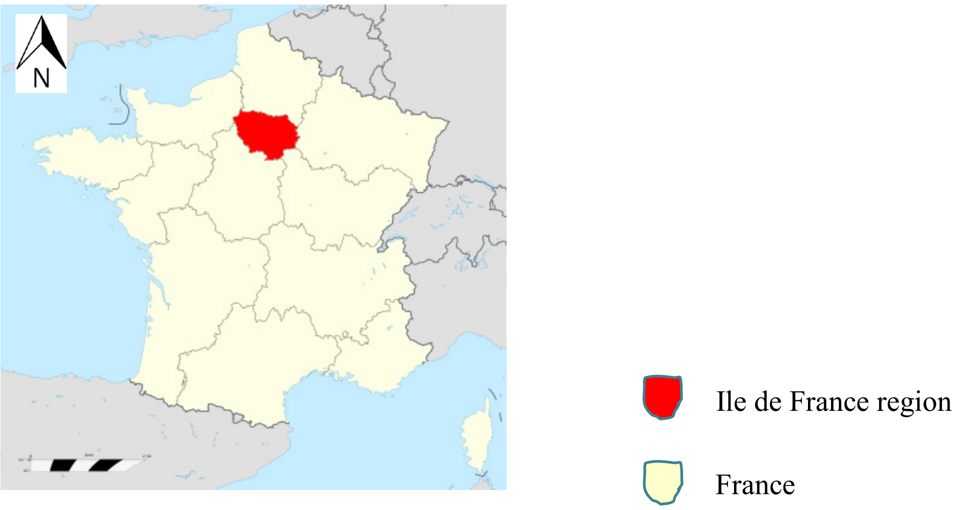
[79] See footnote 15 page 14

Economic and Social Affairs-Population Division, 2018). The Paris urban unit covers Paris Petite Couronne and part of the neighboring *départements* of the Grande Couronne, which are Seine-et-Marne (77), Yvelines (78), Essonne (91), and Val-d'Oise (95). The eight *départements* of *Paris Petite Couronne* and *Grande Couronne* together constitute the Île-de-France region. Île-de-France is one of thirteen administrative regions located in metropolitan France (Figure 13).

Île-de-France, which has a surface area more than four times greater than that of the Paris urban unit, but only slightly more inhabitants (12,027,565 inhabitants in 2014) reveals a radically different landscape characterized by a large proportion of land (75%) covered by agriculture, forests and water. The boundaries of the Paris urban unit show where urban sprawl begins[80]. The compared densities of Paris (21,067 cap/km^2), *Paris Petite Couronne* (6,901 cap/km^2), Paris urban unit (3,763 cap/km^2) and Île-de-France (1,001 cap/km^2) reflect a gradient from the highly dense centre to the rural outlying areas.

Although Île-de-France makes up only 2% of the French metropolitan area, 18% of the French population lives there. The region is the most prosperous location for business activities in France, accounting for 31% of the national GDP, 23% of France's workforce and 41% of its researchers (CCI Paris Ile-de-France et al. 2020). Paris and the Île-de-France region is France's main centre of political, cultural and intellectual life.

Figure 13. The Ile-de-France region within France



Source: http://www.iledefrance.fr

[80] https://www.insee.fr/en/metadonnees/definition/c1501

To complete the picture, a new administrative unit, the Greater Paris metropolis (*métropole du Grand Paris* (MGP)) was founded in 2016. The Greater Paris metropolis is quite similar to PPC as it encompasses the city of Paris, all 123 municipalities in the *départements* of the *Petite Couronne*, plus seven municipalities located in the *Grande Couronne.* It would have made sense to analyse the urban metabolism at the level of MGP as a governance level, but there are a several obstacles to this. Some data do not exist at the municipal level. This is a problem, since seven municipalities added to PPC to form MGP. Furthermore, the new public authority is currently quite weak and dependent on further political choices. As the PPC and MGP do not differ substantially, the conclusions for PPC can easily be applied to MGP. Figure 14 shows the respective geographical scope of Paris Petite Couronne, Ile de France, Paris urban unit and Greater Paris metropolis.

Whereas food system activities close to the end consumer, such as retailing and food services, tend to be located where people live and work, primary activities such as agriculture, processing and wholesale businesses are usually found in more distant agricultural and industrial areas. Waste management activities are also generally located at the outskirts of urban settlements. The spatial distribution of food system-related activities motived the distinction between Paris Petite Couronne and Île-de-France as the geographical scope of this case study. In contrast to other concepts addressing the urban space, a clear advantage of the selection of Paris Petite Couronne and Île-de-France is the fact that both are administrative units, or in the case of PPC, are built of administrative units. Information and data are much more easily available at the scale of an administrative unit where policies are designed and implemented, for example the regional waste prevention and management plan for Île-de France (see Chapter 5). Access to data is key for carrying out meaningful metabolism studies. Paris itself, however, was not analysed on its own. I expect its food system situation to be close to that of PPC, in terms of population density and location of food system activities, and think that the results for Paris alone do not generate additional insight with respect to the research aim of this study.

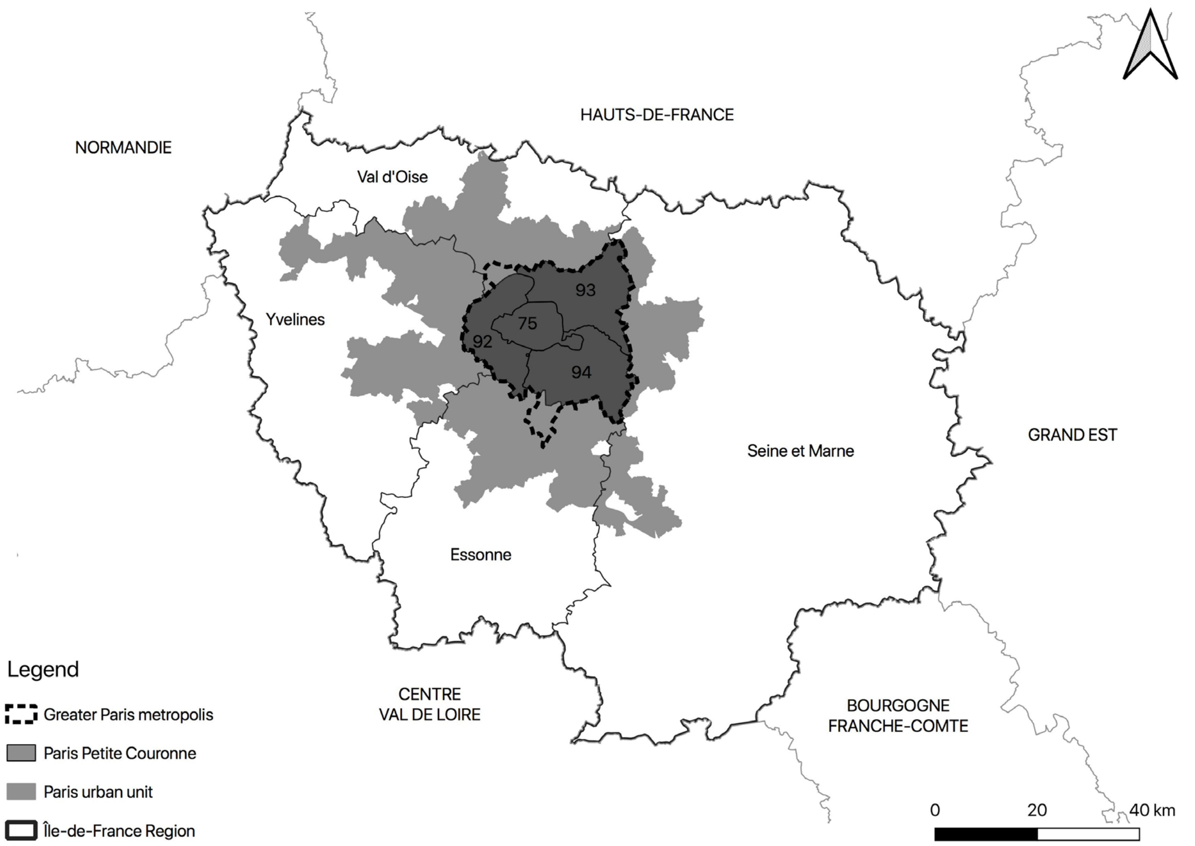
Table 2 shows some characteristics of the geographic and administrative areas of Paris, Paris Petite Couronne*,* Île-de-France, and Paris urban unit.

Table 2. Administrative delimitation, population, surface and density of Paris and related administrative units

Area	Administrative delimitation	Population (inhab.)	Surface (km^2)	Density (cap/km^2)
Paris	*Départment* 75	2,220,445	105	21,067
***Paris Petite Couronne* (PPC)**	*Départements* 75, 92, 93, 94	6,754,282	657	6,901
Paris urban unit	429 municipalities of Paris, *Petite Couronne* and part of the *Grande Couronne*	10,706,072	2,845	3,763
Île-de-France	PPC + *départements* 77, 78, 91 and 95	12,027,565	12,012	1,001

Source: INSEE (2014) except for Paris urban unit (2015)

Figure 14. The respective geographical scope of Paris Petite Couronne, Ile de France, Paris urban unit, and Greater Paris metropolis



Source: IGN data

I studied Paris' food metabolism for the year 2014. Data sources, in particular official statistics, often provide data on an annual basis (for example agricultural production, waste generation, transport). When data are available on another basis, such as daily, they were included in the analysis based on extrapolation to a year.

I chose the year 2014 for the study, for three reasons: i) 2014 was close to the time the research was carried out (2017-2019), and I considered that no major changes had occurred in the system since 2014; ii) no major incidents with relevance to the food system activities occurred in 2014, in contrast to the following years when large-scale terrorist attacks were perpetrated in Paris (2015) and Nice (2016), with a consequent decline in the number of visitors[81]; and iii) data from official pluriennial sources are available for 2014 (occupational mobility of the census, INSEE).

2.4. Summary

Urban food metabolism studies so far have mostly looked at biomass and equated it to material use of food. Addressing food specifically invites us to unpack concepts of established material categories and to have a new look at the way human societies acquire, use and dispose of material such as food. Addressing food specifically warrants a profound analysis of the actors and activities involved, and a food system approach. The black box of the processes between material input and output which so far have often remained opaque in urban metabolism studies, reveals inner system flows once opened, and allows for new insights into the role of food system sectors. We introduced the notion of food waste as a feature of food systems deemed to be incompatible with sustainable societies. In the analysis of food waste flows, it is useful to distinguish between wasted food and inedible parts, as different reduction strategies can be applied. While wasted food can be prevented or reduced at source, and hence is avoidable, inedible parts are intrinsically part of food and are therefore unavoidable.

The novel hybrid method developed in this study is based on a combined use of the Eurostat European-wide MFA and a food system approach. Along with adaptations to the Eurostat method for its regional or urban application, I adjusted three points in the method to account for food (focus on food not biomass; no resource input or human waste output; expressed in fresh weight). Since the territorial principle applied, non-residents' food system activities are part of the urban metabolism and were *per se* incorporated. We defined the concept of an eating

[81] After all, my results show that a decline in the number of visitors does not substantially affect the urban food metabolism of our study area (see 3.2.1).

population and its total food intake as missing links to connect the urban metabolism and the food system approach.

The food metabolism of Paris Île-de-France is analyzed in two subsequent steps. Chapter 3 analyses the food material balance of the urban system by comparing the food input and output flows related to the urban system. Here, the focus is on the nature of food flows and their relationship with the environment. Chapter 4 analyses the inner-urban food metabolism by means of a food system approach. Here, the focus is on the role that food system activities play in the flows of food across the system. The findings presented in the respective chapters for distinct parts of the urban food system are integrated and discussed together in Chapter 5.

Chapter 3: Food material balance

The food material balance provides the first insights on the urban food metabolism for the case study of *Paris Petite Couronne* and Île-de-Paris. This was the initial step of the concentric approach applied in this study. It focused on the input and output food flows to and from the urban system, disregarding at this stage what happens with the food inside the system and considering it as a black box (EUROSTAT, 2011)[82].

Input flows of the urban system comprised:

- Food imports
- Agricultural food production from crops and livestock[83]
- Tap water to drink

Output flows of the urban system comprised:

- Food intake of the eating population (flows become invisible since food disappears)
- Food exports
- Food waste

3.1. Data sources

3.1.1. Food imports and exports

For food imports to and exports from the urban system, data was available from the SitraM (*système d'information sur le transport de marchandises*) database, the French information system on freight[84]. Since 1974, the statistical service of the Ministry of Ecological and Solidary Transition (SOeS) has compiled information annually at the level of *départements* to provide data on both international and domestic freight. International freight data are provided by the French customs. Domestic freight data are drawn from various surveys on different means of transport (Commissariat Général au développement durable, 2012):

[82] Chapter 4 deals with inner-urban system flows and inner-urban metabolism.
[83] By considering livestock products as produced from the local environment and not transformed from biomass by the socio-economic system, I drew the system boundaries of our urban system differently compared to the EUROSTAT method, as explained earlier in the method chapter under point 2.2.2.
[84] https://www.statistiques.developpement-durable.gouv.fr/donnees-sur-les-flux-de-marchandises-sitram-annee-2015

- the TRM (*transports routiers de marchandises*) survey, the French survey on road transport of goods, performed within France on vehicles registered in France, as part of a permanent European survey,
- statistics on rail transport of goods, provided until 2006 by the French railway company SNCF, but excluded from 2007 onwards, following the restructuring of the railway sector,
- data file on inland waterway transport provided by *Voies Navigables de France* (VNF), covering national and international transport.

Transport of goods is measured in tonnes of gross weight, including packaging and tare weight of intermodal transport units, and tonne-kilometres for domestic freight. The French customs report transport of goods in net weight and monetary value.

The Sitram data used for this research was for the year 2012, the most recent data available for scientists at the time of this research. Population change between 2012 and 2014, the reference year of this study, was considered so that the data could be adjusted to the quantification framework, given that the import category structure remained stable. The data are available at the level of the *département* as the smallest possible unit, and of any possible combination of *départements*, for example of a region or the country. It is presented according to the single classification of transported goods called *nomenclature statistique des transports* (NST) from 2007, established by the European Union, covering 362 items organized in 20 divisions.

Data from the two divisions “Products of agriculture, hunting, and forestry; fish and other fishing products (01)” and “Food products, beverages and tobacco (04)” were used. The difference between them is the degree of processing. Items from Division 01 are raw unprocessed commodities, imported and exported in that state. Items from Division 04 are processed products, imported and exported as processed. Since the divisions are defined per material group and not per purpose of use, I made use of my expertise to identify as well as possible items classified as food, and extracted the data of 75 products (see Table A3.1 in the Appendix to Chapter 3).

3.1.2. Agricultural food production from crops and livestock

For primary production of food, annual agricultural statistics (SAA, *statistique agricole annuelle*) were available for both case studies on the statistics website of the Ministry of

Agriculture [85]. These data are available at the level of the *département* as the smallest unit for all crop and livestock systems. While production data are available for most products from agriculture, including livestock, cultivated surface area was used for the four crops: cereals, oil crops, pulses, and beetroot. Yield rates available for these crops for Île-de-France (but not for Paris Petite Couronne) allowed me to calculate production for the case studies.

In the crop production context, production in the sense of agricultural statistics means harvested and shipped to the farm ("*arrivée ferme*") where it is either marketed or used on the farm[86]. Excluded from production data are the following situations: field loss or loss during shipment to the farm, unusable parts (e.g. the crowns of beetroot), loss at sorting and packing, and part of production unharvested for economic reasons. With the aim of establishing a food material balance, the potential food production, including on-field, sorting and packing losses and unharvested part of production, would best capture total food flows. Whereas the concept of potential production as such is acknowledged, no data are available in agricultural statistics. Based on harvested production data, I calculated the potential production of the case study systems using food loss data from the literature (Table 3). At the farm stage, I considered both on-field and on-farm loss as food loss. By adding food loss at farm stage to harvested production I obtained potential production. For fruit and vegetables, I used a percentage from the literature for loss, including on-field and on-farm losses without distinction (Cabinet Gressard, Interfel, FranceAgriMer, UNILET, ANICC, 2015). For potatoes, I referred to Jeannequin et al. (2015) to calculate on-farm losses based on harvested marketable production, whereas on-field loss was provided.

When it comes to meat and dairy, the SAA reports annual production in tonnes of carcass equivalents for meat and in units for eggs. The annual milk production is provided by the annual dairy survey (*enquête laitière annuelle*) and refers to the milk production, excluding the quantity drunk directly from the udder by calves, lambs and kids. Losses "on-field", that is, discarded milk or eggs or deceased animals at the farm stage, are not part of statistical data. As regards plant production, I calculated the potential food production from livestock, including farm losses.

[85] www.agreste.agriculture.gouv.fr
[86] https://agreste.agriculture.gouv.fr/agreste-web/methodon/S-SAA/methodon

The production data for all livestock and crop sectors identified as food were converted to tonnes and summed up. For cereals used for food and feed purposes[87], I estimated the quantity fed to livestock in the case study system and reduced the input flow, consisting of local production and imports, accordingly. The data comprise the inedible parts of the food products, that is, eggs with their shell, fruits and vegetables with peels, pits and stones, and cereal with bran, for example. Meat production data from agricultural statistics are expressed in mass of carcass equivalents and do not include edible parts from the fifth quarter separated from the carcass at slaughter. We calculated total mass of edible parts and total mass of inedible parts of livestock according to Formula 1. Next to meat, edible parts include offal, blood, fat, subcutaneous fat (*couenne*) and bones for gelatine production. The ratios of edible/inedible parts of live-weight animals are available per species in Laisse et al. (2018) (Table 3), where carcass yields were used to convert production expressed in tonnes of carcass equivalents into tonnes of live-weight (Table 3).

Equation 1. Calculation of mass of edible parts from livestock bred for meat

Edible parts (species i) (t) = share of edible parts (species i) (%) * prod (tce) / carcass yield (species i) (%)

With

Prod (tce) = Production in tonnes of carcass equivalents

We considered that livestock raised in Île-de-France is also slaughtered there[88], with the exception of horses (no slaughter reported). This implies that edible and inedible parts are handled where livestock is reported.

Table 3 summarizes all data used for the calculation of agricultural food production, including crop and animal production.

Table 3. Estimation of livestock and crop potential production, Île-de-France and Paris Petite Couronne, 2014

[87] Other crops for livestock feed were not food-competitive and therefore beyond the scope of this research.

[88] One slaughterhouse for pigs operates in Houdon (91). Quantities of slaughtered animals or carcasses from slaughtering are available through the monthly survey of slaughterhouses carried out by the agricultural statistics, but were not published for pigs in 2014 due to industrial secrecy (confidential information because of few operators in the sector).

Food category	Production unit	Production quantity		Carcass yield (in %)	Share of edible parts (in %)	Conversion from production unit to mass (tonnes)	On-field Loss rate	On-farm loss rate
		Île-de-France	*Paris Petite Couronne*					
Livestock								
Beef (veal, etc.)	Tons of carcass equivalent	1 731	0	56 [2]	48 [3]	--	n.s.	
Pork	Tons of carcass equivalent	1 178	0	78	83	--	n.s.	
Goat meat	Tons of carcass equivalent	20	0	49 [5]	n.d. [4]	--	n.s.	
Sheep meat (lamb, mutton, etc.)	Tons of carcass equivalent	229	0	47 [6]	41	--	n.s.	
Poultry	Tons of carcass equivalent	2 159	0	70	62	--	n.d.	
Horse meat		n.d.	n.d.	n.d.	n.d.	--	n.d.	
Egg	Thousand units	200 200	0		90	60 kg/1000 unit$*10^{-3}$		0,5
Milk	Hectoliter (hl)	458 095	0		100	1,03 kg/l $*10^{-1}$	3,2	
Crop production								
cereals	Hectare (ha)	365 040	1 045		80	86 q/ha $*10^{-1}$	2	
Oil crops	Hectare (ha)	80 640	210			39 q/ha $*10^{-1}$	6	
Pulses	Hectare (ha)	20 055	0			40 q/ha $*10^{-1}$	7,5	
Beetroot	Hectare (ha)	42 333	133			916 q/ha $*10^{-1}$	1	
Potatoes	Quintal (q)	1 818 590	29 820			$*10^{-1}$	4	9
Fruits	Quintal (q)	127 082	316			$*10^{-1}$	9[1]	
Vegetables	Quintal (q)	885 309	30 277			$*10^{-1}$	9[1]	

Sources: Agreste annual agricultural statistics; Agreste (2016); FAO (2015), Agreste (2010); Redlingshöfer (Redlingshöfer et al., 2017), Jeannequin et al. (2015); Income Consulting AK2C (2016)

[1] Including on-farm loss due to sorting, grading, packing etc. (Cabinet Gressard, Interfel, FranceAgriMer, UNILET, ANICC, 2015)

[2] Unweighted average from 57% (suckler cow), 50% (dairy cow), and 61% (young bulls) obtained from Laisse et al. 2018.
[3] Unweighted average from 49% (suckler cow), 45% (dairy cow), and 51% (young bulls) obtained from Laisse (2018)
[4] The same share as lamb.
[5] Calculated from Sen et al. 2004
[6] Calculated for lamb.

Whereas most farm commodities are easy to identify as food, for some commodities, multiple uses[89], such as for animal feed, biofuel and, to a lesser extent, the chemical and pharmaceutical industry, are known and are partly reported in national supply and utilization accounts. Yet they are difficult to identify at the level of the *département* or the region. Multiple uses alternative to food use are important to know since supply cannot be equated to food use when there are alternative uses. Previous food supply chain analyses have shown that alternative uses to food are quantitatively important in cereals and starch (Juin, 2015) and in oil crops (Fine et al., 2015). Yet there are no centralized data at regional level that reflect the share of different uses in total supply.

For cereal, I estimated use as livestock feed in Île-de-France (in Paris Petite Couronne, zero livestock reported in SAA except for equine livestock for which data are scarce at this level). Since I lacked data, I did not estimate further alternative uses for cereals or oil crops. For potatoes, I considered production as entirely directed to human consumption, although we know that production includes seeds, at the very least, and possibly other uses. When estimating cereal use for livestock by our own means, the difficulty lies in the variety of feed products: a part of the cereals fed to livestock is processed into compound feed purchased by farmers, and a part is fed to animals without processing. Idele, the technical institute for ruminants in France, has estimated the respective parts at national scale through the livestock network survey (Réseau d'élevage) in different cattle and sheep systems, both dairy and meat oriented. I did not, however, have detailed information about bovine and ovine livestock systems at regional level, where livestock plays a minor role compared to crops – particularly in Île-de-France. I therefore assumed that in terms of livestock feed, cattle and sheep production systems in Île-de-France shared the average national characteristics available in the studies of Idele (Devun et al., 2015; Jousseins et al., 2015) (

[89] Utilization in national Supply/Utilization Accounts (SUA) consists of: exports, feed, seed, waste, processing for food, food, other utilization, and closing stocks (FAO, 2001).

Table 4). Because cereals fed to livestock in the urban system are not food, but feed, the input food flow was reduced by their estimated quantity. We neither allocated them to Île-de-France agricultural production nor to cereal imports, but to an aggregated input flow and reduced it by the estimated amount of grain cereals fed to livestock in the system.

Horses in contrast make up an important population, especially in riding schools and the horse racing sector which both are popular in Île-de-France. There is a wide range of feeding schemes for horses, from no cereal to some cereal and compound feed, depending on the intensity of their physical activity. However, no data were available about the horse livestock typology in Île-de-France and related feeding schemes. Instead, I applied average cereal consumption per horse obtained from the literature (Courtonne, 2016) to half of the livestock (

Table 4). Because cereals fed to livestock in the urban system are not food, but feed, the input food flow was reduced by their estimated quantity. We neither allocated them to Île-de-France agricultural production nor to cereal imports, but to an aggregated input flow and reduced it by the estimated amount of grain cereals fed to livestock in the system.

In poultry, irrespective of the production system, cereal is always fed as compound feed (François Cadudal, ITAVI, 2 dec 2019). We simplified the estimation and assumed that all eggs and meat-oriented poultry systems are fed with compound feed purchased by farmers (feed flows not being covered by this analysis). We retained the same assumption for pig production systems which have a small population in Île-de-France (Table 5). Because cereals fed to livestock in the urban system are not food, but feed, the input food flow was reduced by their estimated quantity. We allocated them neither to Île-de-France agricultural production nor to cereal imports, but to an aggregated input flow, which I reduced by the estimated amount of grain fed to livestock in the system.

Table 4. Estimation of cereal consumption by ruminant and equine livestock, *Île-de-France*, 2014

	Livestock size	Livestock unit total feed	Unprocessed cereal consumption per livestock unit (t fresh weight/year)*	Data source; comments for application
Bovine livestock				
Dairy cows	6,273	1.45	0.246	Devun et al. (2015)
Suckler cows	6,067	0.9		
Heifer (> 2 years)	3,530	0.9		
Males (> 2 years)	582	1		
Heifer (1 – 2 years)	4,132	0.7		
Males (1 – 2 years)	659	0.9		
Calves (<6 months) and male calves (< 1 year)	2,396	0.6		
female calves (< 1 year)	4,777	0.44		
Total bovine animals	28,416			
Ovine livestock				
lamb (female)	1,173	0.12	0.306*0.36	36% of cereals provided by the farm (Jousseins et al., 2015)
Ewe	8,281	0.17		
Dairy ewe	62	0.2		
Other sheep	1,360	0.1		
Total sheep	10,814			
Caprine livestock				
Kids	531	0.14	0.444*0.427	42.7% of compound feed are cereals provided by the farm (Bossis and Jost, 2016)
Goat	1,440	0.3		
Other goat	140	0.06		
Total goat	2,111			
Equine livestock				
Equine livestock	25,124		0.730	Applied to half of livestock (Courtonne, 2016)

Source: Bossis and Jost (2016) ; DRIAAF, SRISE (2014); Devun et al. (2015), Jousseins et al. (2015); Courtonne (2016)
*converted from dry matter to fresh weight by multiplying with 100/86.9 (86.9% dry matter content of fresh weight wheat https://feedtables.com/fr/content/matiere-seche)

Table 5. Estimation of cereal consumption by monogastric livestock, *Île-de-France*, 2014

	Production in tons of carcass equivalents	Consumption index (kg feed / kg live weight)	% of cereals within feed	% of cereals provided by the farm	Data source; comments for application
Porcine livestock					
Pork	1,178*	2.87	71	35	
Poultry and hens					
No unprocessed cereal fed to poultry or egg laying hens					

Source: DRIAAF, SRISE (2014); Laisse et al. (2018); Ifip (n.d.)
*Conversion to live weight by dividing by 0.78 (78% carcass yield)

Apart from the adjustments to SAA data to obtain agricultural food production, there are limitations with the use of the data source. Regional statistics' departments put constant effort into the collection of accurate data because monitoring the food supply for a given population is an essential task for the administration. Maintaining food security means maintaining social peace. At country level, agricultural production data can be considered largely accurate. At the level of the region or the *département*, data can vary with the type of survey, exhaustive data collection or representative sampling, which the regional branches of the Ministry of Agriculture use. Data for some crops and livestock, such as cabbage, roots and tubers, horses, poultry, eggs and honey are available only at the regional level. We have no information about the level of accuracy of data for the Île-de-France region and the *départements* of Paris Petite Couronne. Yet I assumed that part of agricultural food production in Paris Petite Couronne is not being reported and is therefore not available for the food flow analysis. Another limitation stems from the poor knowledge about food loss at production stage. I nevertheless used loss rates from the literature to calculate the potential production of food from crops and livestock. The lack on research literature on food loss at production stage has been unanimously acknowledged and has begun to be addressed (Stenmarck et al., 2016; WRAP, 2019). However, the particularities of agricultural production (e.g. year-to-year variability with weather, fluctuating market situation, heterogeneous loss situations) imply that the few available data could not fit well with the context of this case study. As regards the estimation of local crops used as animal feed, one main limitation lies in the lack of information about feeding schemes and feed supply at the level of the region. Due to low levels of livestock farming in Île-de-France, the impact from this limitation remains small.

3.1.3. Food intake of the eating population

Referring to the concept of the eating population developed in Chapter 2, this section summarizes the information used for the calculation of this population and its total annual food intake. A wide range of data sources was necessary to ideally retrieve, or otherwise estimate, the following parameters: population size or total number of trips or overnight stays, average time spent per year, average daily food intake, and share of daily food intake for the various population types which contribute to the eating population.

Population size

For population size, the census provided data about total residents and residents living in households. The number of residents living outside of a household was obtained by subtracting households from the legal population and factoring in specific data from thematic websites and reports. The number of commuters to and from Île-de-France was calculated by hand from the 2014 raw data (2015 raw data for Paris Petite Couronne*)*[90] for occupational mobility, which is a category measured in the population census. The number of other population types were obtained from thematic websites and reports, indicated below in Table 6. For excursionists, the number of trips and overnight stays to and away from Île-de-France was retrieved from a report from the IAU île-de-France (2014), today called the Institut Paris Région. For tourists coming to Paris Petite Couronne and Île-de-France, the number of overnight stays was retrieved from a document of the regional tourism committee (Comité Régional du Tourisme, 2015). Tourists leaving Paris Petite Couronne and Île-de-France are residents. Their tourism activity was considered in the average time spent per year, in Paris Petite Couronne and Île-de-France respectively.

Thematic reports and websites reported population sizes more often for Île-de-France than for Paris Petite Couronne or for both. When I was not able to obtain the population size for Paris Petite Couronne, I used the one for Île-de-France and reduced it by the Paris Petite Couronne / Île-de-France ratio (0.56) of the resident population (for residents living in retirement homes, prisons, student halls of residence, young workers' hostels, the homeless and others). In the

[90] A colleague helped out with the computation of the number of commuters in the 2015 data file, for Paris Petite Couronne. The initial problem was an incomplete data file for 2014. The difference is tiny between the two years. The total number of commuters to Paris Petite Couronne was 1,049,076 in 2014 and 1,051,255 in 2015, that is an increase of less than 1%. The number of commuters from Paris Petite Couronne was 290,225 in 2014 and 289,642 in 2015, which is a decrease of less than 1%. Detailed analysis per direction and scale was performed only for 2015. This is why the 2015 data were used in the Paris Petite Couronne case study.

case of excursionists, I considered that they visited Paris Petite Couronne in the same proportion (0.79) as tourists to Île-de-France did, that is, 79 out of 100 trips to Île-de-France had Paris Petite Couronne as the destination (IAU île-de-France, 2014). Since the food intake that I calculated in a next step per population type was largely determined by age, I structured the population by age groups, where possible. Based on census data, residents living in households were divided into the following age groups: adults (aged 20 and older), children (aged 0 to 9), and teenagers (aged 10 to 19). For tourists and the homeless, where little information exists, I built a single common group for children and teenagers.

All data sources used for the parameter of population size are compiled in Table 6.

Average time spent per year

For the average time spent per year in the area of residence, two data sources are available. The first data source is a report from the 2014 survey on French people's tourist activities (*Suivi de la demande touristique des Français,* SDT) published by the commissioner general for sustainable development (*Commissariat Général au Développement Durable,* CGDD) of the French Ministry (CGDD, 2015). The survey covers the long-distance trips (>100 km) for personal reasons in the French population aged 15 and older. This survey provides us with the share of travellers (81.1%) and the average number of trips (5.5 trips amongst those who travel, 4.5 trips amongst total population). However, the average length of stay per trip was not available. This information is necessary to estimate the time that residents spent away from their home and hence the food intake taking place elsewhere.

The second data source is a study in 2014 by the IAU entitled *Voyages franciliens*, on the Île-de-France region as a travel destination and its residents' travel activities (IAU île-de-France, 2014). The IAU used the data from the 2008 national transport and travel survey (*Enquête nationale transports et déplacements*, ENTD) to analyse residents' trips. This survey was designed to obtain knowledge on the journeys undertaken by French households and their use of both public and private transport, in addition to information about the vehicles owned by households and their use. For a sample of 18,632 persons representative of the population aged 6 and older, it describes all journeys, regardless of their length, modes of transport, time of year, time of day, or professional or personal reason for the journey (INSEE, n.d.).

We retained the study of the IAU Île-de-France (2014) because of the large population sample, equivalent to 92% of the Île-de-France population in 2008, and because it considered trips for both personal and professional reasons, and both excursions and stays. The results show that Île-de-France residents leave their place of residence on average for 6.8 overnight stays per trip and for an average of 5.8 trips per person and per year (IAU Île-de-France, 2014). This makes a total of 39.4 days of leave per year. For all three age groups, I retained an average leave of 39.4 days and inversely, of 326 days of time spent per year in Île-de-France. We assumed that residents of Paris Petite Couronne spend the same amount of time there (326 days per year) as Île-de-France residents. Furthermore, I assumed that those living in retirement homes and in prisons, as well as the homeless and the remainder of the population of residents not living in households never leave during the year.

For commuters to Île-de-France, the IAU 2014 study established an average number of days of commuting to Île-de-France according to eight principal areas of origin (IAU île-de-France, 2014). It did so by cross-comparing the number of commuters to Île-de-France, based on information from the 2008 census about places of residence and work, and the number of trips from the 2008 national travel survey. As defined in the survey, only distances above 80 km were considered for commuting, to essentially capture those commuting from elsewhere. The results show that commuters to Île-de-France commute on average 28 times per year. Commuters from the two areas closest to Île-de-France, Bassin parisien Ouest and Bassin parisien Nord-Est, commute slightly more often, namely 33 and 37 times per year. Only the small share of commuters who travel more than 80 km within Île-de-France commute on an almost daily basis of 201 working days per year. According to the IAU (2014), the ratio of average number of commuting trips per commuter for 2008 must be considered with caution, due to the methodological differences between the two data sources.

We retained the average of 28 times for Paris Petite Couronne and Île-de-France residents to commute to a workplace outside of Île-de-France. Inversely, I considered the same number of times for residents from outside of Île-de-France to commute to Paris Petite Couronne and to Île-de-France. Only for residents of the Grande Couronne, that is, the *départments* located outside of Paris Petite Couronne but within Île-de-France, I assumed commuting practices close to those of residents from the closest areas to Île-de-France, and retained the number of 201 times per year to a workplace in Paris Petite Couronne, and inversely for residents of Paris Petite Couronne commuting to the Grande Couronne. Although about one fourth of commuting trips to Île-de-France involve one or several overnight stays (13% 1-3 overnight stays, and 14% 4 overnight stays or more), I considered that one trip equals one day spent away. Based on this assumption, I obtained an average number of 28 days that commuters to the urban system of this case study spent there. I retained the same number for commuters who reside in the urban system and travel to a workplace elsewhere. If I considered two overnight stays for 13% of commuting trips to Île-de-France and five for 14%, I would obtain 47 days spent away. The discussion section shows how the assumption of average time spent away by commuters impacts the results of the eating population and associated food intake.

Data for the parameter of average time spent per year are from the year 2008. Compared to 2014 as the reference year of the analysis, this can be a limitation given that home-office working is expected to have increased since, therefore reducing commuting trips. Unfortunately, I have no up-to-date information about changes in working practices since 2008, in particular home-office work, and effects on commuting to and from Île-de-France.

Table 6 summarizes all data sources used for the parameter of average time spent away per year.

Table 6. Legal population (2014) and average time spent away per year (2008), Île-de-France and Paris Petite Couronne

	Legal population (number of inhab.) (2014)		Average time spent per year (number of days) (2008)
Population type	*Paris Petite Couronne*	*Île-de-France*	
Residents	6,754,282	12,027,565	
Living in a household	6,624,460	11,792,157	
0-9 y	860,003	1,623,950	326
10-19 y	762,161	1,477,089	326
20 y +	5,002,296	8,805,973	326
Commuters from Paris Petite Couronne to Grande Couronne	191,293		201
Commuters to outside of Île-de-France	98,350	77,646	28
Living outside of a household	129,822	235,408	
In retirement homes	36,925	65,753	365
In prisons	1,393	12,660	365
In student halls of residence	42,286	75,300	326
In young workers' hostels	3,931	7,000	326
Homeless adults	16,173	28,800	365
Homeless children	3,510	6,250	365
Remainder	25,605	39,645	365
Additional population			
Tourists (overnight stays per year)	135,400,000	170,800,000	
-18 y +	121,860,000	153,720,000	
-0-17 y	13,540,000	17,080,000	
Commuters			
-from Grande Couronne	643,082		201
-from outside of Île-de-France	408,173	364,007	28
Excursionists (trips per year)	6,645,743	8,383,256	

Sources:
Population size: Census 2014; census occupational mobility data (2014); capacity in retirement homes (www.lesmaisonsderetraite.fr); statistics on prisoners on the website of the French Ministry of Justice; accommodation capacity for students (IAU 2016); young workers (ALJT); INSEE study n°423 (2014) on the homeless; regional tourism committee (Comité Régional du Tourisme, CRT) data on tourists' number of overnight stays (2014); and tourist age groups obtained by own calculation based on information about the family structure of tourists.
Average time spent per year: study using national transport survey (ENTD 2008) on Île-de-France as destination and origin (IAU 2014); own calculation.

Note: Absence of tourists and excursionists among the resident population was covered by the average time spent away. Absence through commuting was reported separately. Commuting of Petite Petite Couronne residents was reported by distinguishing commuting to Grande Couronne and to outside of Île-de-France.

Both parameters, population size and average time spent per year, allowed me to calculate the PEEQs of the different types of population and to sum them up to the eating population of the urban system. Two more parameters, average daily food intake and share of daily food intake, were necessary to calculate the total food intake of the eating population.

Average daily food intake

Food intake studies provided the average daily food intake. Their purpose is to provide knowledge on a population's food practices and its nutritional status. This is relevant because food has been scientifically acknowledged as being important in the increase and the prevention of non-transmissible diseases such as cancer, obesity and cardiovascular diseases. Therefore, information about a population's food intake is key for designing and monitoring public health and nutrition policies, such as the national nutrition and health programmes (PNNS) in France, and for identifying further research needs.

Two food intake studies are available in France. The "behavior and food consumption" study (*Comportements et Consommations Alimentaires,* CCAF) is a 3-yearly survey carried out, since 1999, by the private research institute CREDOC. It covers the opinions, habits and food intake of a representative sample of the French population (2,456 adults and 588 children aged 9 to 14 years in the 2016 survey). The results from the latest wave are accessible for a fee. The INCA study (*Étude Individuelle Nationale des Consommations Alimentaires*) is a food intake survey carried out, since 1999, every seven years by the French Agency for Food, Environmental and Occupational Health & Safety (ANSES). Like the CCAF survey, INCA covers the food intake of a representative sample of the French population living in ordinary households. Moreover, questionnaires cover food, cooking and household practices and skills, consumption of dietary supplements, and knowledge about food and attitudes. Use of this government funded survey is free of charge.

Adhering to the principle of supporting publicly funded research, I decided to use the free-of-charge data from INCA 3 (Anses, 2017). The most recent wave of the survey was carried out in France between February 2014 and September 2015. There were 5,855 participants, divided into two samples: 2,698 children and teenagers aged 0 to 17, and 3,157 adults aged 18 to 79. Children and teens were divided into age groups, which made a total of three age groups together with adults: children aged 0 to 10, teenagers aged 11 to 17, and adults aged 18 to 79.

The daily intake for different food and drink categories and total daily intake is available as a mean value, median value, and standard deviation for the national INCA 3 sample. The standard deviation shows a variation of +/- 30% of the mean total intake amongst adults and children, and of +/- 36% amongst teenagers, showing that there are significant differences in the food intake of the sample. Mean and median values are very close (a difference of less than 3% for adults, and less than 5% for children and teenagers), which means that the values of the sample data set are evenly distributed and that there are no very small or very large values which would influence the mean[91]. Considering the small difference, I used the mean daily food intake to calculate the population food intake. Upon request, ANSES provided us with the mean and median daily food intake per food category of respondents from Île-de-France. The structure of the sample was checked for representativeness of the Île-de-France population in terms of sex (slightly more females with 55.2% compared to 52.6% of the legal population) and age (more middle-aged respondents with age group 45 – 64 of 41.5% compared to 34.9% of the legal population)[92] . Despite these differences, I did not adjust the results to compensate for them.

INCA 3 distinguishes food and drink, and I will do the same in the food flow analysis of the urban system in the Paris Petite Couronne and Île-de-France case studies. The distinction is relevant from the perspective of the disposal of uneaten food and drink. Liquids tend to be disposed of through the sewage system, whereas food is managed as solid waste collected and treated in centralized facilities. Drink comprises the following products (Anses, 2017: 102): water (tap water and bottled water), juice (fruits and vegetable juice), soft drinks, infant milk and infant beverages, milk and hot beverages. All other products are classified as food. Note that soup and bouillon are classified as food, although some people drink them. Tap water drunk as a hot beverage (e.g. as tea or coffee) or cold from the tap makes up a considerable share of total average food intake (33% and 34% amongst the adult French and Île-de-France population, respectively). Table 7 summarizes the average daily intake in grams per day for the three age groups, for the French versus the Île-de-France sample.

[91] It however is possible that persons with extremely low or high levels of food intake refused to participate in the survey. Reasons for refusal were predominantly lack of interest and lack of time (60% of reasons given), both of which can hide other reasons. It cannot be excluded that the sample underestimates the prevalence of extreme levels of food intake. Yet no information about the food intake of refusers was available. It therefore was not possible to assess the degree of uncertainty of the average intake in relation to those who refused participation (Anses, 2017).

[92] Sex is one of the most influential socio-demographic determinants of total food intake. Total daily intake of men is higher than that of women: 3,177 g/d and 2,720 g/d respectively, which is a difference of 450 g (Anses, 2017). There are also other determinants. Education level is associated with total daily intake: 2,864 g/d for those having primary or lower secondary education to 3,061 g/d for those having a level equal to or above A-levels. Age, however, plays smaller a role: daily intake does not vary between the ages of 18 and 64, and decreases for adults aged 65 to 79. The INCA 3 Île-de-France sample of adults aged 18 and older has slightly more females than the Île-de-France population, according to the census data (55.2% and 51.7% respectively). Unfortunately, I could not obtain more census information to compare directly with the INCA 3 Île-de-France sample structure.

Table 7. Mean daily food and drink intake, population from France and Île-de-France, per age group, 2014-2015, in g/d

	children (0-10 y)		**teenagers (11-17 y)**		**adults (18-79 y)**	
	France	Île-de-France	France	Île-de-France	France	Île-de-France
Food	774	770	980	1,066	1,094	1,195
Drink	915	921	1,170	1,219	1,766	1,890
-Tap water to drink	370	331	566	449	963	1,038
-Other drink	545	590	604	769	803	852
TOTAL food and drink	1,688	1,691	2,150	2,284	2,920	3,085
share of drink (%)	*54*	*54*	*54*	*53*	*60*	*61*
share of tap water to drink (%)	*22*	*20*	*26*	*20*	*33*	*34*
TOTAL food and drink excl. tap water to drink	1,318	1,360	1,584	1,835	1,957	2,047

Source: Anses 2017 INCA 3 study; Anses data analysis

We used the Île-de-France mean daily intake of the three available age groups, available from the INCA 3 study (Anses, 2017), for the resident population living in ordinary households. There is no statistically significant difference in total intake quantity between the samples from Île-de-France and France. Slight differences of statistical significance exist for the relative contribution of some food categories. For residents living outside of ordinary households and for the additional population I had no food intake data for their specific situation and therefore used the national mean food intake from INCA 3: the data of adults and the data of children aged 0-10 years and teenagers aged 11-17 years for a combined group of children/teenagers (Anses, 2017).

Share of daily food and drink intake in the urban system

I considered that commuters and excursionists travelling to or from the urban system of Paris Petite Couronne or Île-de-France have half of their daily food intake within the urban system and half outside of it. I justified the share through INCA 3 food intake distribution per moment of consumption amongst adults aged 18-79 (Anses, 2017) (see Table 8). I determined that commuters who leave Paris Petite Couronne or Île-de-France have at least breakfast, dinner, and an aperitif at home (47% of daily food intake). Commuters who go to Paris Petite Couronne or Île-de-France for work have the opposite to those who leave: lunch, afternoon snack, and other snacks (53% of daily food intake). For simplification and considering the uncertainty of these data, I assumed a share of daily food and drink intake in the urban system of 0.5 for all commuters. For excursionists, I considered the same situation as for commuters (share of 0.5). All other population types have their total daily food intake within the urban system[93].

Table 8. Distribution of daily food and drink intake according to moment of consumption amongst adults aged 18-79, France, in %

Total moments of consumption	breakfast	lunch	afternoon snack	dinner	apéritif	other snacks
100	16	29	4	28	3	21

Source: Anses, 2017

Table 9 summarizes the share of the daily food intake consumed in the urban system per population type. A share of 1 means that the entire food intake is consumed in the urban system, and a decimal number means that the corresponding share of food intake is consumed there. Populations having no food intake in the urban system, and a share of 0, are by definition excluded from the eating population.

[93] Except for when they travel, which is accounted for in the parameter average time spent in the urban system.

Table 9. Share of daily food and drink intake (in whole unit or decimal) in the urban system per population type, 2014-2015

Population types	Share of daily food intake in urban system	Sample in INCA 3 study [1]
Residents		
-Living in ordinary households		
0-9 y	1	Île-de-France, 0-10 y
10-19 y	1	Île-de-France, 11-17 y
20 y +	1	Île-de-France
Commuters to outside of Île-de-France	0.5	Île-de-France
Commuters to Grande Couronne	0.5	Île-de-France
-Living outside of ordinary households		
In retirement homes	1	France
In prisons	1	France
In student halls of residence	1	France
In young workers' hostels	1	France
Homeless adults	1	France
Homeless children	1	France, average aged 0-10 and 11-17
Remainder	1	France
Additional population		
-tourists		
18 y +	1	France
0-17 y	1	France, average aged 0-10 and 11-17
-commuters		
to Île-de-France	0.5	France
to Paris Petite Couronne from Grande Couronne	0.5	France
to Paris Petite Couronne from outside of Île-de-France	0.5	France
-excursionists	0.5	France

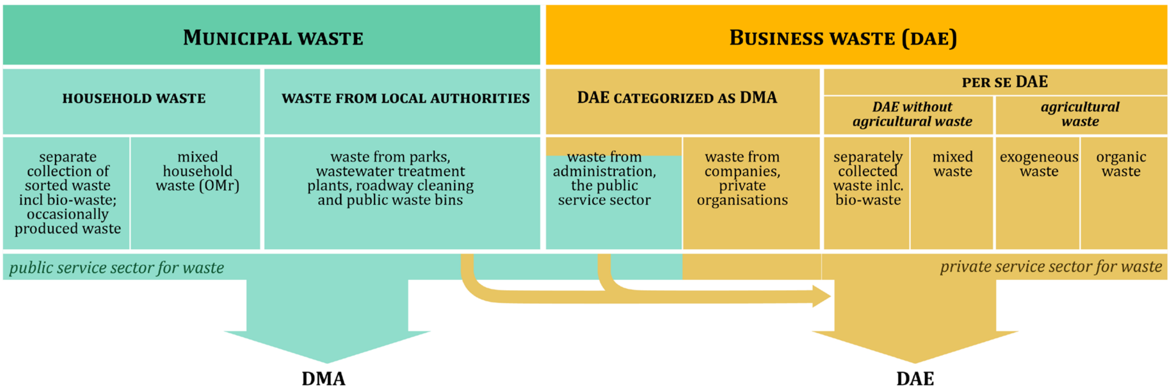
Sources: Anses, 2017 INCA 3; data analysis Anses
[1] The samples are related to adults aged 18 to 79 except where indicated.

For Paris Petite Couronne and Île-de-France, I used the same values of the parameter urban system share of daily food and drink intake and the same INCA 3 sample of origin (see Table 9).

3.1.4. Food waste

Food waste is not a waste category in the sense of official classification in statistics and is therefore not reported separately. Yet waste statistics can be used to estimate food waste from different waste categories that include food waste. The waste category typology reflects a fundamental distinction between waste-generating sectors and the type of service, public or private, in charge of its management. There are two broad categories (Figure 15). Waste from households and related activities (*déchets des ménages et d'activités assimilées,* DMA*),* in short "household waste", primarily includes waste from households and some business waste, called that is similar in profile and amount, mostly from small shops, restaurants, and other facilities, and that is collected together. Household waste is managed as a public service and paid to the local authorities in charge through a tax or a fee[94]. Business waste *(déchets des activités économiques,* DAE) is waste from the remaining sectors that are industry, retail, administration, the education system, the medical system, and the service sector, to name the most important ones. Waste from local authorities such as parks, wastewater plants, roadway cleaning and public waste bins is usually included. The collection and treatment of business waste is directly financed by the waste-generating public or private entity or institution.

Figure 15. Distinction between household waste (DMA) and business waste (DAE)



Source: adapted from ORDIF (2013)

[94] The household waste collection tax (*taxe d'enlèvement des ordures ménagères*, TEOM) is the principal way in which local authorities finance waste collection and treatment. This tax is collected with the annual property rates bill (*taxe foncière*), whether the service is used or not, and uses the same basis for calculation, that is, the rateable value of the property (*valeur locative cadastrale du bien*). A household waste collection fee (*redevance d'enlèvement des ordures ménagères*, REOM) is an alternative to the tax and charged to service users only. It can include an incentive part (*redevance incitative*), and can also include the tax in the form of the TEOMI, calculated from the real use of the service (waste amount, service use frequence etc.). Additionnally, a special fee (*redevance spéciale*) can be charged by the local authorities to collect waste from business and administration. To complete the picture, some local authorities simply decide to finance waste collection and treatment through their general budget. Public policy has provided that users increasingly pay for a service used, according to the polluter–pay principle, with the aim of incentivizing waste reduction (*tarification incitative*) (law n° 2011-1977 of 28 December 2011 for the possibility of an incentive part of the TEOMI). In Île-de-France in 2017, 95% of the 61 local authorities in charge of waste collection levied the TEOM. Four local authorities make use of incentivizing tarification (ORDIF, 2019).

Depending on who generates it, food waste is part of either household waste or business waste. In household waste, the biggest share is the mixed household waste (*ordures ménagères résiduelles*, OMr) that is collected in waste bins and that remains after being sorted by households into cardboard, paper, glass or packaging, for which large-scale separate collection has been implemented by the local authorities in charge. By 2025, now advanced to 2023, the law[95] has provided that households and any other producers of bio-waste[96] will be offered options for the recycling of bio-waste[97]. Separate collection of bio-waste has already been mandatory for big bio-waste producers, with big being defined as exceeding a threshold, progressively lowered from 40 tonnes per year in 2012 to 10 tonnes per year from 2016 onwards[98]. When companies and administration do not sort and separately collect their bio-waste, which at the time of this research was the predominant situation, it ends up in mixed business waste.

Food waste and any other waste generated at agricultural production is considered as being a category apart within the DAE.

Due to the fact that food waste is hidden within these different waste categories that are defined according to sectors generating them, and are treated as mixed or separately collected waste by the public or private waste management service, the compilation of food waste data as such is particularly challenging. It is even more challenging at the level of an urban system that is not a regular unit for the establishment of waste statistics. Data sources were gathered from the available statistics (Figure 16) and completed with reports from the public waste management sector where possible at the level of Île-de-France and where possible for Paris Petite Couronne. Such reports for example monitor local waste prevention strategies, including decentralized

[95] Law n° 2015-992 of 17 August 2015, Article 70.

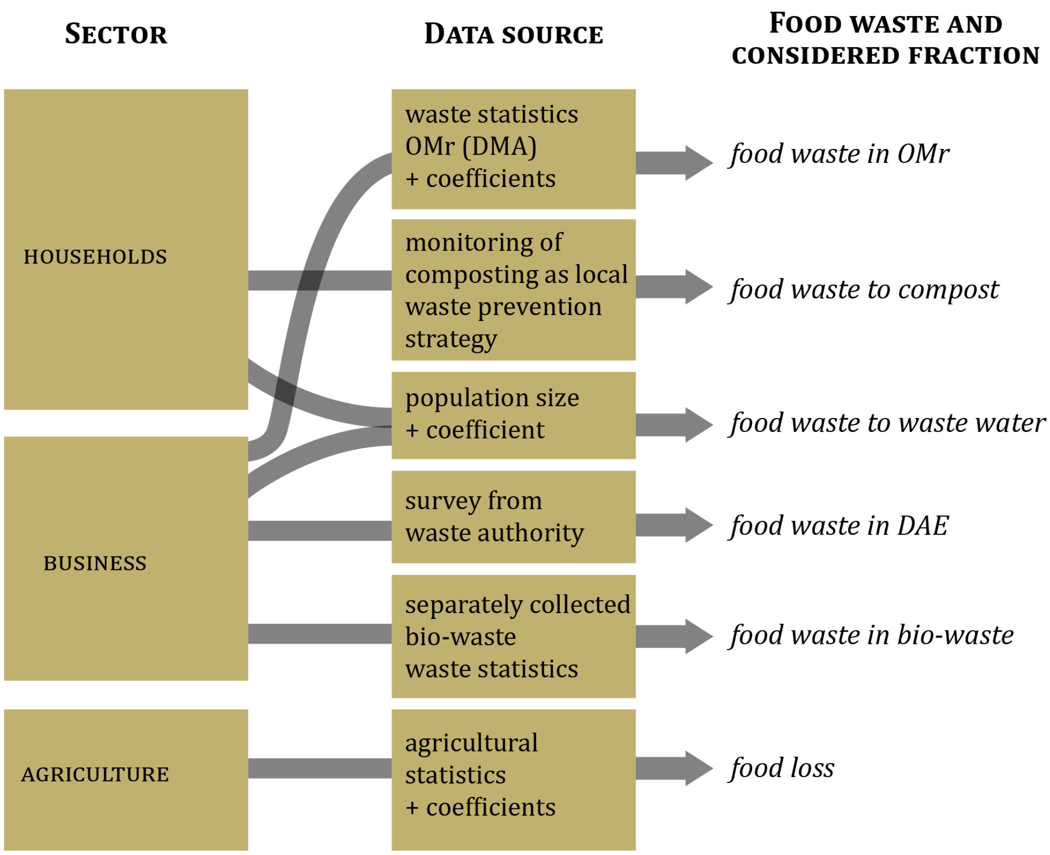
[96] The definition of bio-waste is laid down in the EU framework directive on waste, Article 4 (EC directive 2008/98/EC of 19 November 2008): "bio-waste means biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises and comparable waste from food processing plants."

[97] On 1 January 2016 in France, 125 local authorities separately collected bio-waste, of which 24 collected bio-waste only from businesses, and 101 from either households only or from households and business. Altogether, 5.7% of the French population (3.26 million inhabitants) was offered the service of separate bio-waste collection (AJBD et al., 2018). By 2023, 100% should be offered this service. For Île-de-France, see results in 3.2.2.

[98] An advanced milestone has recently been introduced by law n°2020-105 of 10 February 2020, Art.88 (V), amending Article L. 541-21-1 of the Environment Code. The new text stipulates that by 31 December 2023 at the latest, the obligation will concern producers or holders of bio-waste, including public authorities concerned by the public waste management service and private and public establishments which generate bio-waste."

composting of food waste[99], or analyse the composition of household waste. Case studies from the scientific literature although not specific to this research filled gaps, where necessary.

Figure 16. Data sources for food waste per sector



Source: author

Household waste

Household waste data for Île-de-France are available from the waste department of the Institut Paris Région, formerly known as the Paris Île-de-France Waste Observatory (ORDIF), a non-profit association founded in 1992 by the Île-de-France Regional Council (Paris Region) and

[99] In local waste policy, decentralized composting by households or in neighbourhood composting units is considered as waste prevention. This is because it enables local authorities not to have to organize the collection and management of the waste, and reduces waste in statistics (Conseil Régional Ile-de-France, 2019; Mairie de Paris, 2017). However, in other references at national or supranational level, composting is considered as organic waste recycling, not prevention (European Comission, 2018).

the State, and which was integrated into the Institut Paris Région in 2017. One of its missions is to monitor waste prevention and management in the region.

ORDIF carries out a yearly survey called *enquête DMA* on local authorities in charge of household waste collection or responsible for a recycling depot ("*déchetterie*"). The aim of the survey is to monitor collected amounts, as well as the collection and treatment method of household waste. Once the information is collected, it is recorded in the national database on waste, SINOE ®[100], hosted by the Agency for ecological transition, Ademe (previously the French Environment & Energy Management Agency), to enable further analysis. The response rate is relatively high, with 96% of local authorities representing 97% of the Île-de-France population that responded to the survey on the situation in 2015, carried out in 2016. The survey provides information about the total amount of collected household waste, specifying the sub-categories of mixed household waste (OMr), separately collected recyclables, and bulk waste. Using population data of the corresponding year for normalization, the Institut Paris Région, Ordif, calculates a collected waste amount per capita and year for each of the sub-categories.

While the survey provides a rough picture of the waste amounts, there is little detail about the contribution of different materials, and even less of food waste, to mixed household waste. Studies using waste composition analysis complete the picture by characterizing the mix of materials in household waste. There is a standard methodology called MODECOM developed and used by Ademe for its national campaign for the characterization of household waste[101]. Based on a national sample of local authorities representing the diversity of municipalities with respect to housing and sorting instructions for plastics, mixed household waste samples are collected and analysed. The representativeness of these samples and the accurate application of the study protocol is key for the robustness of the data. The recent MODECOM study has a range of +/- 10% of error (Ademe, 2019), which is acceptable compared to other data sources used in urban metabolism studies.

The method, or an adapted version, is also being used by local authorities in charge of waste. ORDIF has used a transversal approach to analyse the results of characterization campaigns run between 2010 and 2015 in Île-de-France, mostly where the local authorities were committed to a local waste prevention programme (ORDIF, 2017). We use the results from the household

[100] www.sinoe.org
[101] The national campaign for the characterization of household waste has been run three times: in 1993, 2007 and 2017 (Ademe, 2019).

waste survey (ORDIF, 2015) and the characterization campaigns (ORDIF, 2017) to estimate food waste in OMr in Île-de-France and Paris Petite Couronne (Table 10). Data on mixed household waste (OMr) (in kg/cap/y), and on share of biodegradable waste in OMr, of food waste in OMr, of wasted food in OMr (in %), and of food waste in OMr (in kg/cap/y), have been compiled for different administrative units in Île-de-France and in France.

Table 10. Mixed household waste (OMr) (in kg/cap/y), share of biodegradable waste in OMr, of food waste in OMr and of wasted food in OMr (in %), food waste in OMr (in kg/cap/y), different administrative units in Île-de-France and in France

	Year of data	Mixed household waste (OMr)	Share of biodegradable waste in OMr	Biodegradable waste in OMr	Share of food waste in OMr	Food waste in OMr [a]	Share of wasted food in OMr	Source biodegradable / food waste
Paris	2015	358	22	79	17 or 19	61 or 68	7 [1]	Mairie de Paris (2016)
	2017	349 [c]	23	80	16	56	5 [1]	Mairie de Paris (2017)
Greater Paris	2014	313						
Île-de-France	2010 - 2015	293 [b]	28	82	22	66		ORDIF (2017)
France	2007	316	31	98	23 [2]	73		Ademe (2010)
	2017	255 [4]	27	69			10 [3]	Ademe (2017)

Source: ORDIF (2014); Ordif (2017)
[1] Packed, [2] leftover (*restes de cuisine)*, [3] packed and unpacked, [4] final value will be confirmed in 2020
[a] Calculated by the author except for Île-de-France, for which ORDIF (2017) provided this data;
[b] Calculated from share and normalized biodegradable waste in mixed household waste (ORDIF 2017);
[c] Calculated from total collected mixed household waste (OMr) and population size (Mairie de Paris, 2017)

At national scale for comparison, results from characterization campaigns show that the biodegradable part[102] in mixed household waste made up 31% in 2007 (Ademe, 2010) and 27% in the same study ten years later (Ademe 2019). For Paris, this share is 22% (Mairie de Paris, 2016). Putting these shares in relation to normalized amounts of mixed household waste,

[102] This share is named *déchets putrescibles* in the waste composition analysis methodology written in French (Ademe 2019), for biodegradable, decayable, fermentable or organic waste,

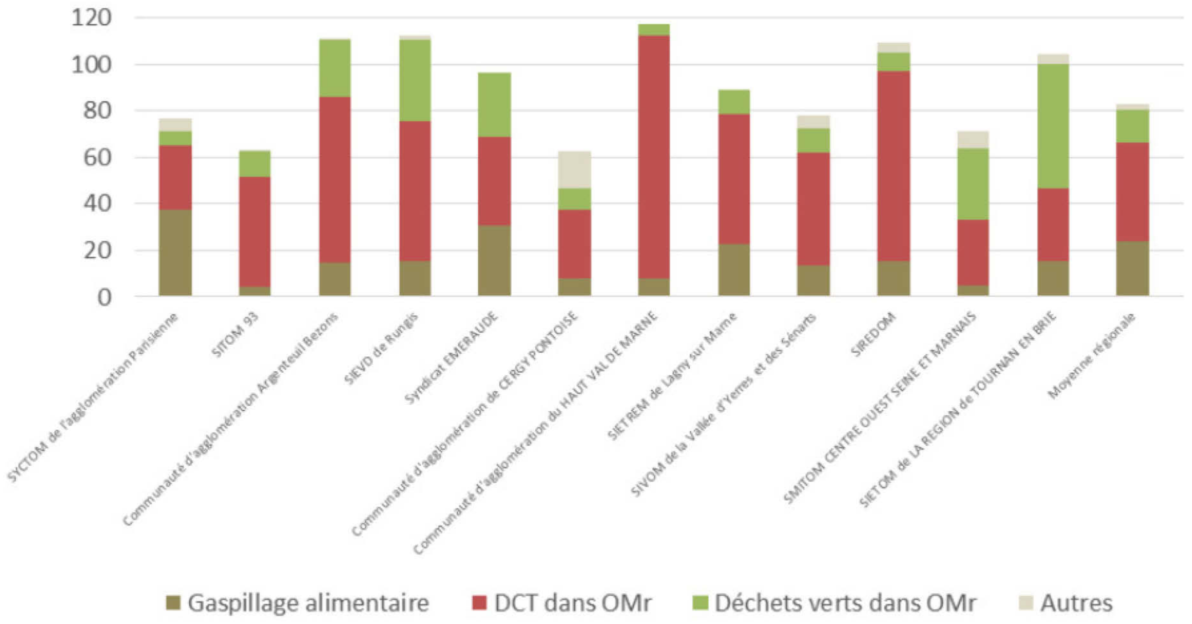
biodegradable waste amounts to 98 and 69 kg/cap/y for France in 2007 and 2017 respectively, and for Paris, in 2015, to 79 kg/cap/y.

While the uncertainty is high for the share of biodegradable waste, due to possible bias in the method (ORDIF, 2017), and consequently for normalized amounts of biodegradable waste, the share of food waste is even more difficult to determine. Results are not being systematically reported for sub-categories in biodegradable waste, such as food waste, and within food waste, of wasted food and inedible parts. Apart from questions of method, the purpose of characterization studies is to inform waste managers about possible treatment methods, and about the physical-chemical nature and noxiousness of waste components. For waste managers, food waste, above all, is biodegradable waste and does not necessarily require further qualification[103]. Further details about the composition of food waste are rarely available. If available, they suffer from ambiguous terminology that hinders the identification of wasted food versus inedible parts that I aim to shed light on through this food flow analysis.

The transversal characterization study by ORDIF (2017) reports, on average, a total of 82 kg of organic waste collected in mixed household waste bins per inhabitant per year, of which 24 kg is packed food (*gaspillage alimentaire*), 42 kg meal leftovers (*reste de repas, déchets de cuisine et de table*), 14 kg garden waste (*déchets verts*) and 2 kg other waste. Beyond average results, the study reveals large disparities in the respective amounts of wasted food, meal leftovers and garden waste in the total biodegradable share of mixed household waste amongst participating local authorities in charge of waste, as shown in Figure 17. Explanation factors can be bias in the characterization method, particularities of the territories in terms of food consumption and organization of waste collection (separate collection of garden waste, home composting, etc.). Further analysis would be necessary to disentangle the factors that induce the large difference.

[103] In newer waste characterization studies, food waste is being systematically reported. Food waste and garden waste, the two main bio-waste components of mixed household waste, are not the same when it comes to organic recycling technologies (composting, anaerobic digestion) in terms of hygiene for example. Policy frameworks and targets for their development require new knowledge about waste composition.

Figure 17. Biodegradable waste in mixed household waste, local authorities in Île-de-France, in kg/cap/y

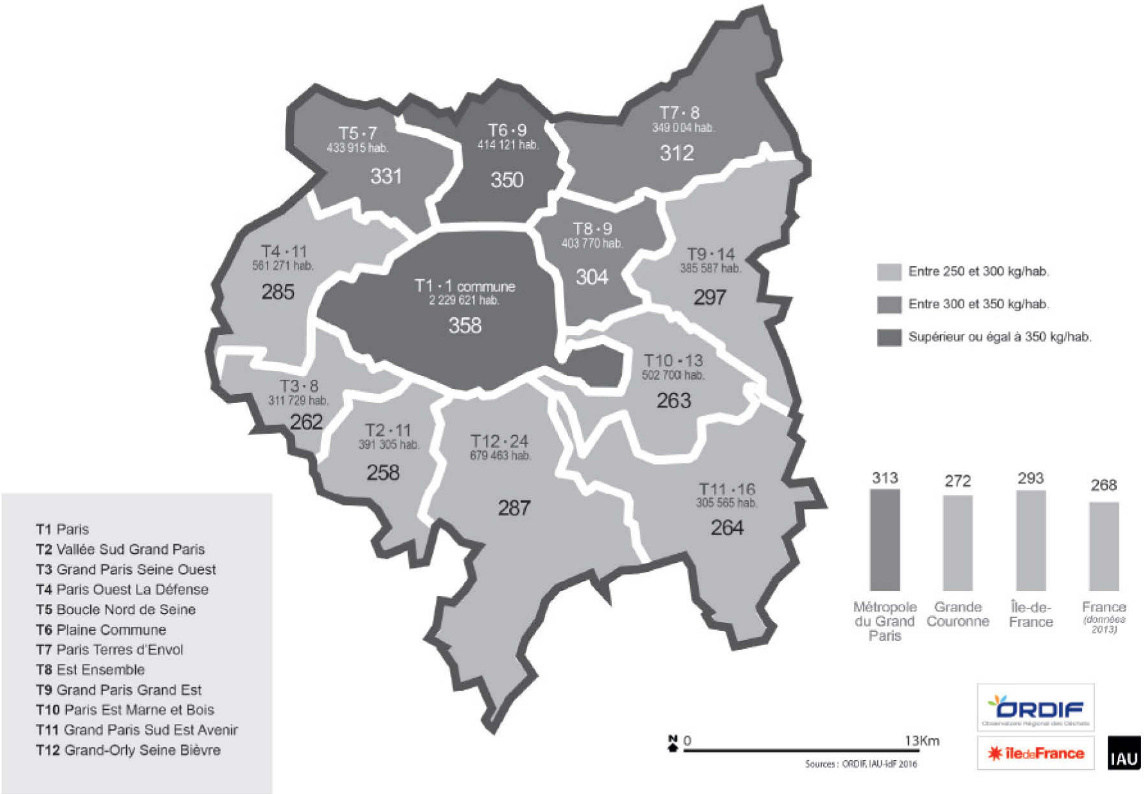


Source: ORDIF, 2017; DCT means table and kitchen waste (*déchets de cuisine et de table)*; the right bar shows the regional average; local authorities are presented from left to right according to decreasing population density.

This composition leads to a share of 80% of food waste in biodegradable waste, which accounts for 28% of mixed household waste and 82 kg/cap/t (ORDIF, 2017). Based on these data, I calculated food waste of 66 kg/cap/y in mixed household waste in Île-de-France and a share of 22% (Table 10). I used this share of 22% to calculate the amount of food waste in mixed household waste, based on the total amount of collected mixed household waste, as reported by ORDIF (2015).

The same approach can be applied for Paris Petite Couronne, using an ORDIF report for the Greater Paris metropolis as a proxy (see Chapter 2 about the case study) (ORDIF 2016 Metropole Grand Paris). In 2014, on average 313 kg/cap/y mixed household waste were collected from the Greater Paris metropolis area, which is 20 kg more than the Île-de-France average (293 kg) and 41 kg more than the average of the Grande Couronne (272 kg). However, there is a difference of close to a hundred kg between the highest (T1 Paris, 358 kg/cap/y) and the lowest normalized amount (T2 Vallée Sud Grand Paris, 258 kg/cap/y) per public authority in charge of waste collection (EPT) within the area of Greater Paris (Figure 18).

Figure 18. Collected mixed household waste, Greater Paris metropolis, 2014, in kg/cap/year



Source: Ordif (2014)

No information about the share of biodegradable waste or food waste is available for either Paris Petite Couronne or the Greater Paris metropolis. The Paris municipality, which is also the EPT T1 in charge of waste, frequently carries out household waste characterization campaigns (in 2011, 2013, 2015, and 2017). It reports 12% food waste and 7% packed food items in mixed household waste[104] from its 2015 campaign (Mairie de Paris, 2016) and 16% food waste and 5% packed food items two year later (Mairie de Paris, 2017). Related to normalized mixed

[104] The report is confusing as regards food waste categories. Packed food items sometimes are considered within the category of food waste (*déchets alimentaires*), sometimes different from it. The municipality of Paris (Ville de Paris 2016:25) defined food waste in the sense of *déchets alimentaires* as kitchen waste remaining from food preparation such as vegetable peelings, meal leftovers, and food items without packaging (there seems to be a mistake in the wording, it should mean packed food items and be written *produits alimentaires non déballés ou encore emballés,* instead of *non emballés* which means without packaging, Ville de Paris, 2016:26) and directly thrown in the bin, often due to the expiry date (*Les déchets alimentaires correspondent à l'ensemble des déchets de cuisine issus des préparations de repas tels que les épluchures de légumes, des restes de repas, mais également les produits alimentaires non emballés et jetés directement à la poubelle, fréquemment dû au dépassement de la date limite de consommation*.). According to the municipality's report, packed food makes up more than half of food waste, which itself makes up 17% of the mixed household waste (Mairie de Paris, 2016:25). However, percentages of food waste and of packed food items are presented separately (*11.9% de déchets alimentaires, 7.4% produits non déballés*), totalling 19% (Ville de Paris, 2016 :48). There seem to be large inconsistencies in the meaning and use of the category of food waste. The same inconsistencies persist in the follow-up report published one year later (Mairie de Paris, 2017).

household waste, food waste amounts to 61 or 68 kg/cap/y (assumption of 17% or 19%) and 56 kg/cap/y in 2015 and 2017 respectively, when I consider that food waste includes all wasted food including items still in packaging (Table 10). I used a share of 19% of food waste in mixed household waste, in line with the results of the Paris characterization campaign (Mairie de Paris, 2016), to calculate the amount of food waste in mixed household waste in Paris Petite Couronne, based on the population-based normalized mixed household waste for Greater Paris metropolis (ORDIF, 2014).

Although it is possible to obtain an overview of the share and per capita amount of biodegradable waste and food waste in mixed household waste, in different nested administrative units of Île-de-France, it is impossible at this stage to distinguish wasted food versus inedible parts based on the characterization campaigns carried out by the Paris municipality and those analysed by ORDIF (2017). Indeed, in these campaigns, only packed food, and in the recent MODECOM study for France (Ademe 2019), packed and unpacked food (together 10% of mixed household waste), were considered wasted food (*gaspillage alimentaire*). Yet, my point of view, in line with international organizations[105], is that also meal leftovers, half-eaten items, and any other food whether fit or unfit for human consumption at the time of disposal, is to be considered wasted food. A common point in these percentages of wasted food is that it can be avoided and therefore requires specific policy measures for avoidance, in contrast to inedible parts that are natural parts of food and which, at best, can be usefully recycled. This is why it is important to have better knowledge about amounts of wasted food.

Apart from lacking a distinction between wasted food and inedible parts, mixed household waste data as published by Institut Paris Région/ORDIF do not allow for a distinction between genuine household waste and business waste that are collected together by the public service municipal services. The distribution for Île-de-France and lower administrative levels is not known. At national level, the recent MODECOM study (Ademe, 2019) reports a distribution of 80% from households and 20% from businesses. Due to the high number of restaurants and shops in the dense urban areas of Île-de-France, I assume that the contribution of business waste is higher in Île-de-France and probably even more in Paris Petite Couronne and in Paris, although I cannot estimate the figures.

[105] See Chapter 2 on food waste.

Estimates of food waste from mixed household waste do not include food items disposed of through the sewage system. In the EU-funded project FUSIONS (Stenmarck et al. 2016), I found the average of 15 kg/cap/y food waste sent to the sewer and used it in the present study.

For any other way of food waste disposal such as feeding pets or composting, no data were available about the quantities at individual or household level. Households in more rural housing situations, especially those with a garden, compost their food and garden waste. Sorting of bio-waste by households and use for local composting, such as home or neighbourhood composting, has been strongly developed since 2010[106]. It is hard to estimate the total amount of food waste redirected to these small-scale composting devices, for 2014. Syctom[107] reported that 2% of the population covered by Syctom waste management services, that is, 121,200 residents out of 6,060 000, had access to composting equipment. Syctom estimates that 13 kt of bio-waste was directed to local composting. As for centralized composting, the Paris municipality started experiments with separate collection of household food waste in two *arrondissements* from May 2017 onwards. Other EPTs, such as Plaine Commune (93), Grand Paris Seine Ouest (92), Est Ensemble (93) and Grand Orly Seine Bièvre (94) have run similar experiments with households. One local authority, the urban community (*communauté d'agglomération*) of Cergy Pontoise, collected 6 kt of household bio-waste in 2014, albeit mostly limited to garden waste.

Business waste

For business waste generated in Île-de-France, there is no survey similar to the one on household waste collected by public authorities[108]. Except when equated to household waste and collected under public service management, information about business waste is available at the waste-producing establishments in the first place.

INSEE carries out a national survey on the production of non-hazardous waste by industrial establishments, including agri-food industries, in terms of physical volume and classified by type of waste and by sector of activity. The survey does not allow a detailed analysis of sorted

[106] The reader is referred to the PhD research of Elisabeth Lehec, carried out under the supervision of Sabine Barles, about local composting in Paris (Lehec, 2018).
[107] *Syndicat intercommunal de traitement des ordures ménagères*. Syctom is the biggest public service provider for waste treatment in Île-de-France. It covers an area of 85 municipalities located in five *départements* (Paris, Hauts-de-Seine, Seine-Saint-Denis, Val-de-Marne and Yvelines). 81 municipalities are located in 11 *territoires* of the Greater Paris metropolis area and 3 municipalities are located outside of it.
[108] *La gestion des déchets ménagers et assimilés en Île-de-France,* annual survey carried out by the Institut Paris Région/ORDIF

or mixed business waste by region, sector and relevant waste categories (by-products, e.g.), as my research would require. Results from the 2012 survey suggest that the food industry compared to other industry branches is the one which least performs waste sorting, leaving 50% of business waste as mixed waste, at national level[109] (INSEE Première, 2019). Similarly, INSEE carries out a survey on non-hazardous waste in wholesale and retail commercial establishments. Again, the survey does not inform about the Île-de-France region and the food waste topic specifically. We nevertheless learn that in 2016, organic waste is the second most sorted waste flow, behind paper and cardboard, in the wholesale and retail sector (INSEE, 2019).

For business waste in Île-de-France, I refer to an estimation performed by the consultants from Inddigo and Solagro as part of the regional plan for waste prevention and management[110] for the Île-de-France Council. They extracted data about bio-waste producing companies from a public database and applied average levels of bio-waste normalized for number of employees. The result is an estimate of 235 kt of food waste in mixed business waste and not considered as household waste, in 2014/2015. I used the ratio (0.65) of the number of employees in the food industry in both areas in 2015 (DRIAAF, 2018, Panorama des IAA) to calculate a relative amount of food waste in mixed business waste in Paris Petite Couronne.

Information on business waste can additionally be estimated from the biennial survey of activities of waste treatment facilities for household and business waste called the Enquête ITOM (*Installations de Traitement des Ordures Ménagères*), carried out by the Institut Paris Région/ORDIF. Initially focused on household waste only, the survey has been extended to also include business waste and is now entitled the non-hazardous waste treatment facility survey (*enquête Installations Traitement Déchets Non Dangereux*, ITDND). The survey provides a good overview of public and private waste sorting and treatment facilities, their treatment capacities, and effective treated amounts. This information is useful to be cross-compared with the Institut Paris Region/ORDIF survey on collected household waste.

Since 2012, separate collection of bio-waste has become mandatory in France for "big producers" (*gros producteurs*), that is, companies which produce bio-waste above an annual

[109] Mandatory sorting and separate collection of bio-waste for big producers just started in 2012. We can expect that sorting of bio-waste quantitatively appears in the 2016 and future results of this survey.
[110] Following the institutional reform of the law NOTRe, the Île-de-France region became endowed with the waste planification task and has devised a regional plan for waste prevention and management (*Plan regional de prevention et de gestion des déchets, PRPGD*) comprising an overview of the situation of waste amounts, management facilities, and future trends and challenges (Conseil Régional Ile-de-France, 2019).

legal threshold of 40 tonnes (Art. L. 541-21-1 du Code de l'environnement), progressively lowered to 10 tonnes since 2016[111]. ORDIF monitors bio-waste collected and treated separately in Île-de-France, identifies food waste versus garden waste, and reports the type of treatment of the different types of waste[112]. For 2014, ORDIF provided the data on the quantities of food waste collected and treated as bio-waste in Île-de-France[113]. The quantities of bio-waste collected in Île-de-France and treated elsewhere are not covered by the ORDIF data collection tools. For business waste, I used the ratio (0.65) of the number of employees in the food industry in both areas in 2015 (DRIAAF, 2018) to calculate a relative amount of separately collected and treated bio-waste in Paris Petite Couronne.

While information on food waste in business waste is scarce, whether the waste is mixed or sorted as bio-waste, for some specific waste categories related to food, the information is clearly identified and documented. For instance, data are available on used frying oil from the food service sector which has been successfully collected and used as biofuel and for industrial applications for many years. 28.2 kt of used frying oil were reported in 2015 for Île-de-France, of which two thirds or 18 kt were collected (Conseil Régional Ile-de-France, 2019). I used the number of commercial restaurants (including street food) per *département* in Île-de-France[114] to establish a Paris Petite Couronne / Île-de-France ratio (81/100) and calculated the pro rata quantity of frying oil generated in Paris Petite Couronne (22.8 kt).

Although food donation is not considered as food waste, precisely because it has been rescued from being wasted, it is a food system internal loop flow that redirects surplus food mainly from the retail sector and the food industry to people in need, primarily via food banks. In most cases this food would otherwise have gone to waste. Pushed by law[115], the infrastructure and logistics have developed significantly in recent years, adding start-ups and associations as operating links between donors and receivers. Quantitative data are still scarce. In 2014, according to the annual report, *Banque alimentaire* has received 5,276 tonnes of food, of which 11% from the industry and 6% from retail (Banque alimentaire de Paris et d'Île-de-France, 2014). Data for

[111] Under the impact of regulation, we can expect a rise in the collected quantities of bio-waste in the future.
[112] ORDIF monitoring tools cover the quantity of bio-waste collected and treated in Île-de-France but not treated elsewhere. To fill the data gap of bio-waste treated elsewhere, the quantities of total bio-waste collected and handled by massification units (*quais de transfert*) were analysed and cross-compared with the data of bio-waste treated in Île-de-France.
[113] Blandine Barrault, ORDIF, per email on 18 November 2019
[114] François Mauvais, DRIAAF, per email on 16 December 2019
[115] n° 2016-138 from 11 February 2016 and n° 2018-938 from 30 October 2018.

the many other non-profits in Île-de-France receiving food donations are not available for compilation. I estimate that food donations from surplus did not exceed 2 kt in 2014.

Food loss in agricultural production

Data on food loss in agricultural production, both crops and livestock, is particularly scarce due to the particularities of the sector (see 2.1.1 on food waste). This knowledge gap is reflected not only in the scarce scientific literature, but also amongst technical and professional representatives, such as farmers' unions or interbranch associations (Redlingshöfer et al., 2017). WRAP (2019) has compared food loss in Europe from the handful of available scientific references, by food category. Only one reference (Redlingshöfer, 2017) refers to agriculture in France. It builds on a large study carried out at INRAE on food loss in agricultural production and processing in France. The scientists gathered food loss data through a variety of data sources, from expert knowledge to surveys and the relevant technical literature. I used the food loss percentages compiled in the synthesis (Redlingshöfer et al. 2017) and calculated food loss amounts related to the different crop and livestock production in Île-de-France and Paris Petite Couronne in 2014. For one sector, sugarbeet, not covered in the INRAE study, I used data from a study commissioned by the Ademe (Income Consulting AK2C, 2016).

3.2. Food flows

3.2.1. Total food intake of the eating population

The total eating population is almost equal in size to the legal population, with 6.6 million permanent eaters, or PEEQs, versus 6.8 million residents in the case of Paris Petite Couronne, as Table 11 shows. For Ile-de-France, it is slightly smaller, with 11.3 million PEEQs versus 12.0 million residents[116]. Despite the region's status as a major tourist destination and a vibrant economic centre in Europe, the additional population of tourists, excursionists and commuters accounts for only 9% of the eating population in Paris Petite Couronne and for 4% in Île-de-France (Table 11). By definition, commuters do not spend the night away from their home and are assumed to have some of their meals (half of them in my estimate based on Anses, 2017) outside of the urban system, primarily at their home. The additional population's contribution to the eating population is more than outbalanced by the residents' travelling and time spent away for personal or professional reasons, which results in a lower number of permanent eaters (PEEQs) calculated from the residents. In fact, when calculated as an eating population, residents in Paris Petite Couronne account for 6.0 million PEEQs, that is, 88% of the residents' legal population. For Île-de-France, they account for 10.8 million PEEQs, that is, 90% of the legal population. The fact that residents in Paris Petite Couronne represent a smaller eating population than those from Île-de-France can be explained by commuters. Amongst Paris Petite Couronne residents, the total number of commuters is higher, and many commute within the Grande Couronne of Île-de-France. I considered that they travel frequently. Amongst Île-de-France residents, in contrast, there are fewer commuters and I considered that they commute less frequently (see 3.1.3 for data sources and assumptions).

[116] Detailed quantitative results can be found in the Appendix to Chapter 3.

Table 11. Legal and eating population, Paris Petite Couronne and Île-de-France, in thousands, 2014

	Paris Petite Couronne			Île-de-France		
	Legal population (number of inhabitants)	Eating pop. (number of PEEQs [1]) and share of eating population (in %)	Variation PEEQs to legal population in %	Legal population (number of inhabitants)	Eating pop. (number of PEEQs [1]) and share of eating population (in %)	Variation PEEQs to legal population in %
Resident population	*6,754*	*5,978 (91)*	*88*	*12,028*	*10,845 (96)*	*90*
living in a household	6,624	5,853 *(89)*	88	11,792	10,619 (94)	90
0-9 y	860	767	89	1,624	1,449	89
10-19 y	762	680	89	1,477	1,318	89
20 y and older	5,002	4,462	89	8,806	7,855	89
Commuters from PPC to GC [2]	191	53	28			
Commuters to outside of Île-de-France [2]	98	4	4	78	3	4
living outside of a household	130	125 (2)	96	235	227 (2)	96
Additional population		*573 (9)*			*493 (4)*	
Tourists [1]						
-18 y +	121,860	334		153,720	421	
-0-17 y	13,540	37		17,080	47	
Commuters from Grande Couronne	643	177	28			
Commuters from outside of Île-de-France	408	16	4	364	14	4
Excursionists [1]	6,646	9		8,383	11	
Total population		***6,550 (100)***			***11,339 (101)***	

source: INSEE, 2014, author's calculations; total percentages may not add up due to rounding.

Total food and drink intake of the eating population amounts to 6,730 kt and 11,583 kt respectively for Paris Petite Couronne and Île-de-France in 2014, as Table 12 shows. In line with the results for the eating population, residents have a predominant share in the total food intake, with 91 and 96% respectively for Paris Petite Couronne and Île-de-France. Conversely, the additional population accounts for respectively 9% and 4% of total food and drink intake.

Table 12. Food intake for Île-de-France and Paris Petite Couronne, 2014

	Paris Petite Couronne	**Île-de-France**
	Food and drink intake (kt) and share of total intake (in %)	Food and drink intake (kt) and share of total intake (in %)
Resident population	*6,134 (91)*	*11,074 (96)*
Living in a household	6,002 (89)	10,835 (94)
0-9 y	474	894
10-19 y	567	1,099
20 y and older	5,025	8,845
Commuters from PPC to GC [2]	59	
Commuters to outside of *Île-de-France* [2]	4	3
Living outside a household	134 (2)	239 (2)
Additional population	*597 (9)*	*509 (4)*
Tourists	382	482
Commuters from Grande Couronne	189	
Commuters from outside of Île-de-France	17	15
Excursionists	10	12
Eating population	***6,730 (100)***	***11,583 (100)***

Source: author's calculations

A few urban metabolism studies have referred to the need to consider the eating and not the legal population [117], but have not specifically calculated it. The underlying assumption made for

[117] Studies often refer to the resident population. Population data are usually given for the legal population which include the municipal population (people having their usual residence in the administrative unit, prisoners and

the cities in these studies is that the eating population, and hence total food consumption, is considerably bigger, because of the additional population of visitors and commuters (Barles, 2009; Niza et al., 2009). The difference can have an impact on the results. When the eating population is bigger than the legal population, per capita food flows are smaller when related to the eating population than to the legal population. But few studies explicitly report additional population, and not all cities attract additional population alike. In Boyer et al. (2019), in a study of nine Indian cities, visitors' food use accounted for less than 1% compared to residents' food use (Boyer et al., 2019).

The results of this study showed a different picture compared to the literature for both the eating population and the contribution of visitors and other additional populations to total food use. The eating population was equal or smaller than the legal population, depending on the urban system studied. Despite Paris Île-de-France's appeal as tourism and business location, I found a counter effect related to the legal population, due to time spent, hence meals eaten, elsewhere for personal or professional motives, such as holidays or business trips. The food and drink intake of the eating population is 3% and 6% smaller than that of the legal population in Paris Petite Couronne and in Île-de-France respectively.

This parameter in the calculation of the eating population is very important yet seems to be ignored often. As explained in Section 3.1.3, the average time spent outside of the urban system is calculated by multiplying the average number of overnight stays per trip with the average number of trips per person and per year known for Île-de-France residents (IAU île-de-France, 2014). If I assumed a +/- 10% uncertainty of the average time spent away considered in this study, which is 39 days, I would obtain a range of 35 to 43 days spent outside of the urban system under study.

Assuming the lower and the higher value of the range of average time spent in the calculation of the eating population and the related total food intake, I found that total food intake changes by only +/- 1% (Table 13).

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homeless people) and the population counted apart, for example students who stay in the administrative unit for education (INSEE, https://www.insee.fr/en/metadonnees/definition/c1999).

Table 13. Simulation of time spent away, eating population and total food intake, Paris Petite Couronne and Île-de-France, 2014

	Paris Petite Couronne			*Île-de-France*		
	Eating pop (in thousand PEEQs)	Food intake (in kt)	Variation food intake to benchmark	Eating pop (in thousand PEEQs)	Food intake (in kt)	Variation food intake to benchmark
Benchmark	6,550	6,735	-	11,339	11,588	-
Simul low time spent away	6,768	6,809	+1%	11,491	11,720	+1%
Simul high time spent away	6,624	6,661	-1%	11,232	11,456	-1%

Simul Low time = 35,46 days away, therefore 330 days present
Simul High time = 43,34 days away, therefore 322 days present

Another limitation in this approach to the eating population is the fact that I used the same value of average time spent for both the Paris Petite Couronne and Île-de-France populations (see 3.1.3), although it was obtained in a study about Île-de-France. One would expect that the population of Paris Petite Couronne spends more time on traveling, motivated by the higher population density in this area (smaller housing surface, fewer gardens) and, for the majority of this population, by the highest average income[118] in France.

3.2.2. The complete food flow balance

The results are summarized in Table 14 and in Figure 19 and Figure 20. The urban system of Paris Petite Couronne and Île-de-France had a very different throughput of food and drink. Food input to Paris Petite Couronne was 11,197 kilotonnes in 2014, for an eating population of 6.6 million PEEQs, that is, 1.7 tonnes of food per PEEQ. Île-de-France has a three times higher throughput with an input of 34,933 kilotonnes, in 2014, and an eating population of 11.3 million PEEQs, that is, 3.1 tonnes per PEEQ.

Only a part of the food and drink input is directed to the consumption of the eating population and ends up eaten. In Paris Petite Couronne, food intake of 6,730 kt made up the predominant share (60%) of food input, that is 1 tonne per PEEQ, for the year 2014. The situation was

[118] In a national ranking of average taxable income per household, three of the four *départements* of Paris Petite Couronne (Paris, Hauts-de-Seine and Val de Marne) are ranked 1st, 2nd and 6th, while the fourth department, Seine-Saint-Denis, is ranked 92nd. The four *départements* of the Grande Couronne are ranked 3rd (Yvelines), 5th Essonne, 10th (Seine-et-Marne) and 11th (Val d'Oise). (http://www.journaldunet.com/business/salaire/classement/departements/revenus?page=2)

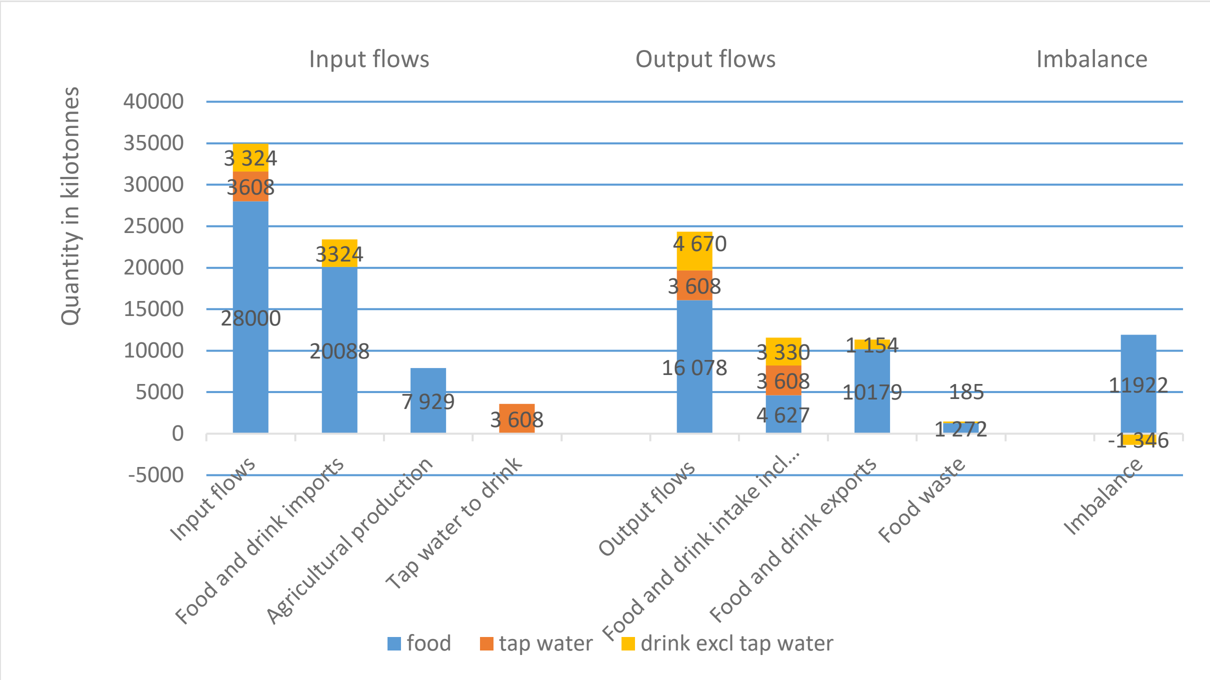
different in Île-de-France, where the estimated food intake of 11,583 kilotonnes represented a third of the food input. Another third, 11,333 kilotonnes of food and drink, consisted of exports that either transit the urban system or stem from food processing within the urban system. The remaining third, that is, 10,577 kilotonnes, was missing in the food material balance, revealed by the imbalance between the food input and food output flows of the urban system. By contrast, the Paris Petite Couronne food metabolism was almost (to 3%) balanced, with -341 kt related to 11,197 kt of food input. The contrasting results between the two urban systems suggest that there might be activities in Île-de-France generating significant material flows that were not covered by the output flows of the model and that therefore stayed within the urban system. Obviously, they neither appeared in the export flow, which implies that they were no longer classified as food, nor were they covered by the other output flows of food waste. They may be dissipative flows to nature or other water or material emissions, possibly including food waste.

Table 14. Compilation of food flow results for the urban system, Paris Petite Couronne and Ile-de-France, 2014

	Paris Petite Couronne	**Île-de-France**
	Quantities (kt)	Quantities (kt)
INPUT FLOWS		
Food and drink imports	9,057	23,412
Agricultural production	29	7,929
- edible parts from meat livestock - inedible parts from meat livestock - crops, dairy and eggs	-- -- 29	8 5 7,915
Tap water to drink	2,111	3,609
Cereals used as animal feed in the urban system	--	-17
Total input flows	**11,197**	**34,933**
OUTPUT FLOWS		
Food and drink intake incl. tap water	6,730	11,583
Food and drink exports	4,089	11,333
Food waste	718	1,457
- food loss in agriculture - food waste in mixed household waste (OMr) - food waste in mixed business waste - food waste to the sewer - separately collected bio-waste - used frying oil	1 402* 153 104 36 23	161 792 235 185 55 28
Cereals used as animal feed in the urban system	**--**	-17
Total output flows	**11,538**	**24,357**
INPUT-OUTPUT	**-341**	**10 577**

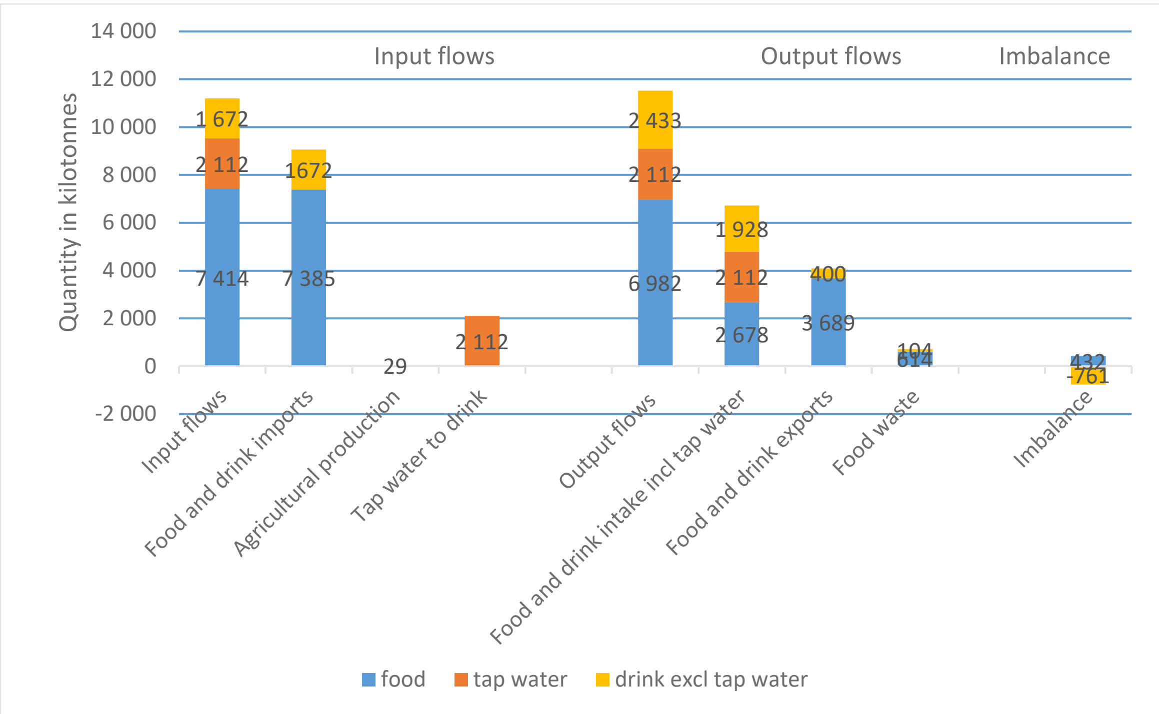
Source: refer to the text

Figure 19. Main food input and output flows, food and tap water and other drink, Île-de-France, 2014, in kilotons



Source: author's calculation from sources in the text

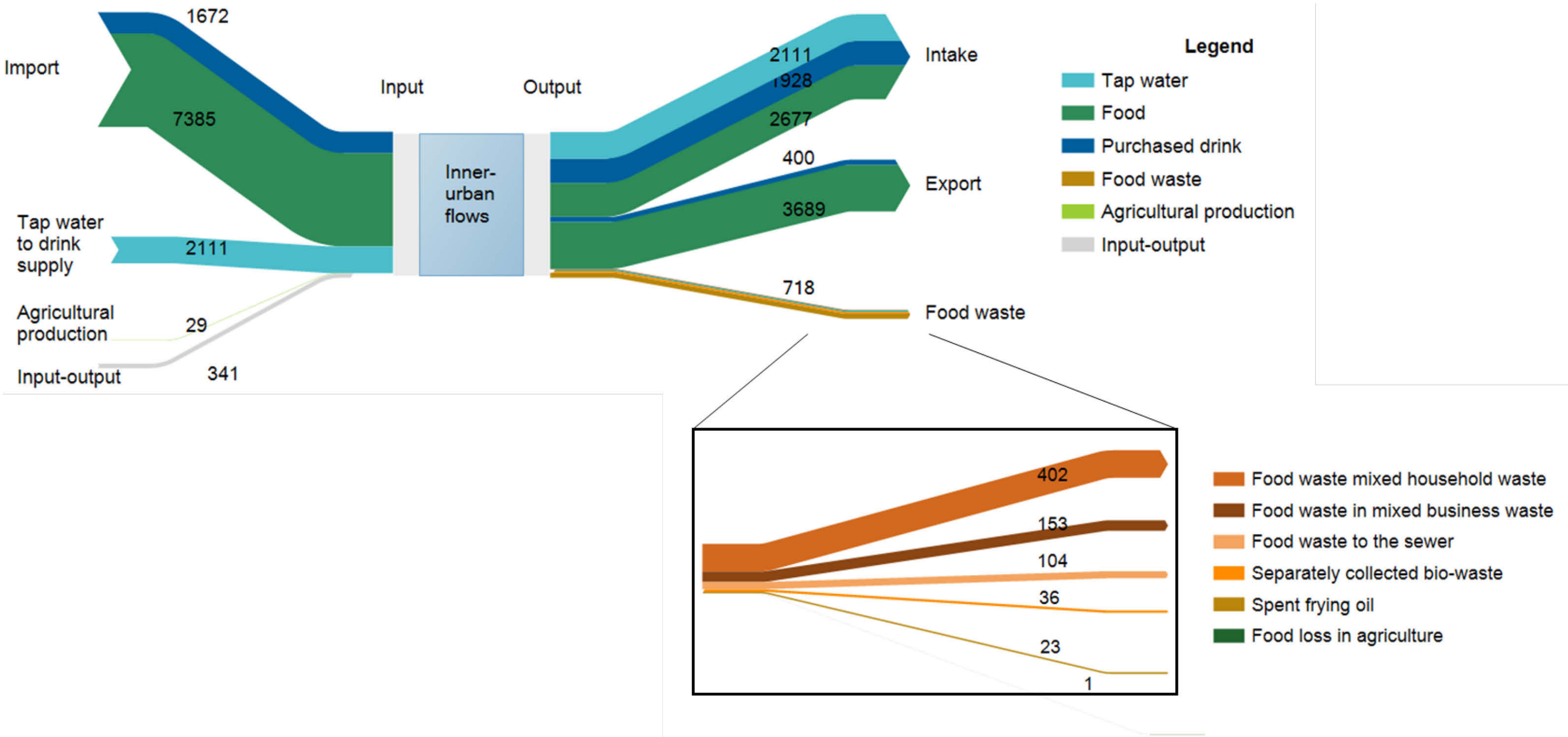
Figure 20. Main food input and output flows, food and tap water and other drink, Paris Petite Couronne, 2014, in kilotons



Source: author's calculation from sources in the text

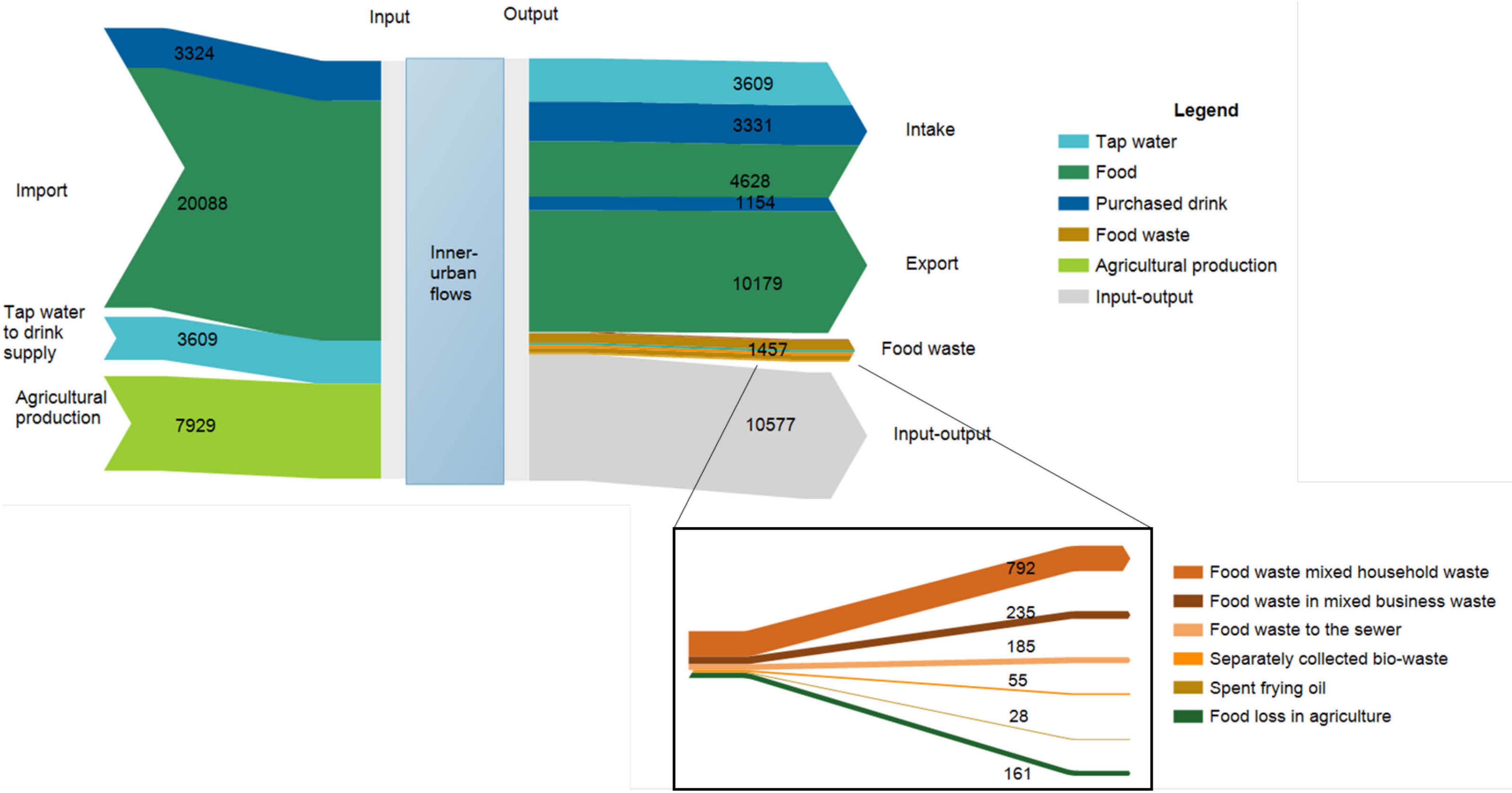
Figure 21 and Figure 22 present a visual representation of the urban food and drink flows for Paris Petite Couronne and Île-de-France, respectively.

Figure 21. Urban food and drink flows, Paris Petite Couronne, 2014, in kilotons



Source: author's calculations, see Table 14

Figure 22. Urban food and drink flows, Île-de-France, 2014, in kilotons

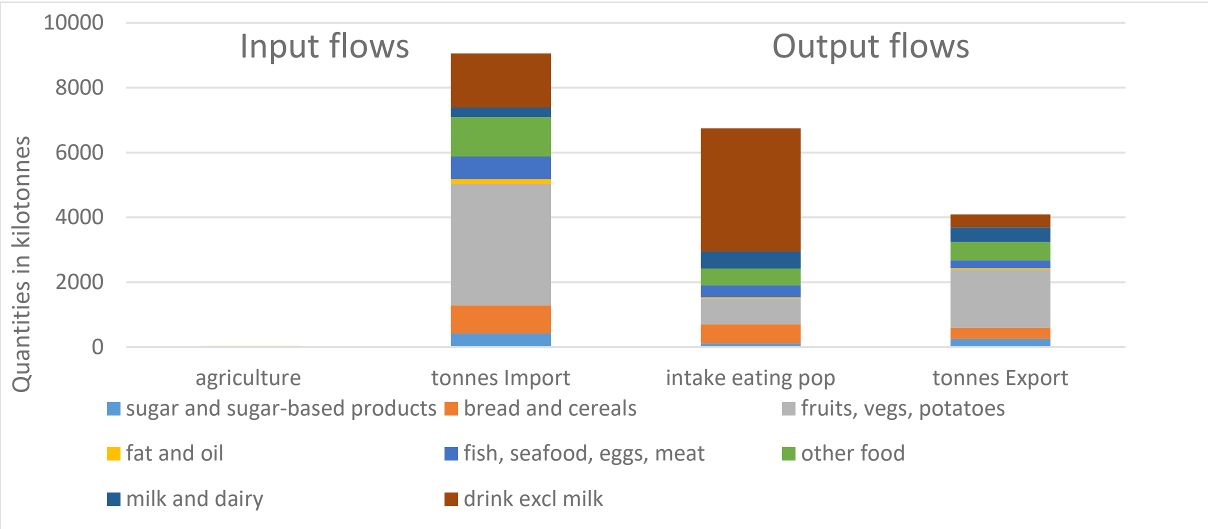


Source: author's calculations, see Table 14

As Figure 23 and Figure 24 show, drink in general contributes significantly to the food metabolism of urban systems. Depending on the type of food flow, its contribution varies. In total food and drink intake of the eating population, drink represented 60% and tap water to drink alone 31%. Because tap water has a dedicated distribution system, imports contain only other drink, excluding tap water. The share of other drink in food and drink imports was 18% and 17% for Paris Petite Couronne and Île-de-France, respectively. Not all drink is directed to the eating population. Exported drink made up 10% of total food and drink exports from both urban systems.

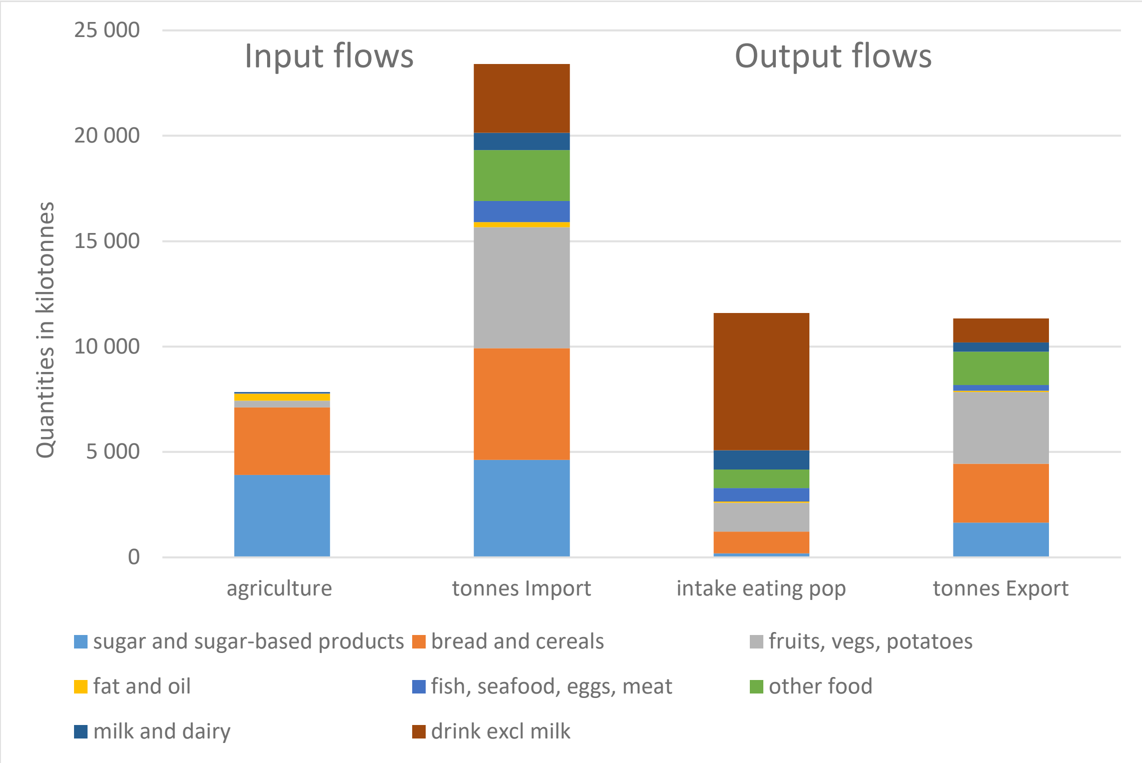
Along with drink, the main food categories in the urban food metabolism were bread and cereals, and fruits, vegetables and potatoes, followed by the other categories in variable size. Milk and dairy, fish, seafood, eggs and meat, and fat and oil were quantitatively less important in all the sectors. Sugar and sugar-based products had a particular situation in the case of Île-de-France (Figure 24), as they contributed little to food intake and to agricultural production or to import and to export flows.

Figure 23. Food and drink category structure of main input and output flows, Paris Petite Couronne, 2014, in kilotons



Source: author's calculation from sources in the text

Figure 24. Food and drink category structure of main input and output flows, Île-de-France, 2014, in kilotons



Source: author's calculation from sources in the text; cereal used for livestock (17 kt) is included in the category bread and cereal

The comparison of the food and drink category structure of the main input and output flows reveals the categories with the biggest imbalance. They contributed most to the food material imbalance shown in Figure 25 and Figure 26. This comparison does not include food waste, as information about the contributing food and drink categories was not available. Information about food categories was available, however, for agricultural production, imports including tap water to drink, food and drink intake, and exports, and could be analysed thanks to the transversal nomenclature developed in this study. Cereal fed to livestock is included as it could not be attributed to either production or imports.

Figure 25. Food and drink category structure of input, output and imbalance, Paris Petite Couronne, 2014, in kilotons

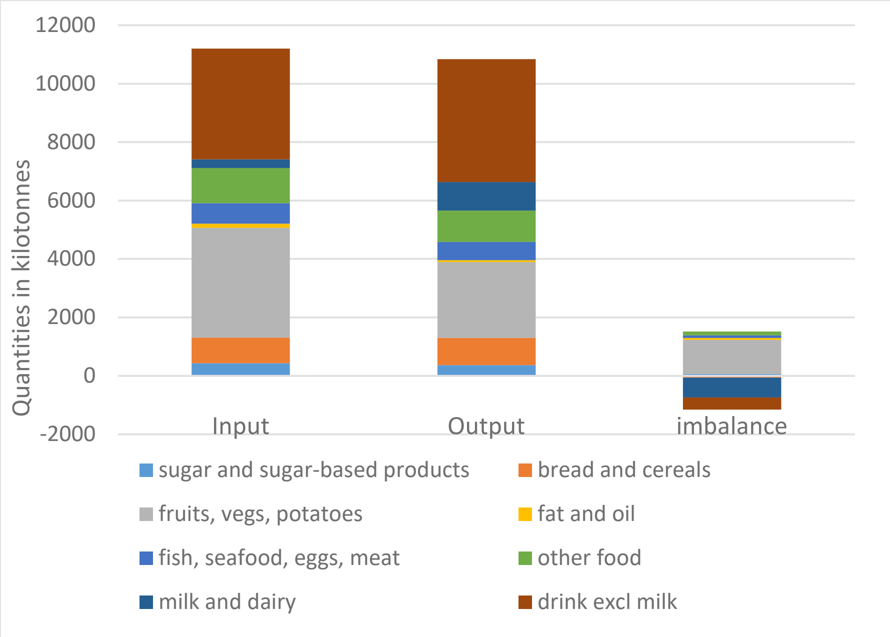


Figure 26. Food and drink category structure of input, output and imbalance, Île-de-France, 2014, in kilotons

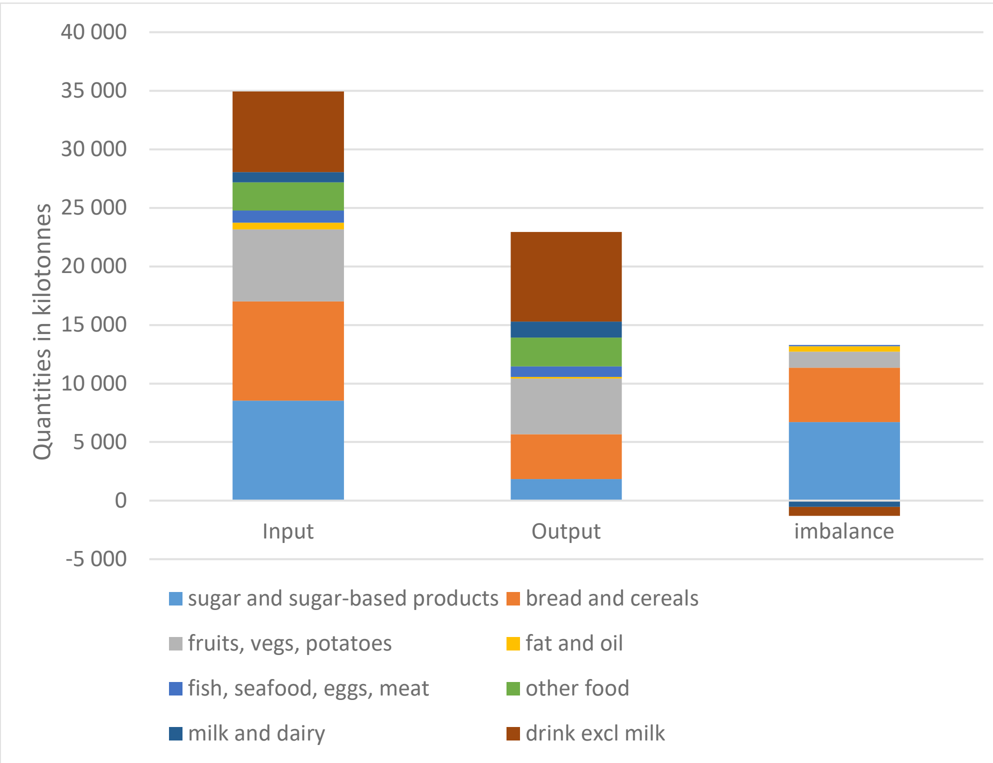


Table 15 shows the main categories according to unbalanced input and output flows. Sugar and sugar-based products, bread and cereals, and fruits, vegetables and potatoes were the three categories that contributed most to the material balance of Île-de-France. Unlike the flow scheme for total food and drink, part of the imbalance can be explained by food waste which cannot be distinguished per food category and linked to the output flow in this representation. The difference between input and output for the three categories made up 78%, 55% and 22% of the input flow respectively, suggesting that a major part of the input flow was not covered by output flows in the category. Several explanations are possible for this situation. Data from a product category can: i) change the product category in transport statistics (see 3.3.2 for limits of data sources) and create an imbalance in the category; ii) be exported in a different product category that is not covered by the quantification method of this study, for example as waste or mixed material (see 3.3.2 for limits of data sources); and iii) become output to nature (dissipative flows), in the sense of the EUROSTAT method, not covered in this quantification method (e.g. evaporated water).

For sugar and sugar-based products, the imbalance likely occurred from processing raw sugar beet. Processing of water-rich sugar beet to refined sugar[119] entails substantial water removal in the course of the refining and drying processes, which presumably largely explains the input output imbalance of 6,694 kt in this category. Because of its bulky nature and high water content, sugar beet cultivated in Île-de-France (3,916 kt), together with raw sugar beet imported mainly from neighbouring *départements*[120] (3,518 kt), is probably processed close by. The water is thus released into nature and appears as part of the imbalance in this study[121]. In addition, sugar beet pulp and other processing residues can further reinforce the imbalance. Pulp is considered a by-product and is often used in animal feed. In transport statistics, it shares a category together with other industry products (category 4.88, see nomenclature in Table A3.1 of the Appendix). Altogether, exports in this category were reported to amount to no more than 9 kt, which seems a negligible contribution given the size of the input-output imbalance for sugar and sugar beet products (6,694 KT). It is unclear from the data sources where the remaining by-products end up. There is no indication of their use within the urban system since

[119] The water in sugar beet with moisture content of 80-85% on average is removed during processing. The final product, crystal sugar, is 99.9% pure sucrose. Various sugar beet by-products in moist or dry form, such as pulp, are generated during processing. One tonne of raw sugar beet yields 160 kg of refined sugar and 200 kg of pressed pulp (dry matter 28%) http://www.mairie-chevrieres.fr/wp-content/uploads/pulpe-surpressee-fr.pdf

[120] Nevertheless, 841 kt of raw sugar beet is exported from Ile-de-France, according to the transport statistics from Sitram.

[121] Water would normally be outbalanced by balancing items according to the EUROSTAT method.

the number of livestock there is small. Their export and use outside of the urban system seem likely. It seems that part of their export is reported elsewhere in the transport statistics than in the Divisions 01 and 04 which cover food and agricultural products (see 3.1.1 for data source)[122]. For cereals, a change in the water content does not seem to play a role. Cereals, in contrast to sugar beet, naturally have a much lower moisture level at harvest [123] and do not undergo substantial drying processes. The input-output imbalance could rather be explained by a change in the product category not covered by the quantification method. Common wheat as the predominant species in this category[124], further called wheat, generates bran and other by-products during milling, amounting to roughly 20% per mass unit (Juin, 2015). Given a total wheat availability in Île-de-France of 4,506 kt (2,590 kt imported and 1,916 kt produced locally), as a rough estimate based on transport and agricultural statistics data for 2012, and exports of 1,429 kt, the remaining 3,077 kt of wheat should undergo processing in the urban system, and then be used or exported in processed form. Milling 3,077 kt of wheat roughly yields 2,462 kt of flour and 615 kt of bran, considered a by-product. Yet transport statistics report only 125 kt of exported bran in a dedicated category[125]. Again, as for sugar beet, it is unclear where bran, frequently used as animal feed, ends up. Either it is exported but not reported in transport statistics, or it is processed and then consumed or exported as processed goods. However, only one company in Île-de-France is registered as an animal feed manufacturer in the official data base for companies in France, SIRENE. We conclude from the example of wheat that there is either misreporting in the statistics, or some transports are not covered by the survey. It would be interesting to draw up a detailed material flow analysis of the common wheat supply chain for Île-de-France, inspired by the work of Courtonne (2016) on the cereal supply chain in France. This would further our understanding of the material impact of important processing steps (milling, and bread and biscuit baking in particular) and reveal trade with other regions.

Some product categories had negative values, such as milk, dairy, and drink, and to a lesser extent bread and cereals in Paris Petite Couronne, and other food in Île-de-France. The negative

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[122] Division 01 "Products of agriculture, hunting, and forestry; fish and other fishing products" and Division 04 "Food products, beverages and tobacco".

[123] The moisture level of mature crops naturally varies in a range of 10 – 20%, depending on the weather conditions. For wheat, the French technical institute Arvalis recommends harvesting cereals and oil crops at a moisture level not exceeding 16%, if possible. Otherwise, the consequence is storage problems. https://www.arvalis-infos.fr/profiter-du-retour-des-temperatures-estivales-pour-recolter-du-grain-a-la-bonne-teneur-en-eau-@/view-10812-arvarticle.html

[124] Wheat, like most other cereals, is consumed in processed form. Wheat is mostly used for bakery products (bread and biscuits).

[125] *son,* category 4.68 in the transport statistics nomenclature NST 2007.

values in these three categories, except for unspecified other food, suggest that input flows were missing, such as water[126]. For bread, water is necessary in baking and increases the weight of wheat grains by a factor of 1.2[127]. The dairy industry uses water to reconstitute milk powder. Likewise, the imbalance in the beverage industry can only reasonably be explained by missing water input. Other issues with input flows can be related to nomenclature in transport statistics (see 3.3.2 for limits of data sources).

Table 15. Food material imbalance per food category, Paris Petite Couronne, Île-de-France, 2014, in kilotons

Food and drink categories	Paris Petite Couronne	Île-de-France
sugar and sugar-based products	62	6,694
bread and cereals	-58	4,664
fruits, vegs, potatoes	1,167	1,375
fat and oil	75	458
fish, seafood, eggs, meat	79	115
other foods	138	-40
milk and dairy	-683	-498
drink (excl. milk)	-416	-770

Agricultural production, located in the urban system, played a significant role only in the case of Île-de-France, where it made up 23% of the food input with 7,929 kt produced, but contributed less than 1%, and 29 kt, in Paris Petite Couronne. The category of sugar and sugar-based products accounted for about half of Île-de-France agricultural production, in terms of quantities, and more than 40% of the 29 kt produced in Paris Petite Couronne in 2014. However, the pathways of the agricultural products between input and output are not known. It remains unclear to what extent production, located in the urban system, contributed to the urban food consumption, and conversely, to what extent it was exported, either as raw material or processed. My investigations showed that livestock in Île-de-France are not necessarily fed with locally produced cereal (see 3.1.2). Compound feed produced elsewhere constitute a large proportion of livestock diets. Not being able to attribute the estimated grain cereals fed to local livestock (17 kt) to neither local production or imports, I reduced the aggregated input and output flows accordingly. We know as little about the destination of agricultural production as

[126] Tap water to drink was accounted for in this study, but not other uses of tap water, such as for food preparation or processing in households or business activity.
[127] 100 kg bread is equivalent to 83 kg grain, which corresponds to a conversion factor of 1.2: http://www.boulangerie.net/forums/bnweb/dt/mp/InfoBlefar.php

we know about the origin – import or urban system production – of products used in processing activities in the urban system.

Food waste amounts to 718 kt and 1,457 kt for Paris Petite Couronne and Île-de-France respectively (Table 14). It accounted for 10% and 11% of the food and drink supply of the eating population and 6% and 4% of the total food and drink input to the urban system, for Paris Petite Couronne and Île-de-France, respectively. A small contribution to the total food waste, that is 104 kt and 185 kt in both urban systems, is estimated to be drink or semi-liquid food (sauces, yoghourt etc.) that households dispose of through the sewage system. However, no data exist on liquid food waste from businesses, for example from the dairy industry or from producers of juices or soup. Since the major part of the food waste estimate is food in solid form, food waste from food alone makes up 8% and 4% of all food input in Paris Petite Couronne and Île-de-France. While the data for mixed household waste enjoy regularly updated surveys from the regional waste agency ORDIF, uncertainty lies in its share of all food waste. Waste composition analysis, the method used to identify the share, has not been tested much for the identification of food waste and does not benefit from a large benchmark. While I consider the given share of 22% and of 66 kg/cap/y food waste in mixed household waste for Île-de-France a reliable estimate, there is uncertainty in the case of Paris Petite Couronne. The share of 17% or 19% food waste in OMR, or normalized collection of 61 or 68 kg/cap/y, valid for Paris according to the municipality report (Mairie de Paris, 2016) is in line with the Île-de-France normalized values [128], yet it seems underestimated. Given the concentration of the commercial food service sector in Paris, with 19,279 or 62% of all restaurants, cafés et cetera in Île-de-France in 2018 [129], and of the food distribution, with 7,214 shops in Paris versus 6,409 shops in the three neighbouring *départements* (APUR, 2015), we would expect a higher contribution of food waste. Many of the restaurants, cafés, and shops use the public service waste collection. Their food waste is expected to contribute, in terms of mass, to mixed household waste and to lead to higher normalized food waste generation, at least higher than the normalized 66 kg/cap/y for Île-de-France, than I have calculated for the current situation.

My research on food waste generated in other sectors likewise suffered from a scarcity of data. For business waste, in particular, the estimate of 235 kt available in the regional waste prevention and management plan (Conseil Régional Ile-de-France, 2019) would need to be

[128] It furthermore seems that this data is underestimated due to undeclared street food units such as food trucks which rapidly increased in number in the past years (François Mauvais, DRIAAF, by email, 16 December 2019).
[129] François Mauvais, DRIAAF, by email, 16 December 2019.

confirmed through a dedicated survey, similar to the ORDIF household waste collection survey. Although it was estimated as the complementary part to business waste collected by the public sector, included in the 792 kt mixed household waste (see 3.1.4), the business waste collected by the private sector seems to be underestimated. Although I do not have the household/business ratio in mixed household waste, and am therefore unable to extract total business waste, the two taken together (including 28 kt of used frying oil) would roughly mean 1,055 kt or 88 kg/cap/y of food waste, which seems little compared to the amounts reported in the food waste literature (see 3.3.3).

As for food waste collected separately as bio-waste, 55 and 36 kilotons are treated within the urban system, organically converted through either anaerobic digestion or composting, for Paris Petite Couronne and Île-de-France, respectively[130]. Anaerobic digestion infrastructure of bio-waste classified as animal by-product category 3, which covers the portion most difficult to treat, was limited, in 2014, to an annual capacity of about 40 kt per year. It was authorized for one single unit (Etampes in the *département* of Essone (91), by the company Bionerval)[131]. The remaining quantity of bio-waste, roughly 13 kt, was composted. Another flow accounted for as food waste is used frying oil, of which 28 and 23 kilotons were collected and recycled as fuel, in both urban systems, respectively.

3.3. Discussion

The results of the food metabolism, obtained with a material balance approach in this chapter, are discussed in Chapter 5 together with the results of the inner-urban metabolism, described in Chapter 4.

In order to discuss the implications of the method and data, and to make the results comparable with other studies, I normalized food flows using legal population since that is the only standardized measure provided by national censuses. There is indeed no capture of the eating population in the statistics of any administrative unit, which is why the eating population cannot

[130] Additionnally, 21 kt of bio-waste collected in Île-de-France and treated elsewhere were estimated for 2014 (32 kt in 2016). The estimate became available for this research at a later stage.

[131] The situation has changed since 2014. Limited capacity of facilities authorized to handle bio-waste classified as animal product category 3 is still a problem and explains the relative stagnation of anaerobic digestion (approximatively 42 kt) and of composting (13 kt) of this waste until 2018 in Île-de-France. But less than half of the collected waste classified with and without animal by-products C3, on a rising trend (106 kt), was shipped and treated elsewhere, that is 49 kt in 2018. For bio-waste without animal by-products C3, increasing capacity for on-farm anaerobic digestion became available and attracted 55 kt of which 20 kt were beetroot and another close to 10 kt potato waste (Institut Paris Region ORDIF, 2019).

be used for normalization. In this study, however, this is not limiting since the difference is small between the normalized results when legal and eating population data are used, due to the fact that for Paris Petite Couronne and even more so Île-de-France, legal and eating population are close in size (see 3.2.1). The normalized results are expressed in tonnes per capita per year (Table 16).

Table 16. Food flows, Paris Petite Couronne, Île-de-France, 2014, in kt and t/cap/y

	Paris Petite Couronne			Île-de-France		
	total quantity	quantity normalized using		total quantity	quantity normalized using	
		legal population [1]	eating population [2]		legal population [3]	eating population [4]
	kt	t/cap/y	t/cap/y	kt	t/cap/y	t/cap/y
Input flows	11,197	1.7	1.7	34,933	2.9	3.1
Import	9,057	1.3	1.4	23,412	1.9	2.1
Agricultural production	29	0.0	0.0	7,929	0.7	0.7
Tap water to drink	2,111	0.3	0.3	3,609	0.3	0.3
Output flows	11,538	1.7	1.7	24,357	2.0	2.1
Food intake	6,730	1.0	1.0	11,583	1.0	1.0
Export	4,089	0.6	0.6	11,333	0.9	1.0
Food waste	718	0.1	0.1	1,457	0.1	0.1
input - output	-341	0	0	10,577	0.9	0.9

[1] 6,754,282 inhabitants; [2] 6,699,952 PEEQs; [3] 12,027,565 inhabitants; [4] 11,355,272 PEEQs

Cereal feed for livestock not shown.

3.3.1. Adjustments to EUROSTAT Economy-wide material flow accounts

The food system-oriented quantification approach used in this study was adjusted in several points to the EUROSTAT Economy-wide MFA method (see method Chapter 2). These adjustments made to both the material selection and the material balance indicators, are not insignificant when it comes to the results of the food metabolism. They affect the results in a positive or negative way. Positive change means that urban food consumption increases with the adjustment, and vice versa. Table 17 summarizes the adjustments, compared to the EUROSTAT method, and shows their impact (positive, negative, or none) on urban food consumption and on general input and output flows, respectively. The four main adjustments are: i) focus on food not biomass; ii) consideration of livestock products as part of the urban system's agricultural production; iii) inclusion of tap water to drink; and iv) use of intake data as a direct way to calculate urban food consumption.

Table 17. Impact of adjustments to the food flow quantification method on urban food consumption

	Direction of change of results		Comment	EUROSTAT method (2001)
	Urban food consumption	Input / output flows		
Material category				
Food not biomass	-	-	Focus on food, as part of biomass, reduces the flow	Biomass includes products from agriculture, fisheries and forestry, for food and non-food use
Tap water to drink	+	+	Tap water when used to drink is considered as part of food and drink intake (average of 30% of total intake amongst the French population)	Direct material input excludes water (except for water content of products); water flows are handled separately from material flows as they are one order of magnitude bigger in size
Indicator				
Agricultural production of food from livestock and crops	+	+	Livestock products from the urban system are part of agricultural production	Livestock products from the urban system are the result of the transformation of biomass by the economy.
Intake for consumption	-	n.a.	Food and drink intake data used for the calculation of urban food demand. Food waste is not part of urban food demand and is considered in a separate output flow; industry food use is not covered	As a proxy for food consumption, domestic material consumption (DMC) = Domestic extraction (used) plus Imports minus Exports; covers food use for in-home and out-of-home consumption and for the industry; A corrected indicator, DMCcorr, suggested by Barles (2009), subtracts exported waste from exports and imported waste.

In my research, I focus on food as part of biomass, and not on biomass as a whole, as in the EUROSTAT method. Biomass includes products from agriculture, forestry and fisheries which have food and non-food uses. Focusing on food as part of biomass automatically reduces the quantity of the flow.

Contrary to the EUROSTAT method and to other studies which carry out distinct material flow analysis for water, I include tap water used for drink (hot and cold). Tap water used for food preparation such as cooking pasta or rice and rinsing fruits and vegetables for example is not considered. Addition of tap water to food and drink increases urban food consumption and appears as additional and distinct input flows[132].

Another difference lies in the direct way in which I estimated urban food consumption. I estimate the total food and drink intake of the eating population based on nutritional data. Food waste is estimated as a separate output flow, and not part of export in the sense of the traditional EUROSTAT method, nor included in the corrected domestic material consumption, following Barles (2009). Urban food consumption in my method therefore appears to be less than the domestic material consumption in the EUROSTAT method.

Sensitivity analysis

I tested how sensitive my food flow results are to the method adjustments described earlier. If urban food consumption was calculated as domestic material consumption[133] of food quantities obtained from inputs minus exports, according to the EUROSTAT method, it would double in size to amount to 23,599 kt and 2.0 t/cap/y for Île-de-France, compared to 11,580 kt and 1.0 t/cap/y when calculated as food intake. The heavy impact of the method, for Île-de-France, can be explained by the large input-output imbalance, equivalent to 0.9 t/cap/y, which is included in the DMC indicator according to the EUROSTAT approach. For Paris Petite Couronne, urban food consumption would increase by 10% to 7,108 kt and 1.1 t/cap/y, compared to 6,733 kt and 1.0 t/cap/year when calculated as intake. The increase is predominantly due to food waste (718 kt or 0.1 t/cap/y) as the input–output imbalance is small (342 kt or 0.1 t/cap/y) in the Paris Petite Couronne material balance.

[132] I did not include tap water to drink in food waste, first because I have no information about it (how much tap water does a person take with the intention to drink it, but then pours some of it into the sewer in the end?), and second because I would not be able to seriously argue why I considered this food waste (additionally to the daily 500 g tap water for hot and cold drink, Anses 2017) while the bulk of tap water use per person in a household (150 l per day), which I do not consider, is higher by a factor of 300.

[133] Export in my approach does not include food waste nor other residues no longer acknowledged as food. Therefore, food waste does not leave the system through export and remains associated with urban food consumption. Technically this means that the calculation of DMC is equivalent to DMC_{corr}, according to Barles (2009).

If, according to the EUROSTAT method, biomass instead of food was considered for the food material balance, and urban food consumption was calculated according to the concept of DMC, there would be a slight increase. Urban food consumption would increase by 5% to 24,832 kt or 2.1 t/cap/y in Île-de-France and by 3% to 7,314 kt or 1.1 t/cap/y in Paris Petite Couronne, the (see Table A3.9 in the Appendix to Chapter 3). The fact that livestock products, in the EUROSTAT method, are not considered as products from agricultural production, but as a result of the urban system economy, changes little in the balance. There is zero livestock reported in Paris Petite Couronne, and only 74 kt in Île-de-France, compared to 7,855 kt of plant biomass, including fodder and wood.

While the indirect approach to estimating urban food consumption blurs the result for Île-de-France by doubling its size, its effect remains invisible in the case of Paris Petite Couronne. In this case, Paris Petite Couronne, the approach to estimating urban food consumption, either from intake or as domestic material consumption, makes no difference to the result. However, I conclude from the sensitivity analysis that it seems to play a role, whether there is food or biomass processing activity in the urban system or not. Processing tends to generate material that is hard to identify as part of the food material balance and ends up in an input output imbalance which is considerable in the case of Île-de-France (0.9 t/cap/y), where it almost equals the food and drink intake (1.0 t/cap/y) and exports (0.9 t/cap/y). This is consistent with results from a sensitivity analysis (Table 18) to test whether and how the material balance results change when biomass, where sugar beet residues would normally be included, is used instead of food. The simulation results in Table 18 show only a slight increase in both the export flow and the input-output imbalance, suggesting that there are other categories of material involved in the imbalance, such as water or material in a waste category. On the other hand, in an urban system with little processing activity, such as Paris Petite Couronne, it is not significant whether a wide range of biomass or only food is considered, since related flows are also small. There appears to be a structural difference in the metabolism profile of Île-de-France compared to Paris Petite Couronne, evident in the size of the input-output imbalance.

As regards the composition of food and drink, tap water to drink contributes 0.3 t/cap/y to the 1.0 t/cap/y of urban food consumption in the urban system of both Île-de-France and Paris Petite Couronne. I can easily perform the food flow quantification without tap water to drink (reduction by 0.3 t/cap/y) and obtain 1.4, 1.4 and 0.7 kg/cap/y input, output, and food intake, respectively, for Paris Petite Couronne, and 2.6, 1.7 and 0.7 kg/cap/y for Île-de-France. Other food flows are not affected, since I consider food waste from tap water to drink as zero and do not consider exports of tap water to drink outside of Île-de-France.

The method adjustments also had impacts on the input flows and on other output flows of the food material balance. Had I considered biomass instead of food for input and output flows, the food material balance would show a slight increase in mass flows (Table 18)[134]. For Île-de-France, per capita biomass input would be 3.1 t/cap/y, of which 2.1 t/cap/y are imports, compared to 2.9 t/cap/y inputs of food, of which 1.9 t/cap/y are imports (Table 18). Biomass outputs would be 2.1 t/cap/y, including 1.0 t/cap/y of exports, compared to 2.0 t/cap/y of food outputs, including 0.9 t/cap/y of exports. For Paris Petite Couronne, the increase due to biomass other than food is negligible, with 0.1 t/cap/y for imports, exports and output flows, respectively, raising them to 1.4 t/cap/y, 0.7 t/cap/y and 1.8 t/cap/y, respectively. The slight increase in both the export flow and the input-output imbalance suggests that there are other categories of material involved in the imbalance, such as water or material in a waste category, that cannot be explained by a shift from food to biomass.

Table 18. Food versus biomass flows, Paris Petite Couronne and Île-de-France, in t/cap/y

	Paris Petite Couronne		Île-de-France		
	food	biomass	food	biomass	
	Our results (data 2014)	Simulation biomass	Our results (data 2014)	Simulation biomass	Barles (2009; data 2003)
Input flows	1.7	1.7	2.9	3.1	2.2
Import	1.3	1.4	1.9	2.1	1.7
Agricultural production	0	0	0.7	0.7	0.5
Tap water to drink	0.3	1.3	0.3	0.3	–
Output flows	1.7	1.8	2.0	2.1	2.2
Food consumption	1.0 [1] 1.1 [2]	1.0 [1] 1.1 [2]	1.0 [1] 2.0 [2]	1.0 [1] 2.1 [2]	0.9 [2]
Export	0.6	0.7	0.9	1.0	1.3
Food waste	0.1	0.1	0.1	0.1 [3]	–
input - output	0.1	0 [1] – [2]	0.9	1.0 [1] – [2]	–

Total amounts may not add up due to rounding off.

[134] For detailed results, see Table A3.9 in the Appendix to the chapter

[1] calculated as food intake; [2] calculated as corrected domestic material consumption (see text); [3] other biomass waste (forestry, agricultural waste etc.) not considered.

This negligible increase is plausible when we consider the high population density of Paris Petite Couronne and the few biomass processing or trading companies in its system. A contrast to this situation is the low-density Grande Couronne area of Île-de-France where industry and farms, including livestock, can explain the slight increase in per capita mass flows when we use biomass instead of food for analysis.

3.3.2. Limits and weaknesses of the data sources

The food-system centred approach used in this study does nevertheless have a few limits. They lie in the difficulty, and the consequent caveats, related to the solutions to adjust a top-down method such as the EUROSTAT Economy-wide MFA not only to an infra-national administrative unit[135], but also to a function or a need that associates specific and various material types. To quantify material flows in urban metabolism studies, access to data is a key requirement. Hereinafter, the limitations and weaknesses of the main data sources used are presented with respect to the specific method adjustments of our food-system centred MFA approach. Unfortunately, due to the large number and heterogeneity of the data used, as well as its relative reliability and exhaustiveness, it has not been possible to calculate uncertainty levels for all data sources. Uncertainty is discussed through a qualitative analysis illustrating the caution that needs to be taken in the interpretation of the food flow results.

Statistics for agricultural production of crops and livestock

The annual agricultural statistics (*statistique agricole annuelle* or *SAA*) provide information about land use and agricultural production: surface, yield, harvested quantities for crops, livestock size, average weight and total quantity produced for livestock (meat, eggs, milk and poultry). The statistics department of the regional service of the Ministry of Food and Agriculture synthesizes all the information available from various surveys, some of which are exhaustive but most of which are based on representative random sampling. Experts and other technical organizations complete and check the compilation of data. Data are collected at the level of the region and the *département.* In the case of industry crops, with the exception of

[135] In France, Barles and colleagues have validated the use of EUROSTAT Economy-wide MFA for the study of a region, a French *département* and an urban unit, thoroughly described in Barles (Barles, 2013, 2009). See method, Chapter 2.

sugar beet, fruits, vegetables, flowers (not relevant for my study) and all livestock except cattle, the data are collected for big producing regions and *départements*, and used to estimate the production of small producing ones. The method description available with the SAA specifies that for these particular products, data from responding regions fill the gap of non-responding and small producer regions. By contrast, at the *département* level, non-response leads to unavailable data for these products. In any case, data about cabbage, roots and tubers, equine and poultry livestock, eggs and honey are available only at the regional level.

In this study, for the urban system of Paris Petite Couronne, where I summed up the agricultural production of the four contributing *départements* for 2014, we cannot be sure what zero production means: no production reported or no production at all? While Paris has no agricultural land surface, the three neighbouring *départements* – Hauts-de-Seine (92), Seine-Saint-Denis (93) and Val-de-Marne (94) –, which together have close to 4,000 hectares of agricultural land surface, report crop production but no livestock, which is in line with the SAA methodology, at least for poultry and eggs. Hauts-de-Seine has no cereal, oil crop, sugar beet or potato production reported, whereas Seine-Saint-Denis (93) has no fruits (Agreste, SAA, 2014). The agricultural census (*récensement general agricole, RGA*) confirms that no farms with livestock were reported for Paris Petite Couronne in its 2007 survey (RGA 2007, Chambre d'agriculture de region Ile-de-France). While it cannot be excluded that agricultural production is under-reported for Paris Petite Couronne, given the high population density and scarce agricultural land surface, I do not expect a big underestimation in the data.

Furthermore, the SAA uses concepts that do not fit with my food-system centeed method. Field and on-farm losses are entirely omitted in the SAA, although they can be substantial in sectors such as fruits and vegetables (9% loss at production stage) (Cabinet Gressard, Interfel, FranceAgriMer, UNILET, ANICC, 2015) and potato (Jeannequin et al., 2015). By filling this gap, I have extended the concept of production to "potential production", including field and on-farm losses, and thus reflecting more accurately the agricultural sector's used and unused mass flows and its related resource use (labour, energy, seed etc.).

Production from private or community gardens and from urban agriculture projects is not included in the estimation of the urban system food production. Given the degree of population density and urbanization, their contribution is insignificant in terms of mass, compared to the total input to the urban system. Accurate data about food production from gardens is however scarce. 1,064 collective gardens on an area of 879 hectares were referenced in Île-de-France at the end of 2015 (IAU île-de-France, 2018). Most of them were shared gardens, which in France provide communal or individual plots, and family gardens, most often divided into individual plots (Pourias et al., 2015, 2014). If I retained an average productivity of 2 to 2.5 kg per cultivated square meter for the Île-de-France region[136] and considered that 70% of the total surface is cultivated for food (depending on the size and the type of the garden, part of the area may be dedicated to fixed elements and recreational areas (Pourias et al., 2014)), food production ranged between 12 and 15 kt. Food production from private gardens is not yet accounted for, and is much more difficult to estimate[137]. In the British cities of Sheffield and Leicester, for example, gardens contribute up to 3% to the urban consumption of fruits and vegetables, and there is huge potential for development, according to Edmondson and colleagues (2020b, 2020a). While the focus here lies on food production, research has shown that gardeners' motives are far from being reduced to quantitative targets of food production. At least as important for them is the wish to eat fresh high-quality food, the pleasure of growing it, and the connection to nature, or the experience of social bonds in the case of collective, shared or community forms (Pourias et al., 2015; Saint-Ges, 2018).

Food obtained through hunting or picking of wild fruit or greens is not included in the quantification of food input to the urban system either, due to a lack of data. Except for Paris, hunting is authorized in the départements of Île-de-France by the authorities (*arrêtés préfectorals*) and organized within the regional federation of hunting of Île-de-France (*Fédération Interdépartementale des Chasseurs d'Île-de-France*). Hunting is actively practised

[136] Christine Aubry, INRAE, email, 10 April 2020; Studies from Pourias et al. (2015) and Marie (2019) point above all to the heterogeneity of yields. They tend to suggest lower average yields, namely 1.2 kg/m2 (Pourias et al., 2015) observed in shared and family gardens, and 1.8 kg/m2 (Marie, 2019) observed in predominantly private gardens. Both authors suggest that the plot size plays a role for gardening practices, and consequently for yields.

[137] The research project CAP-IDF used photographs of plots taken from the air to estimate the surface area of private gardens in sub-regions of Île-de-France that have been recognized as having a vegetable garden. In Plaine de France, a natural region north of Paris, 3,690 vegetable gardens spread over an area of 42 hectares could be identified (Darly, 2019). For the population of Plaine de France (approximately 400,000 inhabitants) there is roughly one garden per 108 inhabitants. On the Plateau de Saclay, there were 1,690 vegetable gardens on 13 hectares (Darly, 2019). For the population of Plateau de Saclay (202,877 inhabitants), this means one garden per 120 inhabitants. For comparison, collective gardens must be arithmetically shared by 11,400 inhabitants per garden, in Île-de-France (IAU île-de-France, 2018). It therefore seems that there are far more private gardens, and related food production, than collective gardens, at least in the areas of the Grande Couronne (to which Plaine de France and Plateau de Saclay belong). To add to the understanding of the role of private gardens in food production, and to other functions, fieldwork has been extended in Île-de-France through the project TERRIBIO. In a study area belonging to the three local authorities Paris-Saclay, Versailles Grand Parc and Saint-Quentin-en-Yvelines, which covers 57 municipalities and a population of 831,404 inhabitants. Gravis et al. (2020) estimated that roughly 5 % of the population has a private garden identified as a vegetable garden. Depending on yield for which estimates vary by a factor of 10, the residents' own production can cover 3 to 27% of their fruits and vegetable consumption (or be partly offered to family, neighbours and friends).

predominantly in the rural areas of the *Grande Couronne*. As with gardening, motives go far beyond the acquisition of food.

Transport statistics

With respect to this research, the SitraM database for the transport of goods has a couple of limitations. The road transport survey TRM, which concerns most of the freight in France considering that in 2015, 87.1% of freight was transported by road[138], covers only vehicles of a total loaded weight of over 3.5 tonnes. Transport in smaller vehicles is not included in SitraM data. Although it would be important to obtain data on total transport amounts, it is not possible to estimate the total amount of food shipped to Paris Petite Couronne or Île-de-France in vehicles of 3.5 tonnes or below. This would include the amounts delivered by farmers to restaurants or sold on markets, but there is no centralized record for them. Another limitation of this data source relates to the fact that the domestic freight data are expressed in gross weight, including packaging that I ideally would need to subtract to obtain food product net weight. There are further uncertainties with trade statistics, notably related to the French domestic road freight survey, with road being by far the most common mode of transport in France. Courtonne and colleagues (2018) have devised a model based on a statistical analysis of the domestic road freight survey, to estimate the uncertainty of any given domestic road transport flow. These authors averaged flows in material flow analysis over several years, and found a 30% reduction for a three-year average (Courtonne et al., 2018).

Difficulties with the use of the SitraM database for my research relate to the classification of products in the nomenclature. The nomenclature is built per material type, for example metal ores and mining products, textile and leather, and so on, and not per purpose or use. Division 01 "Products of agriculture, hunting, and forestry; fish and other fishing products (01)" in particular covers the broad category of unprocessed biomass, including food and non-food products such as wood, fibres and flowers. Division 04 "Food products, beverages and tobacco (04)" includes items which stem from food processing but are not intended for human food consumption. Sometimes they are labelled as such (unfit for human consumption or inedible). For the data extraction, the focus on origin and not purpose of use in the nomenclature required me to decide what is food and what is not. In most cases, this was not a problem. Only in some rare cases was it a problem, since either the labelling of the product category was not explicit,

[138] https://www.statistiques.developpement-durable.gouv.fr/donnees-sur-les-flux-de-marchandises-sitram-annee-2015

or the category included both food and non-food, or it included ingredients for the industry in general.

While the nomenclature in most cases was accurate enough to properly distinguish food from non-food, I could not do so for the food categories that have important non-food uses, which essentially are cereal[139] (Juin, 2015), oil crops (Fine et al., 2015) and legumes (Duc et al., 2015). Therefore, the total quantity of cereals, oil crops and legumes imported, exported and produced within the urban system are classified as food. Supply-use balances, available for national scale in agricultural statistics, are not produced for regional scale. They would help though to distinguish the use of biomass for the different purposes for food, feed, seed, biofuel and other.

The analysis of food flows per food categories using the transversal nomenclature worked well for the trade statistics, with the exception of the item coded 4.85 referring to “Various food preparations (pasta, semolina, vinegar, extracts, essences, etc.)”. This item covers a significant amount of food. It makes up 13% and 10% of total imports to Paris Petite Couronne and Île-de-France, respectively, and 14% of exports from the two urban systems. Any food can be reported in item 4.85., therefore under-reporting other food categories. It is not possible to identify in detail what food item 4.85 consists of.

Furthermore, Division 18 is entirely dedicated to grouped goods, that is, goods from different divisions transported together. This can be the case of a retailer replenishing a shop in one lorry load with various food and non-food items. The division added up to 4,278 kt and 3,575 kt of imports and exports, respectively, for Paris Petite Couronne in 2012, and 9,080 kt and 8,789 kt for Île-de-France, which represents between roughly one third and up to nine tenths of the corresponding food imports and exports. The risk is that food reported in Divisions 01 and 04 is under-reported. Together with the other biases of the transport statistics, I conclude that the food import and export data for the urban systems of Paris Petite Couronne and Île-de-France do not exhaustively cover the category of food.

Food intake survey

There are a few limitations with the use of the INCA 3 survey as a data source for food intake. The limitations concern the scope of the survey, with implications for the sample used for data

[139] Based on data from FranceAgriMer, during the 2012 wheat campaign in France, from 35 million tonnes produced and harvested, 5 million tonnes were used for animal feed, 1.7 million tonnes for biorefinery, and 3 million tonnes for starch extraction which serves important non-food uses (Juin, 2015).

collection. The sample covers the French metropolitan population aged 0 to 79. The food intake of French people aged 80 and older was therefore not included in the calculation of the average daily food intake of the adult group aged 18 to 79. This means for my research that I apply a mean daily intake to a population which was not covered by the data collection. This population aged 80 years and older represents 6% of adults aged 20 and older in both Paris Petite Couronne and Île-de-France. Since food intake tends to decrease with age, and people over 80 are excluded from the INCA 3 survey, we can expect the mean intake for the adult population of all ages to be slightly lower than in my calculation.

Furthermore, the INCA 3 survey covered persons living in ordinary households. Hence, the food intake of those living outside of an ordinary household (in retirement homes, prisons, student halls of residence, etc.) was not included in the data collection. Again, I applied mean food intake to a population that did not participate in the survey. In my research however, since the population living outside of an ordinary household does not exceed 2% of the legal population of Paris Petite Couronne and Île-de-France, I consider that the impact on the calculation of the population food intake is negligible.

I used the INCA 3 mean intake calculated from respondents in Île-de-France although I could not check their average socio-demographic profile more completely than for sex and age. Since there is only a small difference between Île-de-France respondents and the national sample for the mean total food and drink intake (not for food categories) (see Table 12), I used the results for Île-de-France, although in the end I do not expect it to make a difference.

Further limitations of the survey do not relate specifically to the use of the survey for my research. They concern the representativeness of the final sample, for example the risk that non-participants and unavailable persons (40% and 15% of initial contacts) have different consumption practices than the final sample and thus introduce a bias. Data collection tools such as photo images for portion sizes to be used by respondents to estimate the quantity of food intake and, more generally, the fact that respondents report the quantities themselves generate uncertainty, estimated at 10 to 30% (Anses, 2017).

Waste statistics

In contrast to the data sources for agricultural production, trade and food intake, data sources for waste are multiple, and they all have their limitations. Moreover, the fact that food waste is not a category in the sense of official classification in statistics and has been a matter of interest only recently, implied that I needed to use additional means for the estimation of the food waste flow.

Household food waste

For household waste, the yearly survey *enquête DMA* provides an almost exhaustive picture of the household waste collection in Île-de-France. The population-based normalized household waste quantities are available for various administrative units, from the region to the *départements*, and the intermediate groups Petite Couronne, the Grande Couronne and the Greater Paris Metropolis. I used them to calculate the quantity of household waste for the urban systems of Paris Petite Couronne and Île-de-France.

The share of food waste in mixed household waste available for Île-de-France from the transversal characterization study of ORDIF (2017) must be considered as less robust. This comparative study used a sample of data from available characterization campaigns. The sample covers 26 campaigns, 21 local authorities, 223 different zones, 373 data sets covering 70% of the Île-de-France population, that is 8,400,000 inhabitants. Disregarding questions of representativeness, the results can be biased by differences in the understanding and application of the waste analysis method, such as in sorting and classification of waste, or by the non-representative nature of the participating local authorities in terms of housing and urban density. Since there is no dedicated study to assess the food waste share in mixed household waste for Paris Petite Couronne, I used the characterization campaigns carried out for Paris by the municipality. They seemed closest to the situation of Paris Petite Couronne. I nevertheless think that the share of 19% of food waste in mixed household waste and a normalized quantity of 68 kg/cap/y are underestimated, given the high density of restaurants and shops. Whatever the share of food waste, it is to be understood as an estimate not an absolute value. Further characterization campaigns should be carried out to refine our understanding of the composition of waste, and to distinguish wasted food, including meal leftovers, from inedible parts. This is probably technically challenging in sorting (for half-liquid items, sauces, meals, etc.). Characterization studies can in parallel take place in households where sorting can be requested from household members, prior to sending food waste to a mixed bin (Ademe, 2014).

For food waste sent to the sewage system, I used an estimate calculated in a European research project (Stenmarck et al. 2016), although it was not produced for the context of my study, nor for France. It is possible that liquid or semi-liquid food leftovers are handled differently in households in France than in other countries, and that the estimate used in Stenmarck et al. (2016) does not reflect the situation in my case study.

Business waste

Little information is available on the study carried out as part of the regional plan for waste prevention and management (PRPGD) (Conseil Régional Ile-de-France, 2019) that estimated food waste from mixed business waste, collected and treated by the private sector. Bio-waste producing companies were extracted from a public database and the average quantity of bio-waste normalized by the number of employees was applied. The question is whether data on average quantities of bio-waste in companies are robust and sufficiently consider diversity in the food industry. We know from previous studies that companies keep fairly confidential information about waste amounts. I therefore consider that the result of 235 kt of food waste in mixed business waste, and not included in household waste, is a very rough estimate that needs comparison with further studies. More generally, it would be important to have a more robust knowledge base about business waste, which so far has largely continued to exist in the realm of obscurity.

As regards food waste collected and treated as bio-waste in Île-de-France, ORDIF has included bio-waste in its monitoring through the survey *enquête ITOM*. It seems however that part of the bio-waste collected by private waste companies is missing from the monitoring, notably when the bio-waste is shipped for treatment outside of Île-de-France, the scope of the survey. The reasons for private waste companies to do so can be limited treatment capacity for bio-waste category ABP3 in Île-de-France and a strategy of the company to treat the waste in its own facilities, although these facilities may be located far from Île-de-France[140].

Food loss in agriculture

Several limitations need to be kept in mind when we use food loss shares from the study from Redlingshöfer et al. (2017) to estimate food loss in agriculture. The study provides a rough picture valid for agriculture in France in general and not for the particular situation in Île-de-France or Paris Petite Couronne. Yet agriculture is the stage where food loss is particularly difficult to measure due to its heterogeneity in terms of products, production systems, or geographical setting (Stenmarck et al., 2016). In plant production, for oil crops, cereals, pulses

[140] Blandine Barrault, ORDIF, email, 18 September 2019.

and potatoes, Redlingshöfer et al. (2017) obtained qualified estimates from professional and academic experts. They were deemed to be of adequate quality. For fruit and vegetables, the authors collaborated in a small study providing loss data from a sample of fruit and vegetable growers. The data quality of fruit and vegetable loss percentages are considered high, although in all crops further research would be important to consolidate these first food loss data. Uncertainties about food loss in livestock farming are of little relevance considering the small extent of livestock production in Île-de-France, and its absence in Paris Petite Couronne. With regard to the overall food flows in the urban system, uncertainties about food loss percentages in agriculture unfold only little due to the small contribution of agricultural production compared to trade, in terms of mass.

3.3.3. Comparison with other studies

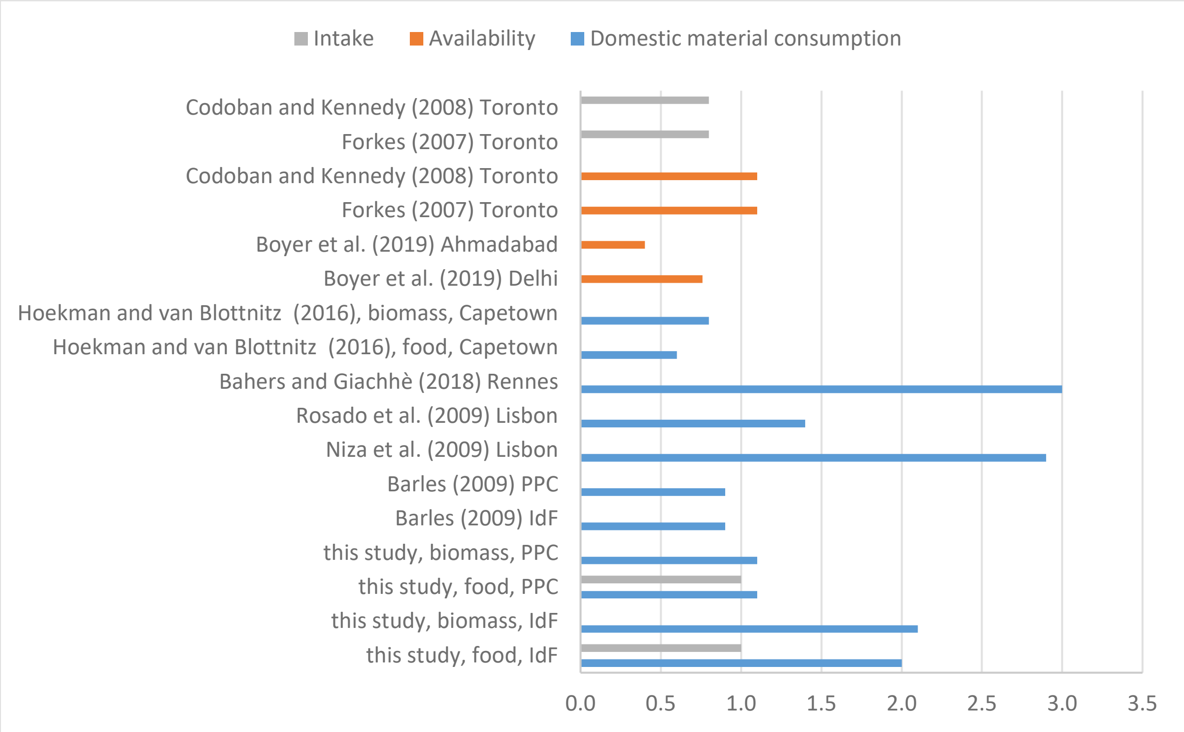
Comparison with other urban metabolism studies helped me to assess where I stood with my results and to analyse determinants to explain differences I might observe. I looked at studies carried out on cities and city regions other than Paris Île-de-France, or studies on Paris Île-de-France using other years of reference than 2014.

Concerning urban food consumption, my results of 1.0 t/cap/y of food intake in Paris Petite Couronne and Île-de-France, for both types of normalization, are in line with other MFA study results, as reviewed by Goldstein et al. (2017). These authors found urban food consumption of 0.8 ± 0.3 tonnes per year on average, based on a review of 20 MFA studies about cities worldwide the provided 32 assessments. For Paris Petite Couronne and Île-de-France (but not Paris itself), Barles (2009) has calculated urban food consumption of 0.9 t/cap/y, which lies in the range of averages. Structured according to approaches to estimating urban food consumption, Table 19 and Figure 27 present the results from this study compared to selected studies totalling twenty assessments. This provides enough insights to discuss the indicator of urban food consumption.

Generally, urban food consumption is higher when the indirect way of calculation as domestic material consumption, following the EUROSTAT approach, is used. Studies report values in a wide range from 0.6 to 3.0 t/cap/y (Bahers and Giacchè, 2019; Barles, 2009; Hoekman and von Blottnitz, 2017; Niza et al., 2009; Rosado et al., 2014). The results of my study tested with the EUROSTAT approach lie within the range. The results of studies that used the direct way of estimating urban food consumption, either through availability data (national food balances, purchase data) including household food waste, or through intake data from nutrition surveys, excluding household food waste, are generally lower. They lie in a range of 0.42 to 1.1 t/cap/y (Boyer et al., 2019; Codoban and Kennedy, 2008; Forkes, 2007). Naturally, due to the distinct presentation of the food waste flow, urban food consumption estimated from intake data should be lower than from availability. However, this effect is blurred by the fact that different studies totally or partly exclude certain product categories such as drink, making the results in this literature heterogeneous and hardly comparable. Boyer et al. (2019) for example consider only food, including milk but no drink, whereas Forkes (2007) and Codoban and Kennedy (Codoban and Kennedy, 2008) included drink except for tap water. While excluded, tap water used for the preparation of beverages is known to be 0.24 t/cap/y in the study of Codoban and Kennedy (2008), which is similar to my estimation (0.3 t/cap/y) and can explained by cultural differences. I found no other study than my own which included tap water to drink in the food flow analysis.

The different approaches to analysing food flows, as depicted above, are widely used in the international urban metabolism studies literature. Essentially, they use more or less aggregated material categories for food, and direct and indirect ways of estimating the urban food consumption. Similar to the work of Goldstein et al. (2017), a systematic analysis of the urban metabolism literature about food would be useful. It would serve to disentangle the influence of each of the method choices on the quantitative results compared to the influence of structural determinants of the metabolism profile.

Figure 27. Urban food consumption in cities according to selected studies, t/cap/year



Source: Table 19

Table 19. Urban food consumption in cities according to selected studies, t/cap, city, year

	Food	Biomass (excluding forestry)
Domestic material consumption	This study: 1.1 t/cap, Paris Petite Couronne; 2.0 t/cap, Île-de-France, 2014 Hoekman and van Blottnitz (2016): 0.6 t/cap, Cape Town, 2013	This study (EUROSTAT method): 1.1 t/cap[7], Paris Petite Couronne; 2.1 t/cap[7], Île-de-France, 2014 Barles (2009): 1.8 t/cap, Paris; 0.9 t/cap, Île-de-France, Paris Petite Couronne, 2003 Niza et al. (2009): 2.7 t/cap, Lisbon city, 2004 Rosado et al. (2014): 1.4 t/cap[1], Lisbon Metropolitan area, 2009 Bahers and Giacche (Bahers and Giacchè, 2019): 3.0 t/cap[2], Rennes Metropolitan area, 2012 Hoekman and van Blottnitz (2016): 0.8 t/cap, Cape Town, 2013
Availability	Boyer et al. (2019): 0.42 – 0.76 t/cap[3 4], 9 cities in India, several years Forkes (2007): 0.9 t/cap[6], 1990; 1.1 t/cap[6], 2001 and 2004, Toronto Codoban and Kennedy (Codoban and Kennedy, 2008): 1.1 t/cap [6] , national, Canada, scaled to population, 2000 Warren-Rhodes and Koenig (2001): 0,7 t/cap, Hong-Kong, 1997	
Intake	This study: 1.0 t/cap[5], Paris Petite Couronne, Île-de-France, 2014 Forkes (Forkes, 2007): 0.7 t/cap[6], 1990; 0.8 t/cap[6], 2001 and 2004, Toronto Codoban and Kennedy (Codoban and Kennedy, 2008): 0.8 t/cap[6] , national, Canada, scaled to population, 2000	

[1] including four categories of biomass: agricultural biomass, animal biomass, oil and fats, sugar
[2] food, agricultural and agro-industrial products
[3] urban consumption of residents and visitors, excluding industry uses
[4] expressed as food raw products, including up-stream waste, but excluding drink (milk is included)
[5] including 0.3 t/cap tap water to drink
[6] excluding tap water
[7] including forestry

Looking at input and output flows other than urban food consumption, despite the fact that this study used a food centred approach, the results are higher than those in Barles (2009) focused on biomass, for Île-de-France. With 2.9 t/cap/y of food input they are higher compared to 2.2 t/cap/y biomass input in Barles (2009). The difference can be partly explained by 0.3 t/cap/y of tap water to drink included in my research. With 0.7 t/cap/y, agricultural production provides more food per capita in my research compared to 0.5 t/cap/y of biomass in Barles (2009). In contrast to the EUROSTAT method used by Barles (2009), livestock products in this study's food-centreed approach is accounted for as agricultural production. However, it contributes to less than 1% to the 0.7/cap/y which predominantly is crop production. Furthermore, in contrast to the EUROSTAT method, I quantified the potential quantity produced by agriculture, not the harvested and shipped quantity which defines the concept of production quantity in agricultural statistics (see 3.1.2). The difference between potential production on the one hand, and harvested and shipped production on the other, amounts to 161 kt, or 2% of the potential production. These are essentially field and on-farm losses occurring in the predominant crop sectors in Île-de-France, but they do not either explain the difference of 0.2 t/cap/y in agricultural production in Île-de-France between this study and Barles (2009). Apart from the discrepancies in methods, this study fails to further explain this difference.

Concerning urban food waste, the results of this study can be compared with studies which use similar direct approaches to estimating urban food consumption (see 3.3.1), and are based on food waste data from city-level waste statistics (Table 20). In contrast to the indirect approach from EUROSTAT where food waste is embedded in the indicator of domestic material consumption, food intake and food waste were quantified as two distinct output flows in these studies. With 0.10 t/cap and 0.12 t/cap food waste in the urban systems of Paris Petite Couronne and Île-de-France*,* respectively, in 2014, the results of this study are similar to those of Warren-Rhodes and Koenig (2001) who calculated 0.16 t/cap for Hong-Kong for the year 1997. However, the big timespan between the reference years of these two studies limits comparability. The study from Bahers and Giacchè (Bahers and Giacchè, 2019) calculated lower per capita waste, with 0.07 t/cap, for the city of Rennes, France. It was bio-waste and covered the three sectors: households, industry, and distribution.

Goldstein et al. (2017) reviewed the urban metabolism literature covering food. These authors found urban food waste to amount to 0.2 ± 0.1 tonnes per year on average, based on a review of 14 MFA studies on cities from both OECD and non-OECD countries worldwide. All of the

14 studies, including that of Warren-Rhodes and Koenig (2001), referred to statistics for the food waste data.

Urban food waste is twice as high when food waste is the result of the difference between food and drink availability –meaning available for sale at distribution – and food intake, in the studies of Forkes (2007) and Codoban and Kennedy (Codoban and Kennedy, 2008) (Table 20). This is surprising because this approach a priori covers only distribution and household food waste, and nevertheless yields much higher food waste quantities, with 0.28 t/cap in Forkes (Forkes, 2007) and 0.29 t/cap in Codoban and Kennedy (Codoban and Kennedy, 2008). Two hypotheses can be derived: i) waste statistics are incomplete and miss important waste flows; or ii) the difference between availability and intake also covers flows other than food waste. For both hypotheses, the analysis of inner-urban food flows and contributing sectors in Chapter 4 will bring more insights to explain these discrepancies.

Table 20. Urban food waste in cities according to selected studies, t/cap, city, year

	Food	Biomass (excl. forestry)
Data sources for waste	Our results: 0.10 t/cap , 0.12 t/cap, Paris Petite Couronne, Île-de-France, 2014 Warren-Rhodes and Koenig (2001): 0,16 t/cap, Hong-Kong, 1997	Bahers and Giacche (Bahers and Giacchè, 2019): 0.07 t/cap[1], Rennes Metropolitan area, 2012
Difference availability to intake	Forkes (2007): 0.25 t/cap, 1990; 0.28 t/cap, 2001 and 2004, Toronto Codoban and Kennedy (Codoban and Kennedy, 2008): 0.29 t/cap[2], national, Canada, scaled to population, 2000	

[1] solid food waste from households, distribution and the industry
[2] including drink but excluding tap water

3.3.4. Analysis of food categories

Few urban metabolism studies have analysed food categories in detail (Barles, 2013; Boyer et al., 2019; Codoban and Kennedy, 2008; Forkes, 2007). Cultural differences in food consumption can be strong not only between countries but also within countries. Such differences can inherently explain differences in food category flows. Boyer et al. (2019) for example analysed the diet composition in their study on the food metabolism of nine Indian cities. The consumption of rice versus wheat (the regions have either rice- or wheat-based diets), milk and vegetables varied most. Since diet and economic situation are not comparable with that in Western European cities, as in my case study, results from Boyer et al. (2019) are not meaningful for comparison with mine.

The French CONFLUENT research project (Barles, 2013) looked at fruits and vegetable in particular, as their supply is crucial in efforts to transform food systems towards fostering connections between producers and consumers, shortening supply chains, and re-localizing agriculture to urban and peri-urban areas (Barles, 2013). In the case study on the food metabolism of the French *département* Haute-Garonne, domestic material consumption of fruits and vegetables amounted to 274 kg/cap in 2006. Compared to the work of this study for the category, which additionally includes potatoes according to the transversal nomenclature, and using the same calculation approach, the results lie in the same order of magnitude. They amounted to 229 kg/cap for Île-de-France and to 291 kg/cap for Paris Petite Couronne, in 2014. Actually, Paris Petite Couronne has a higher per capita input of fruits, vegetables and potatoes than does Île-de-France (556 kg/cap versus 511 kg/cap) and lower exports (265 kg/cap versus 282 kg/cap). Hence, a bigger quantity remains within the urban system. While in Paris Petite Couronne the proportion of fruits, vegetables and potatoes finally ingested made up 52% of domestic material consumption, in Île-de-France*,* it decreased to 41%. This difference in the share of intake suggests a varying difference between intake and DMC, either in the form of food waste or as an additional so far badly identified proportion, due to a difference in input data between the two urban systems (I assume that the per capita intake is equal between the two).

An important point in my food flow analysis is the fact that whatever the food category, fresh unprocessed products are summed up together with processed products. In the trade statistics, they initially belong to two different divisions (Divisions 01 and 04) but are summed up as flows of processed and unprocessed goods for the calculation of import and export flows of a food category. Dry matter instead of fresh weight could be used to exclude mass change from water. The difference between processed and unprocessed is not only a matter of water content, but also of refining, milling, pressing, cutting, centrifuging, coagulating and subsequent removal of parts that are deemed inedible to humans. In urban metabolism studies, the processing of raw food products influences output flows through the generation of non-food residues, as we have seen with the input-output imbalance of Île-de-France, but which so far is badly characterized. Processing activities in local industry are an important feature that shape the metabolism profile of the urban system, as in the case of Île-de-France in my case study. Contrastingly, imports of processed food imply processing residues generated outside of the urban system, induced by urban consumption. These residues have so far been completely absent from urban food metabolism studies.

In contrast to my approach, Codoban and Kennedy used per capita availability data for the main food categories. For fruit and vegetables, the category is labelled as fresh and processed but reported in the mass of fresh equivalents (Codoban and Kennedy, 2008b). By doing so, I have no means to distinguish whether the fruits and vegetables have been processed within or outside the urban system.

3.4. Summary

In this chapter, the food material balance of the urban system was calculated to characterize the food metabolism. Results of an adjusted version of the Eurostat method of material flow accounts yielded the main input and output flows.

Urban food consumption was addressed directly through the calculation of the population's food and drink intake. The notion of the eating population was developed in this study to account for the food and drink intake of the additional population of tourists, excursionists and commuters, in the same way as residents' time spent away and having food elsewhere than in the urban system is taken into account. Food waste was compiled from waste statistics and other data sources for the main segments and sectors. The quantification of the other input and output flows followed standards established in previous urban metabolism studies which used this method.

The main difference in the food metabolism of the two urban systems, Paris Petite Couronne and Île-de-France, lies in the degree of externalization of the food input. It is highest for Paris Petite Couronne as almost no food is produced locally. Another difference is the significant input-output imbalance in Île-de-France, suggesting important food processing activity. Processing activities in Île-de-France generate significant material flows that tend not to be covered by the output flows of the model and hence stay within the urban system or become outputs into nature, such as dissipative flows.

Work in this chapter provided novel insights into the composition, food category-wise, and spatial organization, sector-wise, of the food metabolism. However, what happens with the food flows within the urban system remains largely unknown and hidden from the researcher's gaze. The hybrid food system–material flow analysis developed in this study has opened the black box of the urban system so that the inner-urban food flows can now be analysed in the Chapter 4.

Chapter 4: Inner urban metabolism

The analysis of inner urban system flows allows for in-depth understanding of the food system sectors involved, because of the combined use of the food system approach. Whereas detailed information is available for urban food consumption, there is little data on other food system sectors, notably food processing and distribution. This is why the focus in this study lies on urban food consumption.

4.1. The inner-urban system flow model

Urban food consumption of the eating population takes place in two sectors. As in-home consumption, it predominantly takes place in households and concerns food purchased by household members through the retail distribution sector. Residents not living in households and tourists may also consume in-home, when the meals they consume are purchased from the retail sector and prepared in the places they stay, such as the homes of friends and family[141]. As out-of-home consumption, urban food consumption takes place in the food service sector which covers a wide range of establishments. They can be broadly classified into a commercial sector, including traditional restaurants, fast-food and street-food vendors, and social catering, including catering in companies and the administration, in hospitals, the education sector, retirement homes, day-care centres, and the military. Like households, the food service sector uses food stuffs that have been processed to various degrees[142], but are supplied via distinct circuits, notably the wholesale market and a specific food processing industry. In 2018, there were 30,893 commercial restaurants in Île-de-France and 25,812 in Paris Petite Couronne (Paris alone has 19,279 commercial restaurants, that is, 62% of the number in Île-de-France) (DRIAAF, extraction Resytal database, 16/12/2019). The social food service sector has 16,500 places of meal preparation and consumption, of which more than 8,000 are kitchens (DRIAAF, 2015).

Strictly speaking, a third option exists and concerns an intermediate situation where food is consumed neither in-home nor in the food service sector. This option refers to various situations where food is purchased in a retail outlet and consumed out-of-home, such as lunch prepared

[141] This is a difference compared to the captive population in retirement homes and prisons where all meals are provided by the catering company.

[142] The sector refers to ranges, classifying raw unprocessed products as 1st range, canned products as 2nd range, frozen products as 3rd range, ready-to-use raw products (for example cut, sliced, or grated vegetables) as 4th range and ready-to-eat, heated products as 5th range (Juin et al. 2015).

at home and eaten at the workplace, or take-away sandwiches, mixed salads et cetera, purchased at retail points of sale, such as supermarkets and bakeries (however, take-away food purchased at a street food vendor is considered as being from the food service sector). According to a market research company, out-of-home consumption other than in the commercial or social food service sector restaurants accounted for 12% of the total out-of-home consumption market in 2014 (GIRA Food Service, 2014). A recent study (2019) showed that 25% of the Île-de-France working population eats a home-made lunch at the workplace (Crédoc, 2019). In this study, this third option is considered together with in-home consumption in households.

To simplify the representation of the food system, in-home consumption essentially takes place in households (tourists and persons living in student accommodation and young workers homes also consume in-home and refer to non-household in-home consumption), and out-of-home consumption in the food service sector. Both sectors are represented as sub-systems of the urban system, which are characterized by input and output flows and obey the mass balance principle, just as the urban system does.

In-home consumption:

Input flows to the in-home consumption sector comprised:

- Household purchases of food and drink other than tap water
- Supply of tap water to drink
- Purchases from population living outside of an ordinary household and from non-resident population

Output flows from in-home consumption comprised:

- Food and drink intake
    - allocated to households
    - allocated to population living outside of a household and of non-resident population (non-household population)
- Food waste
- Drink waste

Out-of-home consumption:

Input flows to out-of-home consumption comprised:

- Food and drink supply

Output flows from out-of-home consumption comprised:

- Food and drink intake
  - allocated to households
  - allocated to population living outside of a household and of non-resident
- Food waste

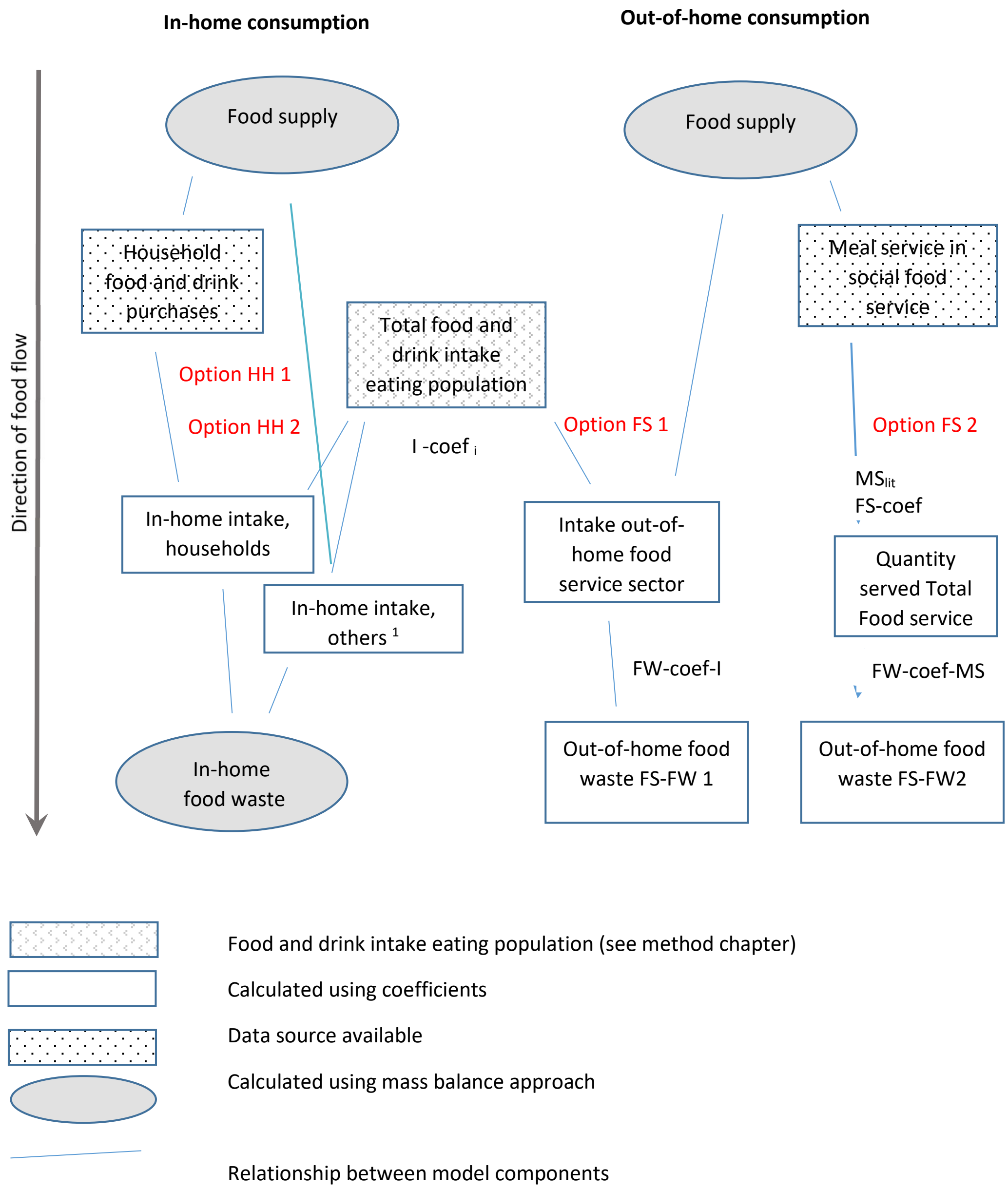
Drink waste in the food service sector was not considered as no data on drink waste were available.

Figure 28 provides the general scheme of the accounting approach adopted in this chapter. For each input and output flow, the scheme presents available data and the calculation flow based on them. Data are available for some, but by far not for all distinct input and output flows of the household and the food service sector. Some flows are derived from data available for other flows, using coefficients or a mass balance approach. Like a puzzle, adding one piece of information to another gradually and steadily completed the picture of the inner urban food metabolism, as shown in Figure 1. The starting point is the total annual food and drink intake of the eating population, calculated in Chapter 3, based on which food flows were allocated by distinguishing food and drink intake in households versus food and drink in the food service sector. The figure shows model components – supply or purchase, intake, waste – , the direction of the food flows, and the direction of food flow accounting. For the sake of simplification, food flows are not shown in the figure.

For households, the difference between food and drink purchase data, for which two data sources were available (HH1 and HH2), and intake data was taken as a rough estimate of food waste.

As purchase data was not available in the food service sector, food and drink supply (FS1) was calculated, following a mass balance approach, from food and drink intake plus food waste, with the latter obtained through coefficients. An alternative option of calculation (FS2) was the use of data on the number of meals served in social catering facilities. The commercial food service sector and related food waste were calculated using coefficients. Both together yielded food and drink supply for the food service sector.

Figure 28. Principles of the inner-urban food flow model



I - coef $_i$ = allocation coefficients for in-home and out-of-home consumption per population type i

FW-coef-I = food service food waste coefficients from intake

FW-coef-MS = food service food waste coefficients from meal served

FS-coef = coefficients for the share of social versus commercial catering in the food service sector

MS_{lit} = average meal mass served

[1] non-household eating population including residents not living in ordinary households and additional population

Where relevant, food flows were analysed according to types of population of the eating population. The distinction between the household population and the non-household population or between residents and the additional population is relevant since different populations, although by far not homogeneous, have common points in the social organization of food flows related to food consumption. For example, food preparation and consumption in-home is linked to different upstream and down-stream sectors than out-of-home consumption, with partly common but also different regulation frameworks and different opportunities and limitations with respect to a more sustainable organization of the food system.

4.2. Data sources

4.2.1. Food and drink intake in-home and out-of-home

For the eating population living in a household, the INCA 3 survey (see 3.1.3) provided the allocation of food intake according to consumption places for the three age groups analysed in the survey, by distinguishing in-home and out-of-home consumption (Anses, 2017). The findings of this survey show that out-of-home consumption accounts for 25%, 22% and 21% for age groups of 0-10, 11-17 and 18-79, respectively, and in-home consumption accounts for the rest. Because these allocation coefficients are valid for the national population disregarding particularities of the Île-de-France population for eating out, household expenditure data were used to adjust allocation coefficients to the Île-de-France population. The underlying assumption was that, in terms of mass, the out-of-home food and drink intake of the Île-de-France population was different to that of the French population, in the same proportion as the difference between household expenditure structure for in-home and out-of-home intake of food and drink. The assumption, however, failed to consider that different prices for food and drink also influence the expenditure structure in Île-de-France. For the same meal, eating out is more expensive in Paris than in a French rural village. It was not possible to additionally integrate food prices into the adjustment of the allocation coefficients to the Île-de-France population, which is a limitation to the assumption that intake in mass changes in the same proportions as expenditure. Household expenditure data are available from the national

Household budget survey[143] for the population of the Paris agglomeration, an administrative unit that largely overlaps with to the Île-de-France Region (see 4.2.2). Firstly, drawing on the allocation coefficients from the INCA 3 survey, an average share of out-of-home consumption, in terms of mass, was calculated for the household population weighted according to population size per age group. Second, the coefficient related to out-of-home consumption for Île-de-France was calculated from the weighted national share, in terms of mass, in proportion to the allocation of expenses using the Rule of Three. Third, the difference between the coefficient for out-of-home consumption in Île-de-France compared to that of France was expressed as an adjustment factor and applied to other types of population for which the allocation between in-home and out-of-home consumption needed to be established.

Calculations yielded the following results. The weighted national average coefficient for out-of-home consumption, in terms of mass and across age groups, was 22%. Expenses for out-of-home consumption accounted for 23% and 29% of total expenses for food and drink for all French and Île-de-France households, respectively[144] (INSEE, 2011). Proportional to higher share of out-of-home eating expenditure of Île-de-France households, the coefficient for out-of-home consumption, in terms of mass, for Île-de-France households across age groups was calculated as 28%. From this calculation follow two intermediate results: a 26% higher out-of-home consumption, in terms of mass, of Île-de-France households and an adjustment factor of 1.26. Applied to the coefficient of out-of-home consumption I-coef $_i$, the adjustment factor of 1.26 increased the share of out-of-home consumption of Île-de-France households compared to all households in France.

For residents living outside of a household, depending on the type of residence they live in (see 2.2.4), the same allocation increased by the adjustment factor was used for students and for young workers as for adults living in households. By contrast, the complete food intake of the homeless, the captive population of residents living in retirement homes and prisons, and the remainder of the resident population, was allocated to out-of-home consumption. As regards

[143] A detailed explanation of the characteristics of the French household budget survey follows in Section 4.2.2 where its use for the quantification of households' food and drink purchase quantities in Île-de-France and Paris Petite Couronne is explained.

[144] In 2011, Île-de-France households spent 50% more on eating out than the average French households, that is €2,171 versus €1,451 per annum (INSEE, 2011). Expenditure for in-home-consumption was higher, too, but only by 12% for food (€4,890 versus €4,361) and by 5% for alcoholic beverages (€399 versus €379) (INSEE, 2011), which explains an overall 29% higher share of food and drink intake out-of-home for Île-de-France compared to French households.

the non-resident population, 36% of tourists' food intake was allocated to households' in-home consumption and 64% to the food service sector for out-of-home consumption. The allocation was based on a survey result showing that, in 2014, 36% of tourists' overnight stays concerned non-commercial accommodation, that is, with friends or family (Comité Régional du Tourisme, 2015). Commuters and excursionists as part of the eating population had their total food and drink intake allocated to out-of-home consumption, although in reality they probably had more diverse ways of having lunch (Crédoc, 2019; Lhuissier et al., 2018; Mathé et al., 2015).

Table 21 summarizes the allocation coefficients, referred to as I-coef $_i$ in the inner-urban food flow model (Figure 28) for food and drink intake in-home versus out-of-home for the various population types of the eating population. The right column informs about the data sources used to retrieve the allocation coefficients.

Table 21. Allocation coefficients I-coef $_i$ for annual food and drink intake for in-home consumption versus out-of-home consumption per type of population, Île-de-France, %

Population	In-home consumption	Out-of-home consumption	Data sources
Residents			
-Living in ordinary households			
0-10 y	1-25*1.26	25*1.26	INCA 3, HBS 2011
11-17 y	1-22*1.26	22*1.26	INCA 3, HBS 2011
18-79 y	1-21*1.26	21*1.26	INCA 3, HBS 2011
Commuters	100	0	Assumption see text
-Living outside of ordinary households			
in retirement homes	0	100	Assumption see text
prisoners	0	100	Assumption see text
students	1-22*1.26	22*1.26	INCA 3, HBS 2011
young workers	1-22*1.26	22*1.26	INCA 3, HBS 2011
homeless adults	0	100	Assumption see text
homeless children	0	100	Assumption see text
remainder	0	100	Assumption see text
Non-residents			
tourists	36	64	CRT 2015
commuters	0	100	Assumption see text
excursionists	0	100	Assumption see text

Lacking data for the specific situation of expenses of households living in Paris Petite Couronne, the same allocation coefficients for out-of-home and in-home consumption were used for the food flow quantification in Paris Petite Couronne and Île-de-France. The allocation coefficients were moreover applied equally to food and drink and all categories within these groups, although results from the INCA 3 study show that some foods and drink are over-consumed out-of-home (e.g. alcohol, soft drinks, potatoes, desert and ice-cream) or under-consumed (e.g. eggs, dairy products, bread, juice) (Anses, 2017). Finally, the expense structure of households is not equally transposable to individual household members. However, in the case of this study, effects of variations within households are cancelled out since the entire household population is considered.

4.2.2. Food purchase by households

For households, food and drink purchase data are available for Île-de-France households. Food and drink purchases do not include tap water to drink. Households have access to tap water for various uses altogether, without distinguishing its use for drink.

Two data sources are generally available in France for information on household food purchases: the INSEE Household budget survey, and the consumer panel from Kantar Worldpanel. For this study, both data sources were used and informed the household input flows in a comparative approach, distinguishing option HH1 which used Kantar Worldpanel data, and option HH2 which used the Household budget survey data. Household input flows refer to food and drink purchased from the retail sector for in-home consumption[145].

Kantar Worldpanel, a private market research and consulting company, has been running a large consumer panel in France since 1990, today built from 20,000 households (Kantar Worldpanel, n.d.). Panel data about purchases reported by households are regularly acquired by companies as they provide detailed information not only about purchase expenses and quantities, but also about the brands involved. This highly detailed data is accessible only against a high fee that was not compatible with this study's budget. FranceAgrimer, a public institution under the authority of the French Ministry of Agriculture, kindly provided the household purchase data for food and drink for use in option HH1, after having calculated mean purchase quantities per product category, using the same transversal nomenclature as that used in this study (see Table A3.1 in Appendix), per one hundred households in Île-de-France for the years 2011 and

[145] As shown for the adjustment of the allocation of food and drink intake to consumption places in Île-de-France (see 4.2.1), the household budget survey also covers food and drink consumed out-of-home. However, the composition in terms of food and drink categories is not given at all and the conversion to mass units is difficult to perform, which makes the data unexploitable for the purposes of this study.

2014[146]. The sample contained 3,750 households in 2014, compared to over 5 million households in Île-de-France in 2014, according to INSEE. Participating households scan the barcodes of all purchased products over the course of one year. The panel covers the whole range of distribution channels for food, including supermarkets, convenience stores, butchers, fishmongers, greengrocers, dairy shops, delis (*traiteurs*), farmers' markets, and on-line shops. Traditional bakeries (*boulangeries*) and points of sale in supermarkets are not covered by the data collection since bakery goods are largely sold there without barcodes. The magnitude of this channel compared to other channels for bakery products implies for Kantar to renounce to extra reporting by panelists due to the risk of errors. While the data collection process in other shops, such as fishmongers, butchers or green groceries, requires extra reporting of purchased items without barcodes[147], in the case of bakeries, purchase data remain incomplete for products without a barcode. Hence, for bakery goods – bread, *viennoiseries* and *patisseries* –, this study completed the panel data by adding purchase quantities representing the sales share (58%)[148] of total bakery goods purchased in traditional bakeries in France. The share sold in supermarkets at bakery points of sale was not compensated for, but it was much smaller in any case.

INSEE carries out the 5-yearly Household budget survey (e*nquête Budget de famille*), a national survey to analyse households' accounts (INSEE, n.d.). Covering expenditure on goods, services and resources, the survey provides the full picture of the financial side of the living conditions of households in a country. For each household, data collection covers the category of the expense, the amount, the quantity if relevant, and the point of purchase. In the past, INSEE carried out a dedicated food consumption survey, named *Consommation alimentaire*, that covered food purchase quantities, in terms of mass. As the survey was stopped in 1991, the Household budget survey included questions about purchase quantities, starting from its 2006 survey and onwards. While INSEE analyses and widely disseminates the results of household expenses, as the survey core information, it has not analysed purchase quantities so far. The

[146] The Kantar Worldpanel data for 2011 were relevant for the use of the second data source, the INSEE household budget survey from 2011. The change in purchase quantities from the panel data between 2011 and 2014 was applied to purchase quantities of the INSEE survey, to align data from both sources with the same reference year.
[147] Kantar Worldpanel expects a high level of errors for such frequent purchases of small quantities like bread, but considers a much lower risk of errors for other food items also sold without a barcode, for example sold at a fishmonger, butcher or green grocer. The sales share of channels which do not sell pre-packed food with a barcode is highest for bread, with a share of 58% of total sales.
[148] Sandrine Bize, *Confédération générale de l'alimentation en détail* (CGAD), personal communication, 17/12/2019.

2011 survey, used in this study in option HH2, was on 10,300 households on the French mainland, and 5,500 households in overseas *départements*, including Mayotte.

The raw data of the 2011 survey ("Budget des familles - 2010-2011, INSEE [producteur], ADISP [diffuseur]," n.d.)[149] gathered in nineteen data sets or files were used for calculating food flows to households in option HH2. Various data sets cover socio-demographic information of participants at the individual and the household level. Other data sets are dedicated to categories of expenses, such as consumer goods, automobile, internet and telephone contracts, health care, insurance policies, and consumer durables. The relevant file for this study, named CARNETS (the French word for diaries), contains information about all purchases reported in a diary by household members over the course of one week. This study for the first time analysed purchase quantities of food and drink from the INSEE Household budget survey. The aim of the analysis was to obtain the average quantity, in mass, of food and drink of all Île-de-France households for one year. Based on the data of participating Île-de-France households, we used the software R to calculate the mean purchase quantity of food and drink per household per week, and extrapolated it to all Île-de-France households and to one year. The food and drink product categories, initially following the classification used in the national accounts, were restructured to follow the transversal nomenclature developed for this study (see Appendix to Chapter 3). The initial Classification of Individual Consumption by Purpose (COICOP) is one of the "functional" classifications of the national accounts system (SCN) (INSEE, n.d.), and is used to classify transactions made between producers and households as an institutional sector. It is called functional because it identifies objects or objectives for which these transactions are made (INSEE, n.d.). Households' spending on food, health, education and so forth are analysed regularly.

The relevant data set CARNETS used for the analysis contains ten variables, which are types of information arranged as columns in a tabular data set, related to household purchases and expenses. The ten variables are household identification number (IDENT_MEN), number of a person (NOI), distance between the municipalities of the store and the household residence (DIST), store code (CODE_MAG), product code (NOMEN5), purchase unit (UNITE), purchase quantity (QUANTITE), purchase expense (MONTANT), line number (NUMLIGNE)

[149] The data set is available to scientists from the Quetelet network and was accessed through the Réseau Quetelet (*réseau français des centres de données pour les sciences sociales*), French data archives for the social sciences.

and size of urban unit (TUU). CARNETS is 712,652 lines long, with each line referring to one purchased item characterized by the ten variables. 15,469 households altogether have filled in the purchase diaries coded in the CARNETS data set. To check the representativeness of the households' socio-economic profile, we used a second data set called MENAGES, containing socio-demographic information at the household level.

For the purposes of this study and based on CARNETS, we extracted a secondary data set named *francbis* by filtering out purchases of food and drink items by Île-de-France households only. By doing so, the *francbis* dataset was reduced to 55,387 lines, that is, 8% of the CARNETS data set. All further steps of data analysis were done with *francbis*. The relevant information concerning the purchase quantity of an item was available in the three variables: product code (NOMEN5), purchase unit (UNITE), and purchase quantity (QUANTITE). The variable purchase expense (*montant*), expressed in euros, was additionally used to fill data gaps in the purchase quantity. Product codes of food and drink items followed the COICOP nomenclature on sixty-one categories. The purchase unit was given optionally for mass, volume or unit.

The data analysis of the mass of total food and drink purchases of Île-de-France households had to deal with several difficulties. Firstly, in the case of 11,601 purchases, that is, 21% of the data set *francbis*, no answer was given for the variable for purchase quantity. To fill in empty fields with purchase quantity, we calculated average prices per purchase unit (mass, volume, unit) using purchase expense and defined rules for imputation. By doing so, we built a second variable for purchase quantities based on the initial one but completed for the imputed values. The new variable for purchase quantities had no more fields with no answer.

Secondly, respondents could report the purchase unit of a given product from three different units (mass, volume or unit) or leave the field empty. For most of the sixty-one product categories, there were answers in at least two units and no answer given[150]. Since the research aim of this study was to quantify food flows in mass, we converted quantities to mass. For quantities given in volume we used density, and for quantities given in unit we used average prices and standardized mass. By doing so, we built a third variable for purchase quantities

[150] Table A4.2 in Appendix to Chapter 4 shows the number of observations per unit and product.

based on the second one, comprising initial values of purchase quantities given in mass and converted values from initially other units given.

Thirdly, errors can have occurred at data collection stage in either reporting purchase quantity and unit, or when the two lack coherence. We found errors in the reporting of purchased eggs, for instance. Some respondents reported the number of egg boxes instead of the number of eggs, as requested. We found the same type of error with yoghourt. We found errors in unit choice, for example litres of bread. In most cases, lacking a solution for correction, we left the information unchanged. In the cases of eggs and yoghourt however, where purchases were reported for one unit, the error seemed obvious because these items are usually not sold unit-wise. We removed these purchases – that is, 14 out of 322 and 235 out of 459 for eggs and yoghourt – from further data analysis and later compensated for missing quantities when extrapolating the food and drink purchases of Île-de-France households.

A detailed description of the data analysis together with the script written under R is provided in the Appendix to Chapter 4.

Besides completing under-reported or missing purchase data, other adjustments were necessary. Their purpose was to reduce biases which originate in the discrepancy between the data sources used and the analysis framework of this study, for example differences in geographical or temporal system boundaries relevant for data collection. Table 22 provides an overview of the various adjustments made to the calculation of the annual purchase quantity for 2014. For example, in line with the concept of the eating population, we reduced the annual purchase quantity proportionally to the average time spent away by households from the urban system (see 3.1.3). Furthermore, we adjusted total purchase quantity proportionally to the differences between the samples and the average number of people per household in the resident population, referred to as household size, for Île-de-France. Since in 2014, the average household size is slightly smaller in Paris Petite Couronne than in Île-de-France (2.19 versus 2.32 members per household) according to the census, and we adjusted purchase quantities accordingly.

Table 22. Household purchase data characteristics and adjustments to the calculation of annual purchase quantity for 2014

	Household budget survey data		Kantar consumer panel data	
	Data characteristics	**Adjustments to the calculation of annual purchase quantity**	**Data characteristics**	**Adjustments to the calculation of annual purchase quantity**
Reference unit	Total quantity of household samples	Extrapolation from sample to total household number	Mean quantity per household	Extrapolation from one household to total household number
Temporal scope of purchase quantity data	One week	Extrapolated to one year and reduced by time spent away from the urban system (39 days)	One year	Reduced by time spent away from the urban system (39 days)
Reference year for data	2011	Augmented by the increase of 2.2% of household purchase quantities observed in yearly Kantar panel data between 2011 (1,255 kg) and 2014 (1,283 kg) according to Kantar panel data	2014	None
Lack of data / coverage	Raw data with many missing values in variables for purchase quantity; reporting errors	Augmented by estimated purchase quantities of eggs and yoghourt initially removed because of obvious reporting errors (252 kg for both items, that is, less than 1% of total purchase quantity)	Bakery goods without barcode	Augmented for *bread*, *viennoiseries* and *pâtisseries* by 58% of the purchase quantities, corresponding to the sales share of independent bakeries in France
Difference in household size between survey samples and resident population, for Île-de-France	Average household size of Île-de-France survey sample is 2.415	Decreased proportionally with the difference (3.9%) between survey sample (2.415) and resident population (2.32)	Average household size of Île-de-France sample is 2.08	Increased proportionally with the difference (10.3%) between survey sample (2.08) and resident population (2.32)
Adjustment to Paris Petite Couronne case study	Average household size of Île-de-France survey sample is 2,415	Decreased proportionally with the difference (9.3%) between average household size of Paris Petite Couronne population (2.19) and survey sample (2.415)	Average household size of Île-de-France survey sample is 2.08	Increased proportionally with the difference (5.3%) between average household size of Paris Petite Couronne (2.19) and survey sample (2.08)

Apart from the household purchase quantities, the Household budget survey provided information about where people shop for food, analysed by INSEE based on food expenditure (INSEE Première, 2014). In 2011, 70% of households located in the urban unit of Paris[151] but excluding Paris from these figures, shopped for their food at large food retailers (super- and hypermarkets, discount markets), 17% at specialized shops (bakeries, butchers etc.), 6% at the market, and 5% at small or medium-sized retailers. Yet Parisian households purchased less of their food at large food retailers (63%) and more at small or medium-sized retailers (9%) and in specialized shops (20%) (INSEE Première, 2014). Internet purchases for food were negligible at the time. We used the food expenditure distribution to allocate the food supply of the household eating population, and after extrapolation, of the total eating population according to given types of shops. The expenditure distribution is probably slightly different from the mass distribution as prices for food are higher in specialized shops and markets and possibly also small- and medium-sized retailers.

4.2.3. Meal service in the food service sector

As shown in Figure 28, we tested two possible options, FS1 and FS2, for the quantification of food flows in the food service sector.

Quantification according to option FS1 is based on the quantity of food and drink intake allocated to out-of-home consumption in the food service sector (see 4.2.1). Following a mass balance approach, food and drink supply (FS1) is calculated from food and drink intake plus food waste, the latter obtained through coefficients from the literature (see 4.2.4). However, as drink does not have the same high levels of waste as food, drink supply was calculated disregarding food waste in food supply.

Quantification according to option FS2 was based on the number of meals served. For the social food service sector, the regional service of the Ministry of Food and Agriculture in Île-de-France provided on request the total number of meals, summarized in Table 23, served in 2014 in the different establishments in Île-de-France and in Paris Petite Couronne. The data was available from the Resytal database, a national information system about safety in the field of agriculture, livestock and food, hosted at the French directorate general of food (*Direction générale de l'alimentation*, *DGAL*). Meals that are counted are the number reported as service

[151] The urban unit of Paris comprises a population of approximately 10 million inhabitants, located in the urban area of the Île-de-France region. It makes up 80% of the population of the region (see 2.3 for characteristics of the case study and definitions).

capacity when the restaurant site opened. They comprise lunch and dinner, but not breakfast or any snacks. Table 23 shows that the education sector, followed by companies and administrations, are the sectors where the most meals in social food services are served. To calculate the total quantity served, the number of meals served was multiplied by the mean mass of a meal served, retrieved from the literature and accounting for food only, by distinguishing meals served to adults, with 580 grams per meal (Income Consulting, 2016), and meals served to children, with 476 grams per meal (Bigue, 2016). For residents in prisons, we increased the mean mass of a meal by a factor 1.35 to account for the penitentiary administration's tendency to oversupply[152]. In the education sector, the mean mass of a meal served to children covered all age groups. For establishments where residents stay and eat all their meals (hospitals, retirement homes, prisons, etc.), we augmented total quantity served for lunch and dinner in order to obtain daily food intake of adults, that is, by a factor of 0.44 compared to a factor of 0.29 and 0.28 for lunch and for dinner each (see 3.1.3). For students living in student homes, we counted one breakfast out of two. To account for drink additionally to food, the ratio of food to drink, 0,4/0,6, retrieved from the food intake study INCA 3 (Anses, 2017) allowed us to calculate the additional supply of drink.

Table 23. Number of meals served in the social food service sector per type of establishment for Île-de-France and Paris Petite Couronne, 2014

	Île-de-France	Paris Petite Couronne
Military establishments	12,867,710	4,918,010
Prisons	7,589,810	839,500
Nurseries and daycare centres (*crèches – centre de loisirs*)	19,016,830	14,304,800
Hospitals, retirement homes	153,729,185	89,797,440
Companies and administration	187,335,750	124,897,230
Education sector	282,326,755	154,807,900
Total	**662,866,040**	**383,807,370**

source: extracted from the Resytal database for the year 2014, version 1/1/2018

[152] Food is a highly sensitive issue in prisons. The prison administration wants to avoid any risk of letting food become an issue of resentment and therefore tends to oversupply (François Mauvais, DRIAAF, per email on 16 December 2019).

In contrast to social food services, the number of meals is unknown in the commercial food service sector. GIRA Food, a market research and consulting company in the field of food services, estimated that, at national scale, the number of meals served in the social and the commercial food service sectors is about the same (GIRA Food Service, 2014). Referring to the assumption that the distribution of 50/50 is also valid for Paris Petite Couronne and Île-de-France, we doubled total quantity and, according to the principles of the inner-urban food flow model (Figure 28), applied a multiplicator of 2 for coefficient FS-coef served in the social sector. This enabled us to account for the commercial sector and to obtain total quantity served in food services. Again, expenditure from the Household budget survey for eating out in the social and the commercial sector does not help to establish the relative weight of food and drink intake in terms of mass, due to the difference in prices.

4.2.4. Food waste

While the quantification of food waste at the system level, discussed in Chapter 3, was mostly based on survey data, it is not possible to apply the same approach for sector-wise food waste quantification in Chapter 4. Data sources are not available to directly quantify food waste for either households or food services. Instead, I have used a mass balance approach and data from the literature. The food waste results from both the systemic and the sector-wise level fed into the hybrid MFA-food system model are discussed in Chapter 5.

At the household level, the quantity of food waste was obtained using the data sources described above, and subtracting food and drink purchases and intake data. Since two data sources for household purchases, the INSEE Household budget survey and the Kantar consumer panel, were available, the food waste quantification was performed according to two options, HH1 and HH2. Flows of food and of drink, excluding tap water, were shown distinctly from the analysis of food waste.

At the level of the food service sector, several types of information from food waste studies and field data were used. These are summarized in Table 24. They all refer to food only and exclude drink. Overall, studies about food waste in the food service sector point out huge variability in the quantities generated (Betz et al., 2015; Sebbane and Costa, 2018; Silvennoinen et al., 2015), influenced by many different factors (management, type of meal service, over-supply, target population, etc.). Hospitals for example have the highest levels of wasted food due to the particular eating situation of hospitalized persons. The proportion of wasted food (*pertes et gaspillages alimentaires*) established in a French report commissioned by the Ademe (Income Consulting AK2C, 2016) provided the ground for the food waste quantification in both the social and the commercial sector. 22 restaurants in the social and 37 restaurants in the commercial food service sector participated in the study by reporting wasted food quantities, but the number of meals served during the weighing process was not reported in this study nor was the standard deviation of the mean values given. Data obtained through weighting, which are more reliable than data from declaration, came from two restaurants, one in each sector, but unfortunately they were not tagged in the report. While the study reports a mean quantity of wasted food of 157 g per meal in the commercial food service sector, the quantity is lower in the social catering sector, with 116 g per end user and per meal (Income Consulting AK2C, 2016). Related to the average mass of 580 grams for a meal, excluding drink, the share of wasted food is 27% in the commercial food service sector and 20% in the social food service sector. According to this study, better management of the stocks prior to the meal preparation explains the difference between the two sectors. The study however does not include in the analysis wasted food at meal preparation when this is done in central kitchens. Central kitchens centralize meal preparation at one place and deliver the meals on order to mostly institutional establishments, such as schools, universities, hospitals, retirement homes. Since the study does not provide details about the organization of the surveyed restaurants, it is hard to see whether the quantities and share of wasted food for both food service sectors relate to exactly the same stages. Quantities of wasted food in the social catering sector should be slightly higher when meal preparation is included, although studies showed that central kitchens generate little such waste[153] as they provide meals on order.

Another study analysed the generation of bio-waste in the commercial food service sector and found that plate waste and unserved or expired food, together regarded in the study as wasted food, totalled 125 g per end user and meal on average, weighed across 11,402 meals served (Moulinot Compost et Biogaz, 2015). Related to an average meal of 580 g excluding drink, the

[153] Central kitchens generate 1 – 3% wasted food compared to total turnover (Anne Tison, Excellents Excédents, 14 May 2020). The point is that, compared to the other stages in food service, this stage is highly predictable and well organized, in contrast to meal service and meal intake where the end users' choices and preferences strongly determine food waste (Income Consulting AK2C, 2016). This illustration is also confirmed by a study from the national food service organization (*Groupement National de la Restauration, GNR*), cited in a study by Ademe (Ademe, 2013), which reports a quantity of bio-waste of 11g per meal in central kitchens. This value is very low compared to quantities per meal reported for establishments of social catering (125 g and 134 g) or for commercial restaurants (140 g).

share of wasted food amounts to 22%. This study, carried out with a view to testing the feasibility of bio-waste collection and recycling, covered eighty restaurants in Paris, nearly all of which prepare the meals themselves from raw products. This implies that all wasted food at meal preparation stage is included. Driven by a gradual implementation of separate bio-waste collection[154], the management of restaurant waste from meal preparation has moved into the focus of one of the financing bodies, the Synhorcat professional organization representing independent business in hotels, cafés, restaurants, catering companies and the nightlife business.

A data set of quantities of wasted food was kindly made available for this study by *Excellents Excédents*, a small company located in the Île-de-France region, acting as an intermediate chain between the food service industry and charities, by collecting surplus food for redistribution. Based on extensive weighing campaigns, *Excellents Excédents* has in-depth knowledge about food waste in the social food service sector. The data set, available in Table A4.9 in the Appendix to Chapter 4, contains mean quantities of wasted food per establishment and per meal, the number of days of weighing, the number of meals prepared, for 31 establishments almost exclusively in the education sector in Ile-de-France, with the participation of the four school types for pupils aged 3 to 18 [155]. The data were collected in the course of the period from 2014 to 2017; at a time before establishments started to implement any food waste reduction enablers[156]. We calculated a mean quantity of wasted food, weighted for the number of meals served, of 156 g per end user and meal and a standard deviation of +/- 59 g.

In another study about school canteens, Bigue (2016) analysed wasted food in nine primary schools in the north-east of Montpellier[157]. Over twenty-three days, wasted food was weighed for a total of 3,810 meals. Bigue found a result of 137 g per end user and per meal, and a standard deviation of +/- 52 g (Bigue, 2016).

[154] Law n° 2010-788 from 12 July 2010 on national commitment to the environment.

[155] Kindergarten or pre-school (*école maternelle*) for pupils aged 3 to 6; primary schools (*école primaire*) for pupils aged of 6 to 11; middle school (*collège*) for pupils aged 11 to 15; high school (*lycée*) which covers the last three years of secondary education, for pupils up to 18 years old, and which finishes with the *baccalaureat*.

[156] For twenty-two establishments, wasted food quantities were also measured at a second point of time to assess the impact of implemented enablers. Yet the vast majority of these measurements were made for one day only, which is not enough to conclude on an impact. These first findings show a wide variability in the decrease of wasted food. In some cases though there was an increase.

[157] P-G&City study (2015-2016) funded by the INRA-CIRAD GloFoodS Metaprogram

All values of wasted food reflect the situation at one point of measurement, here at the restaurants, but do not cover potential externalized stages, such as centralized meal preparation. Meal preparation for a given food service establishment can require different forms of organization (Sjögren et al., 2015), but a detaile description of the situation at a regional or municipal level is only partly available, most often for institutional catering such as for schools. Considering poor information and since the overall contribution of central kitchens to wasted food is small, we did not additionally account for it. We did not account for differences between food service establishments either. While quantities of wasted food are available for the social and the commercial food service sector in general and for school catering specifically, there is no comprehensive data base for the entire sector, although some data is published in one of the first reviews for France carried out in 2011 by Supkova (2011). For the quantification of the food waste flow in the food service sector, we therefore retained a mean quantity of wasted food of 140 g per end user per meal, or a share of 24%, applied to the entire food service sector on a basis of an average meal of 580 g excluding drink (Income Consulting AK2C, 2016)[158]. This value is in-between a mean quantity (143 g), weighted for the number of meals served, of the three data sources which provided these numbers, and a mean value (138 g) of all five data sources, without weighing. Standard deviation could not be calculated.

Data about the quantity of inedible parts, as the other fraction of food waste, are available from the study of Moulinot Compost et Biogaz (2015). Inedible parts in this study refer to the portion of bio-waste at meal preparation that was collected separately. Coffee grinds, another type of bio-waste that is regular in restaurants, was not included. In this study, 54% of the bio-waste related to a meal, is considered inedible, that is, a mean of 150 g per meal. As with wasted food, the variability in the generation of bio-waste between different types of restaurants is high. In the case of inedible parts, it tends to increase particularly with the use of raw, first range ingredients, such as fresh fruits and vegetables or sea food with shells, in contrast to the use of canned, frozen, and other ready-to-use ingredients. For instance, the extremes of bio-waste quantities in the study are set by 153 g per meal in fast food restaurants and 1,290 g per meal in upper class gastronomy, reflecting such differences in meal preparation. The sample of eighty restaurants participating in this study however was over-represented with traditional restaurants, 75% of the sample, with a majority of on-site preparation, therefore not representing

[158] In school catering, the average mass of a meal is probably lower than in establishments serving adults. Bigue (2016) has calculated average mass of 469 g for meals in primary schools.

the restaurant structure in Paris or even less so in Paris Petite Couronne or Île-de-France. The mean quantity of 275 g of bio-waste per meal seems overestimated compared to the general restaurant structure in Paris, including commercial restaurant chains. However, since all bio-waste at meal preparation is included, this value can be used as a proxy value for bio-waste generation in the food service sector, irrespective of whether meals or meal ingredients are prepared on-site or in external services. When we use this value for the quantification of food waste in the food service sector in Paris Petite Couronne and Île-de-France, we assume that the bio-waste is generated within the system.

Table 24. Mean quantities of wasted food and inedible parts per end user and meal

Data source	Food service sector	Number of meals served at the time of weighing	Wasted food [1] (g per end user and meal) and share, %, of a meal [2] (in italics)	Standard deviation (g per end user and meal)	Inedible parts (g per end user and meal)	Total food waste (g per end user and meal)
Ademe (2016)	Social	n.r.	116 *20*	n.r.	--	--
Ademe (2016)	Commercial	n.r.	157 *27*	n.r.	--	--
Moulinot Compost et Biogaz (2015)	Commercial	11,042	125 *22*	n.r.	150	275
Excellents excédents	Social (school catering)	18,094	156 *24*	59	--	--
Bigue (2016)	Social (school catering)	3,810	137 *24*	52		
Mean value	all		140 *24*		150	285

[1] drink was not considered
[2] average meal weight: 580 grams excluding drink for all types of establishments (Income Consulting AK2C, 2016);
n.r. signifies not reported

Coefficients for the calculation of food waste in the food service sector can be derived based on Table 24. With a mean value of wasted food of 24%, coefficient wf-MS was 24. While wasted food referred to average meal served, total food waste includes inedible parts, usually generated at meal preparation. The ratio of wasted food to inedible parts, R-wf/ip, of 47/53 adjusted from the study from Moulinot Compost et Biogaz (2015), allowed me to calculate the food waste coefficient FW-coeff-I by dividing food supply through meal served, based on Table 24. Applied to results of out-of-home food intake excluding drink, it yielded total food supply for the food service sector, excluding drink, in the quantification option FS1, according to the following formula:

Formula 1

I * FW-coeff-I = FS1

FW-coeff-I = FS_{lit} / I_{lit} = (wf-MS*MS_{lit}*1/R-wf/ip + MS_{lit}) / I_{lit}

FW 1 = FS1 – I

With

I = intake, in tonnes
FS1 = food supply in option FS1, in tonnes
FW 1 = food waste in option FS1, in tonnes
FW-coeff-I = coefficient that augments food intake by food waste, obtained from the literature in Table 24
FS_{lit} = food supply obtained from the literature, in grams
MS_{lit} = mean meal served from the literature, in grams
I_{lit} = food intake obtained from the literature, in grams
wf-MS= share of wasted food in meal served
R-wf/ip = ratio of wasted food to inedible parts

Based on Table 24, FS_{lit} was 736 g, MS_{lit} was 580 g, I_{lit} was 441 g, wf-MS was 0.24 and R-wf/ip was 47/53. The coefficient FW-coeff-I was found to be 1.67.

For quantification option FS2, the same references were used as for option FS1, but in a different way. Since the starting point for quantification was meal service, wasted food and inedible parts were calculated separately. While together building food waste, only inedible parts were used to calculate total food supply for the food service sector in quantification option FS2, according to the following formula:

Formula 2

MS + FW-coeff-MS*MS = FS2

FW-coeff-MS = $wf - MS * 1$/R-wf/ip

$MS + wf - MS * 1$/R-wf/ip * MS = FS2

I = MS – MS*wf-MS

FW 2 = MS*wf-MS + FW-coeff-MS*MS

with
MS = total quantity of meals served, in tonnes
FS2 = food supply in option FS2, in tonnes
FW 2 = food waste in option FS2, in tonnes
FW-coeff-MS = food service food waste coefficient from meal service (inedible parts)
wf - MS= share of wasted food in meal served
R-wf/ip = ratio of wasted food to inedible parts

Based on Table 24, wf-MS was 0.24 and R-wf/ip was 47/53. The coefficient FW-coeff-MS was found to be 0.27.

Table 25 summarizes all coefficients obtained from Table 24 for the calculation of food waste flows.

Table 25. Coefficients for food waste quantification in the food service sector

coefficient	Value	Unit	source
FS_{lit}	736	g	Income consulting (2016), Table 24
MS_{lit}	580	g	Income consulting (2016), Table 24
I_{lit}	440	g	Income consulting (2016), Table 24
wf-MS	0.24	-	Table 24
R-wf/ip	47/53	-	Table 24
FW-coeff-MS	0.27	-	Table 24
FW-coeff-I	1.6	-	Table 24

4.2.5. Tap water

When food flows are calculated from various data sources in the food system, special attention is required for the issue of water. This is because water is commonly added or removed in food processing and preparation, therefore changing the mass along the process, without proper accounting for it. Changing water content in biomass, from the point of extraction from the environment to its return back, disturbs the readability and interpretation of material balances. The reason is that the size of material flows usually measured in fresh weight is affected without changing society's use of biomass since the dry matter does not change. Incomplete material balances due to missing water flows affect the reader's comprehension of it.

To account for water changes in biomass, such as food, so-called balancing items are used (Eurostat, 2001). They are introduced for balancing but are not part of the indicators related to input, output or consumption, derived from the balance accounts. They are very different from water flows which circulate in the food system without being incorporated into food, and which are used for very different purposes in agriculture, the industry and sites of food preparation. The EUROSTAT method (2001) suggests that water flows in the economy represent enormous mass flows compared to material (one order of magnitude more than all other materials) and that accounts should be drawn up and presented separately. Balancing items for water generally include water exchange with the environment from human and animal respiration. For the purposes of this study, human metabolism is not considered. Food flows end in this study when food is eaten or directed away from being eaten. Water flows as balancing items serve to balance food and drink input and output flows, in particular for drink.

At least two issues must be resolved: the preparation of liquids from dry products by the addition of water and, partly related to that, the use of tap water to drink. In the case of hot drinks, intake data report quantities in volume, whereas purchase data refer to unprepared dry products, notably of tea and coffee. With 486 g per day for adults (Anses, 2017), hot drinks represent an important share (17%) in daily food and drink intake, and therefore need to be adequately modelled by considering additional water flows. We consider that the additional water flows used for hot drinks are tap water. Soup is less of a problem for two reasons. With a mean intake of 100 g per day for adults or 3% of daily intake (Anses, 2017), intake quantities are smaller than for hot drinks, and I have adjusted purchase data from the Kantar panel to reflect prepared soup expressed in volume, not in mass. Water use for instant soup preparation therefore does not need to be considered in option HH1 for household purchases[159]. In option HH2, instant soup is not reported distinctly from liquid soup in the soup category of the

[159] The category soup, composed of liquid ready-to-eat soup and dry instant soup, is expressed as liquid, in volume. The category already includes water whether added at manufacturing or at household level. In the data, instant soup makes up 3.1 litres (water included) out of 8.4 litres of soup. This is why in option HH1, no more water needs to be added to the category of purchased soup to make it comparable with intake data.

Household budget survey. As I was unsure about the relative share of instant and liquid soup in purchased soup, I did not account for additional water in this option either. This decision is of minor importance since soup accounts for less than 1% of household food and drink purchases in the course of one week in the Household budget survey[160].

To account for tap water to drink, daily drink intake from the INCA 3 distinguished according to age group between the two categories tap water to drink (hot and cold drinks) and purchased drink (see Table 7), was used to calculate the respective quantities of tap water to drink and of purchased drink for the eating population. To add tap water supply to food and drink purchases in options HH1 and HH2, for the reason of simplification we added the quantity of tap water intake. This implies that loss or waste of tap water to drink in households is ignored here.

4.3. Food flows

4.3.1. In-home consumption

As shown in Figure 28, the food and drink flows related to the in-home consumption of the eating population were built from two parts. First, food and drink flows were calculated for the household population. Second, the flows were extrapolated to include the flows of the non-household population, therefore leading to the food and drink flows for in-home consumption of the eating population.

The results of food and drink flows related to the in-home consumption of households in 2014 are compiled in Table 26 and in Table 27 for Île-de-France and for Paris Petite Couronne, respectively. Sankey-diagrams in Figure 29 and Figure 30 show a visual representation of the results, completed by the distribution circuits for food and drink supply. For Île-de-France, households purchased food and drink (excluding tap water) in a quantity of 5,520 kt according to option HH1, and 5,717 kt according to option HH2. In addition, 2,454 kt of tap water to drink were supplied and ingested, with no waste being considered. In Paris Petite Couronne, households purchased food and drink in a quantity of 3,106 kt, according to option HH1, and 3,216 kt according to option HH2. In addition, 1,381 kt of tap water to drink was supplied and ingested, with no waste being considered.

[160] In option HH2, purchased soup amounted to 358 kg out of a total of 42,433 kg of food and drink purchased over one week by a sample of 1,732 Île-de-France households (see Table A4.6 in Appendix to Chapter 4).

Table 26. Food and drink purchases and intake of households for in-home consumption, Paris Petite Couronne, 2014

	Purchases [1]		Intake	Purchase – intake (food waste)			
	Quantities (kt) Share of total food and drink (%, in italics)		Quantities (kt) Share of total food and drink (%, in italics)	Quantities (kt) share of purchase (%, in italics)		Per capita quantities [3, 4] (kg/cap)	
	HH1	**HH2**		**HH1**	**HH2**	**HH1**	**HH2**
Food	1,762 *39*	1,994 *43*	1,764 *40*	-1 *0*	230 *12*	0 0	40 34
TOTAL drink	2,725 *61*	2,603 *57*	2,649 *60*				
- Drink, purchased	1,343 *30*	1,222 *27*	1,268 *29*	76 *6*	-46 *-4*	13 11	-8 -7
- Tap water to drink [2]	1,381 *31*	1,381 *30*	1,381 *31*				
TOTAL FOOD AND DRINK	4,489 *100*	4,597 *100*	4,413 *100*				
Food and drink (excl tap water)	3,106 *69*	3,216 *70*	3,032 *69*				

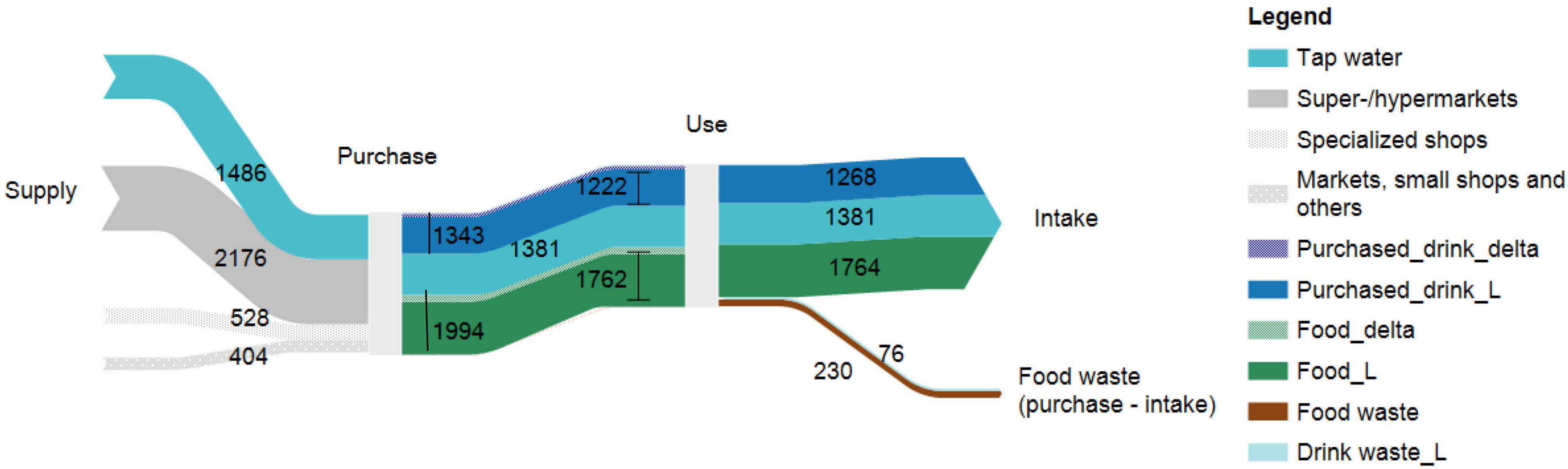
[1] data for food and drink purchases in HH1, from Kantar Worldpanel, in HH2, from INSEE Household budget survey
[2] estimated from intake data
[3] normalized with household eating population
[4] normalized with legal population

Table 27. Food and drink purchase and intake of households for in-home consumption, Île-de-France, 2014

	Purchases [1]		Intake	Purchase – Intake (food waste)			
	Quantities (kt)		Quantities (kt)	Quantities (kt) share of purchase (%, in italics)		Per capita quantities [3, 4] (kg/cap)	
	HH1	**HH2**		**HH1**	**HH2**	**HH1**	**HH2**
Food	3,132 *38*	3,545 *43*	3,159 *40*	-26 *-1*	386 *11*	-2 -2	36 32
TOTAL drink	4,842 *61*	4,626 *57*	4,724 *60*				
- Drink, purchased	2,388 *30*	2,172 *27*	2,271 *29*	117 *5*	-99 *-5*	11 10	-9 -8
- Tap water to drink [2]	2,454 *31*	2,454 *30*	2,454 *31*				
TOTAL FOOD AND DRINK	7,974 *100*	8,171 *100*	7,883 *100*				
Food and drink (excl tap water)	5,520 *69*	5,717 *70*	5,429 *69*				

[1] data for food and drink purchases in HH1, from Kantar Worldpanel, in HH2, from INSEE Household budget survey
[2] estimated from intake data
[3] normalized with household eating population
[4] normalized with legal population

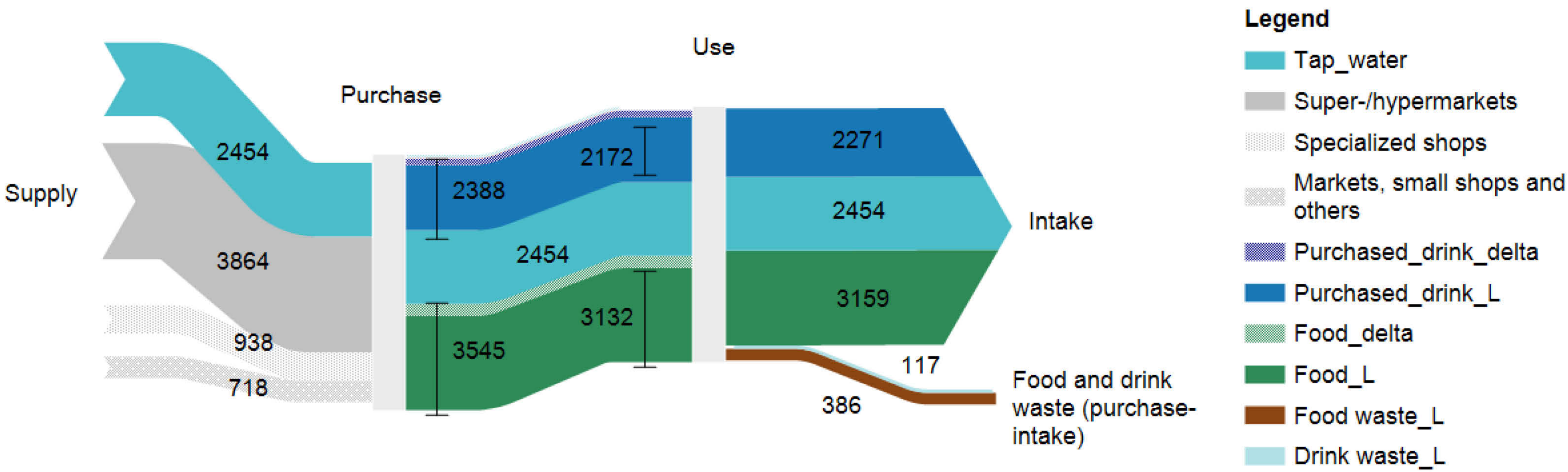
Figure 29. Food and drink flows related to in-home consumption of households, Paris Petite Couronne, 2014, kilotons



Source: Table 26

The figure should be read as follows: Labels ending with _L show the flows with the lowest (_L) value in the case of at least two options. Labels ending with _delta show the remaining flow to add to obtain the flow with the highest value. For given values, highest (not the delta) and lowest values are shown. The difference between purchase and intake was negative in the case of food (-2 kt) and drink (-46 kt) (not shown). To facilitate reading, flows of distribution circuits are displayed for the quantification option with the low result (3% lower than the result for HH2) for food and drink purchases, which was HH1 (3,106 kt). The difference compared to the upper result is small (110 kt).

Figure 30. Food and drink flows related to in-home consumption of households, Île-de-France, 2014, kilotons



Source: Table 27

The figure should be read as follows: Labels ending with _L show the flows with the lowest (_L) value in the case of at least two options. Labels ending with _delta show the remaining flow to add to obtain the flow with the highest value. For given values, highest (not the delta) and lowest values are shown. The difference between purchase and intake was negative in the case of food (-26 kt) and drink (-99 kt) (not shown). For comfort of reading, flows of distribution circuits were displayed for the quantification option with the low result (3% lower than the result for HH2) for food and drink purchases, which was HH1 (5,520 kt). The difference compared to the upper result is small (197 kt).

As Table 26 and Table 27 show, the difference between purchase and intake of food, a proxy for food waste, calculated in HH2, amounted to 230 kt and 386 kt for Paris Petite Couronne and Île-de-France, respectively, and accounted for 12% and 11% of purchases. By contrast, the difference calculated in option HH1 was slightly below zero in both urban systems, suggesting possible effects from methodology or data in the modelling. Other reasons are hard to find. Purchase and intake quantities can hardly be that close or inferior to intake, at a minimum because of inedible parts (e.g. fruits and vegetable peelings, some bones, egg shells, etc.) present in food when food is purchased but removed before intake. Unless the addition of water at cooking outbalances the discarding of food and inedible parts, we can expect that purchase quantities would exceed intake.

Normalized with the household eating population, per capita food waste calculated in HH2 amounted to 40 and 36 kg/cap/y for Paris Petite Couronne and Île-de-France, respectively, in HH2. As the difference between purchase and intake was calculated for the eating population and therefore excludes food that is eaten and wasted elsewhere over the year, household eating population is the relevant population for normalization. However, normalization with the legal population enables the use of the same indicator base used for local waste statistics and therefore allows for comparison. Per capita food waste decreased to 34 and 32 kg/cap/y when normalized with the legal population. The results in option HH2 appeared low compared to estimates of different local waste statistics for food waste in mixed household waste[161] (see Table 10 in Chapter 3) set at 66 kg/cap/y (pluriannual estimate) for Île-de-France and 56 kg/cap (2017) and 61 or 68 kg/cap (2015) for Paris. Overall though, the comparison with waste statistics is hindered by the fact that mixed household waste includes a share of waste from related economic activities. Because of missing information on the respective contribution of households and related economic activities in the context of Paris Petite Couronne and Île-de-France (at national level, 80% of mixed household waste comes from households and 20% from related economic activities (Ademe, 2019)), food waste in this study cannot be disentangled according to its origin.

For drink, the difference between purchase and intake was calculated as negative in HH2. A negative difference means that purchase quantities were lower than intake, which is plausible

[161] The difference between household purchase and intake of food (not drink), used as a proxy for food waste, can be compared with the waste statistics for the household waste management system (see Chapter 3). Liquid food and drink is rather disposed of the wastewater system and not included in the solid waste statistics, which is why it makes sense to look at the difference between purchase and intake separately for food.

only under certain conditions (see discussion 4.4.3). The difference amounted to -46 kt and -99 kt for Paris Petite Couronne and Île-de-France respectively and accounted for -4% and -5% of purchases. Conversely, the difference was positive in the quantification with HH1 and accounted for 6% and 5% for Paris Petite Couronne and Île-de-France, respectively.

Overall, a negative difference between purchase and intake can have several reasons. It can be a consequence of overestimated total intake in-home. Despite adjustment of the allocation coefficients retrieved from the INCA 3 study (Anses 2017) to the Île-de-France situation, using the expense structure, coefficients may still not apply and reflect the local situation. In-home intake may indeed still be lower than the result obtained through the adjustment process, and reversely out-of-home consumption may even be higher.

A negative difference between purchase and intake can also be a consequence of overestimated intake of tap water. This could come from the fact that I assumed the use of tap water for hot drinks such as tea and coffee for which the preparation mode is unspecified, which increased the tap water intake. Simulation shows that if half of the hot drinks were prepared with bottled water instead with tap water, the results would change only a little. This is because increased bottled water intake through hot drinks would not increase bottled water purchases, only redirect its use, whereas additional tap water supply would decrease (by 3%). Finally, hot drinks do not weigh enough to impact the category of purchased drink and explain a negative difference between purchase and intake.

All in all, the difference in purchase quantities between the two data sources used for the purchase quantification, Kantar Worldpanel for HH1 and INSEE Household budget survey for HH2, is substantial. Not only is the total food and drink quantity higher in option HH2, but food also represents a bigger share in HH2 (43%) than in HH1 (38%). The reason for the lower share in HH1 may be that some purchases are still missing, despite attempts to compensate for those data that we knew from the Kantar survey methodology were lacking (essentially bread and other bakery products) (see 4.4.2). Conversely to food, more drink (61%) was reported in option HH1 than in option HH2 (57%). The difference in drink comes from purchased drink, 30% and 27% in options HH1 and HH2, whereas tap water supply and intake was estimated to amount to the same quantity and accounted for the same share (31% and 30%) in both options. The difference turns negative for the categories that appear as underreported in the quantification options (food in HH1, drink in HH2).

Chapter 5 has a section specifically dedicated to a more detailed discussion about the compared food waste results, including those obtained as a difference between purchase and intake in in-home consumption, for urban and inner-urban flows quantified in Chapters 3 and 4.

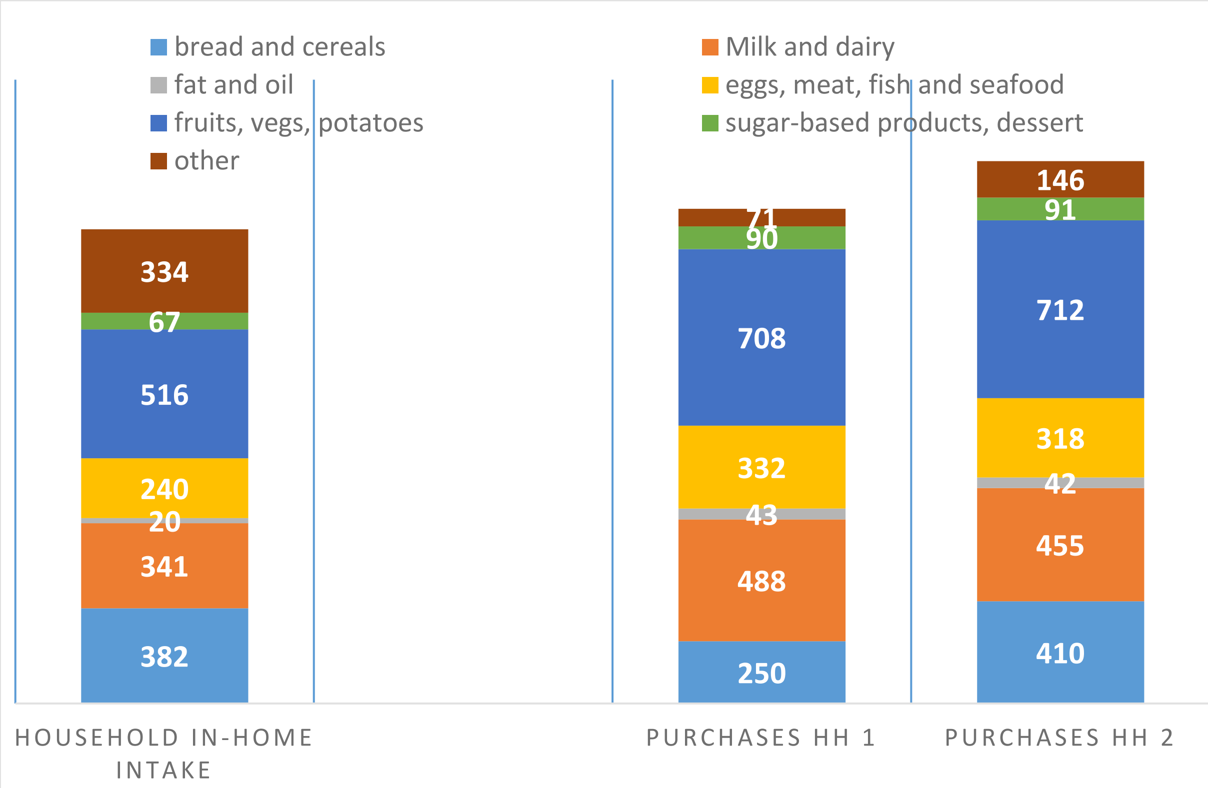
Figure 31 and Figure 32 show the contribution of different food categories to total food intake and purchases, by distinguishing between the two quantification options HH1 and HH2 for purchases. Drink is not considered in these figures. It accounts for so much (61% and 57% in option HH1 and HH2 respectively) and would determine the scale of the food and drink flows in such a way that it would leave the remaining share for food too small for an accurate and informative representation of the seven food categories defined in this study. Overall, the difference in purchase quantities between HH1 and HH2 is small. Most of the food categories are similar. Exceptions are bread and cereals and the category of other products, which is a mixed category containing pizza and other baked products, ice cream, soup and stock, etc. In these categories, purchase quantities were higher in HH2 than in HH1, with 410 kt and 250 kt, respectively, and for other products with 146 kt and 71 kt respectively in Paris Petite Couronne. In Île-de-France, the situation is similar, with 716 kt and 444 kt of bread and cereals in HH2 and HH2 respectively, and 256 kt and 127 kt for other products. While purchase quantities were lower in HH1 than in HH2 for bread and cereals and other products, more importantly, they were also lower than intake quantities. With 693 kt in Île-de-France (Figure 32), the intake of bread and cereals was 6% higher than purchases in HH1. With 606 kt, intake of other products was 478% and 237% higher than purchases in HH1 and HH2, respectively. In Paris Petite Couronne, the proportions are similar, with bread and cereal intakes being 50% above purchases in HH1, and other products 468% and 228% in HH1 and HH2, respectively. The intake of these categories could be even higher when the allocation between in-home and out-of-home consumption, equally applied to food and drink in this study (see 4.2.1), is considered category-specific over-consumption in-home, which is the case for the categories of bread and bakery products and soup and stock (Anses, 2017).

There are two possible explanations for this. For bread and bakery products, the difference with intake is particularly high with HH1. In HH1, the data of the Kantar Worldpanel suffered from missing purchase quantities since bread and bakery products in traditional bakeries did not have a barcode and therefore could not be reported. Coding of barcodes is the data collection method in Kantar panel data. Although we increased purchase quantities in this category (see 4.2.2) to account for purchases from traditional bakeries not using packaging with a barcode, it is possible that this solution was insufficient and that more data are missing.

For the category of other products, the intake quantity contains 47% of soup and stock, which consist essentially of water and therefore weigh heavily in the category which is already large. In HH1 and HH2, soup and stock represent a much lower share in purchases of the category of other products (35% of a quantity of 127 kt in HH1 and 18% of a quantity of 256 kt in HH2). Since the purchase quantities of the whole category is below the intake quantity, there presumably is an issue with water variation. It is possible that purchased quantities of soup and stock are partly reported as instant products to be prepared with water in-home[162]. Water addition to the category would increase the purchase quantity and would add to the supply of tap water to drink. However, considering tap water for meal preparation would require more detailed information about the types of products sold and their share in purchases, and in particular about water content variations between the purchase and the preparation of a food product. This level of detail was not available with the purchased food products in HH1 and could not even be collected in HH2.

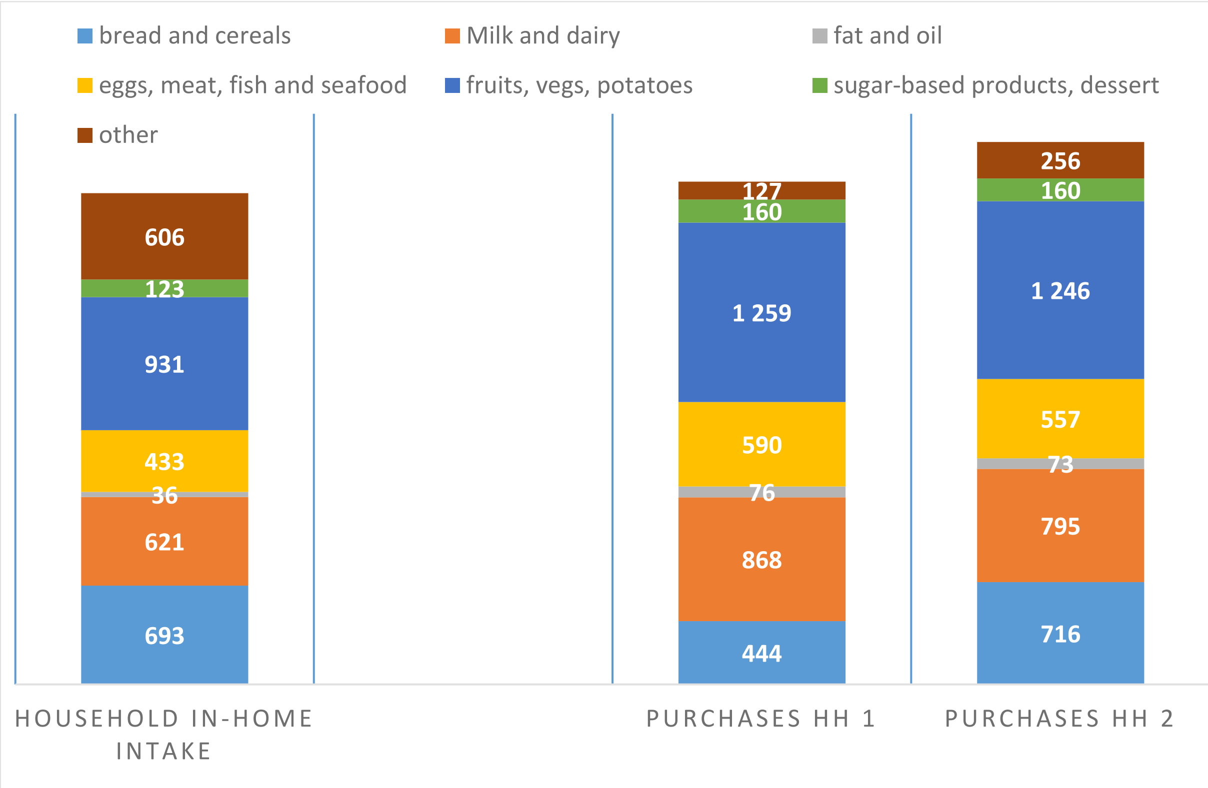
[162] Kantar panel data for soup and stock, which include liquid soup in packs and instant soup ready to prepare, reported the quantities ready to be eaten with water added for preparation being considered.

Figure 31. Household purchase and intake of food categories excluding drink in-home, Paris Petite Couronne, 2014, kilotons



Source: calculated for intake from INCA 3 study (Anses, 2017); data for food and drink purchases in option HH1 from Kantar Worldpanel, in option HH2 from INSEE Household budget survey

Figure 32. Household purchase and intake of food categories excluding drink in-home, Île-de-France, 2014, kilotons



Source: calculated for intake from INCA 3 study (Anses, 2017); data for food and drink purchases in option HH1 from Kantar Worldpanel, in option HH2 from INSEE Household budget survey

The inconsistencies in the role that food categories play in household food intake and purchases are shown differently in Table 28. For bread and cereals, the comparison of the distribution structure reveals that purchases are under-represented in the total annual food and drink purchases compared to intake (20%), in particular purchases according to HH1 (13%) despite bread purchases taking place in independent bakeries that I compensated for in this study. The difference is even larger and can be explained with water content in the category other products, with purchases accounting for 3% and 7% according to HH1 and HH2, versus 18% in intake.

Table 28. Distribution of food and drink purchases and intake of households for in-home consumption, Île-de-France, 2014, %

	bread and cereals	milk and dairy	fat and oil	eggs, meat, fish and seafood	fruits, vegs, potatoes	sugar-based products, dessert	other
Intake	20	18	1	13	27	4	18
Purchases HH1	13	25	2	17	36	5	4
Purchases HH2	19	21	2	15	33	4	7

Source: calculated for intake from the INCA 3 study (Anses, 2017); data for food and drink purchases in option HH1 from Kantar Worldpanel, in option HH2 from INSEE Household budget survey

As regards the eating population, the household population made up the most, that is 97% of the in-home food and drink intake of the eating population, with 4,413 kt and 7,883 kt for Paris Petite Couronne and Île-de-France, respectively (Table 29). Conversely, the non-household eating population, that is, residents not living in ordinary households and the additional population of tourists, commuters and excursionists, counted little with only 4% and 3%, or 169 kt and 232 kt for Paris Petite Couronne and Île-de-France, respectively. For in-home and out-of-home intake taken together, residents not living in ordinary households and the additional population contributed only 11% and 6%, in Paris Petite Couronne and Île-de-France, respectively (see Chapter 3). But in-home, this population accounts for less consumption as it predominantly eats out (see 4.2.1).

Table 29. Food and drink intake in-home of the household, non-household and total eating population, Paris Petite Couronne and Ile-de-France, 2014, kilotons

	Paris Petite Couronne			Île-de-France		
	Total eating population	Household eating population	Non-household eating population	Total eating population	Household eating population	Non-household eating population
Food and drink (excl. tap water)	3,143	3,032	111	5,586	5,429	151
- Food	1,828	1,764	64	3,246	3,159	87
- Drink, purchased	1,314	1,268	47	2,334	2,271	65
Tap water to drink[1]	1,436	1,381	55	2,529	2,454	75
TOTAL drink	2,751	2,649	102	4,863	4,724	139

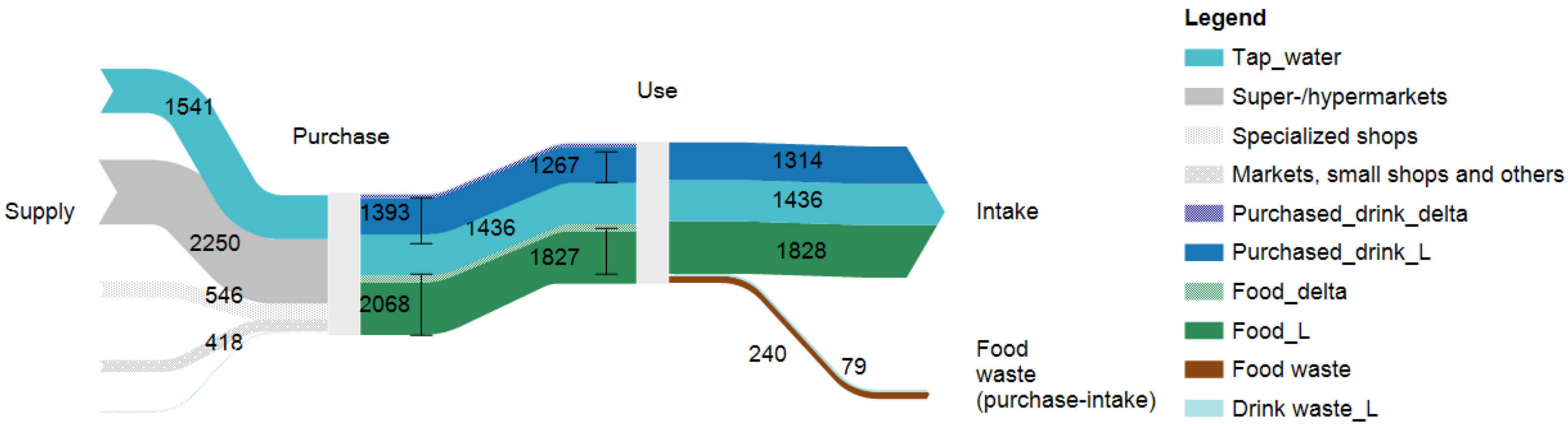
TOTAL FOOD AND DRINK	4,579	4,413	166	8,115	7,883	226

[1] estimated from intake data

Considering the non-household eating population in this study translated into an increase of household purchases to obtain total food supply for in-home consumption (Figure 28). The increase, 4% and 3% for Paris Petite Couronne and Île-de-France respectively, corresponded to the share of the population represented in the in-home food intake of the eating population, calculated from Table 29. Figure 33 and Figure 34 show the visual representation in the form of Sankey-diagrams for food and drink flows related to the in-home consumption of the total eating population, for Paris Petite Couronne and Île-de-France, respectively. Due to the small increase, the results for the total eating population differ only very slightly in the quantities of food flows compared to the results for the household eating population, shown in Figure 31 and Figure 32.

The integrated analysis of in-home and out-of-home food flows of the total eating population is considered in Section 4.3.3.

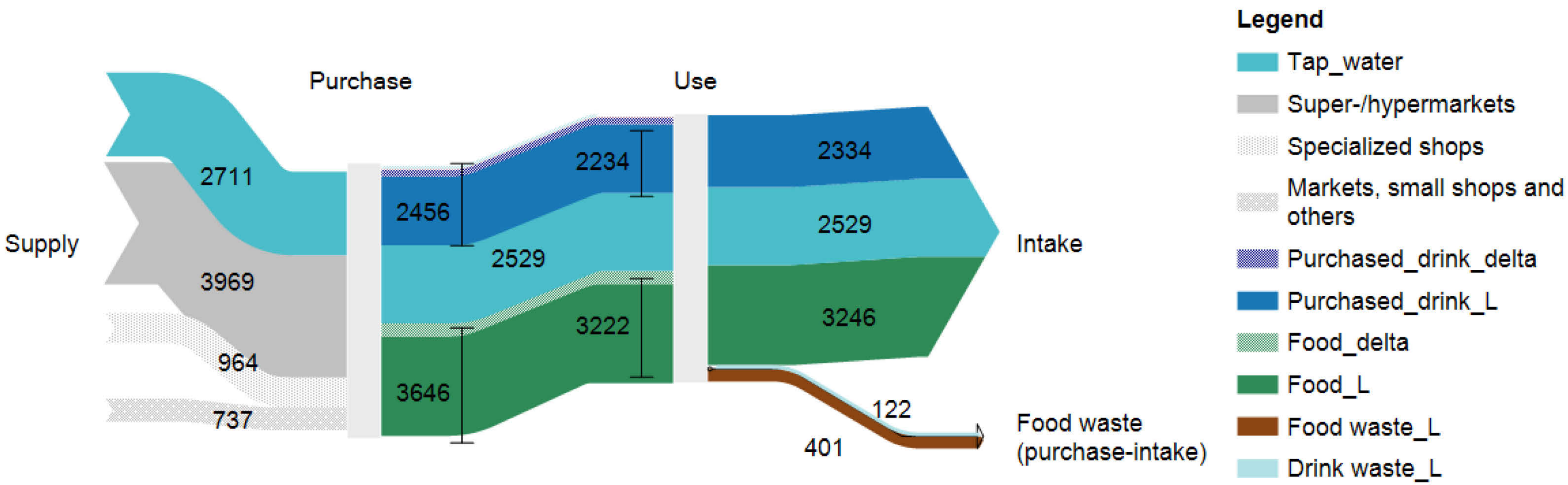
Figure 33. Food and drink flows related to in-home consumption, eating population, Paris Petite Couronne, 2014, kilotons



Source: Table A4.10, A4.12 and A4.14 in Appendix to chapter 4

The figure should be read as follows: Labels ending with _L show the flows with the lowest (_L) value in the case of at least two options. Labels ending with _delta show the remaining flow to add to obtain the flow with the highest value. For given values, highest (not the delta) and lowest values are shown. The difference between purchase and intake was negative in the case of food (-2 kt) and drink (-46 kt) (not shown). For comfort of reading, flows of distribution circuits were displayed for the quantification option with the low result (3% lower than the result for HH2) for food and drink purchases, which was HH1 (3,220 kt). The difference compared to the upper result is small (115 kt).

Figure 34. Food and drink flows related to in-home consumption, eating population, Île-de-France, 2014, kilotons



Source: Table A4.11, A4.13 and A4.15 in Appendix to chapter 4

The figure should be read as follows: Labels ending with _L show the flows with the lowest (_L) value in the case of at least two options. Labels ending with _delta show the remaining flow to add to obtain the flow with the highest value. For given values, highest (not the delta) and lowest values are shown. The difference between purchase and intake was negative in the case of food (-22 kt) and drink (-100 kt) (not shown). For comfort of reading, flows of distribution circuits were displayed for the quantification option with the low result (3% lower than the result for HH2) for food and drink purchases, which was HH1 (5,678 kt). The difference compared to the upper result is small (202 kt).

4.3.2. Out-of-home consumption

Table 30 and Table 31 summarize the results for food and drink flows related to out-of-home consumption according to the quantification options FS1 and FS2 [163], for Paris Petite Couronne and Île-de-France, respectively. Sankey-diagrams in Figure 35 and Figure 36 show a visual representation of the results.

A huge difference was found in the results between both quantification options, for both Île-de-France and Paris Petite Couronne. For Île-de-France, results were 207% higher for food and drink intake calculated in FS1 (3,457 kt) than calculated in FS2 (1,665 kt). For Paris Petite Couronne, the difference was even larger, with food and drink intake being 222% higher when calculated in FS1 (2,137 kt) than in FS2 (964 kt). Possible reasons for this huge difference in results between FS1 and FS2 are discussed under 4.4.2, and essentially relate to the use of coefficients and absolute quantitative data in both options. The fact that the difference between the quantification options FS1 and FS2 is larger for Paris Petite Couronne than for Île-de-France can again be attributed to a higher share of out-of-home consumption in the total eating population's food and drink intake in Paris Petite Couronne.

Results of food waste accounted for food only, excluding drink. Unlike studies about household food waste (Lee and Willis, 2010; Quested and Johnson, 2009), the available literature about food waste in the food service sector did not consider drink at all. No data was available to model food waste of drink, which is why in this study food waste for drink was also considered to be nil in out-of-home consumption.

Reflecting the coefficients used for the calculation of food waste (see Table 25), food waste accounted for 40% of food supply to the food service sector, including both wasted food and inedible parts, in both quantification options and urban systems under study (see Table 30 and Table 31). Similarly, the distribution of wasted food and inedible parts established in 4.2.4 determined the food waste flows, in FS1 and FS2, respectively. After application of coefficients (Table 25), wasted food and inedible parts amounted to 263 kt and 306 kt in FS1, and to 122 kt and 137 kt in FS2 for Paris Petite Couronne. For Île-de-France, wasted food and inedible parts amounted to 428 kt and 497 kt in FS1, and to 210 kt and 237 kt in FS2.

[163] See Figure 28 for the difference between quantification options FS1 and FS2.

Table 30. Food and drink flows related to out-of-home consumption, eating population, Paris Petite Couronne, in 2014, kilotons

	FS1			FS2		
	Supply	Intake	Food waste[1]	Supply	Intake	Food waste[1]
Food	1,418	849	569	644	386	259
TOTAL drink	1,288	1,288	--	579	579	--
TOTAL FOOD AND DRINK	2,706	2,137	569	1,223	964	259

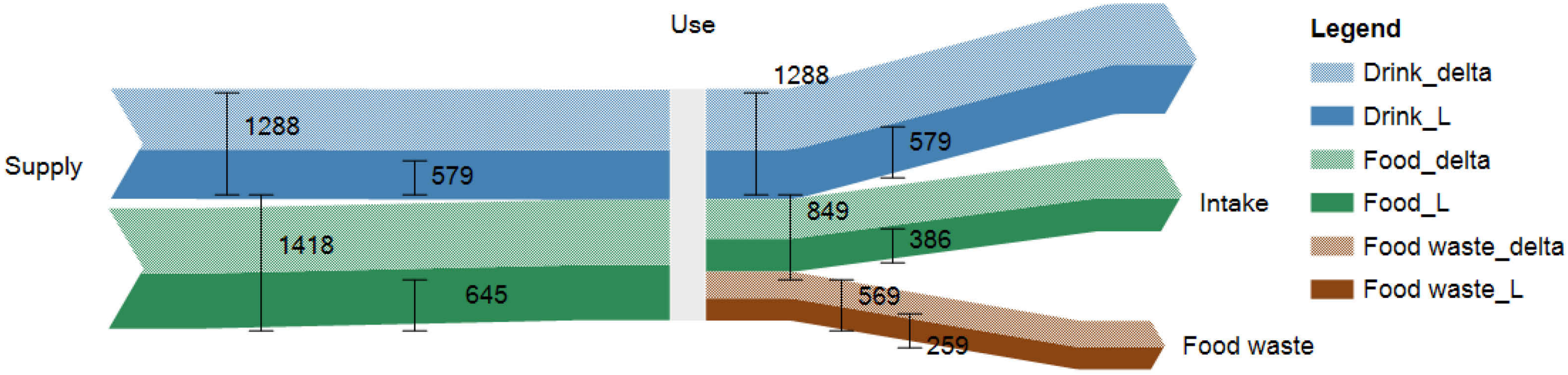
Note: [1] After application of coefficients (Table 25), wasted food and inedible parts amounted to 263 kt and 306 kt in FS1, and to 122 kt and 137 kt in FS2.

Table 31. Food and drink flows related to out-of-home consumption, eating population, Ile-de-France, in 2014, kilotons

	FS1			FS2		
	Supply	Intake	Food waste[1]	Supply	Intake	Food waste[1]
Food	2,306	1,381	925	1,113	666	447
TOTAL drink	2,075	2,075	--	999	999	--
TOTAL FOOD AND DRINK	4,382	3,457	925	2,112	1,665	447

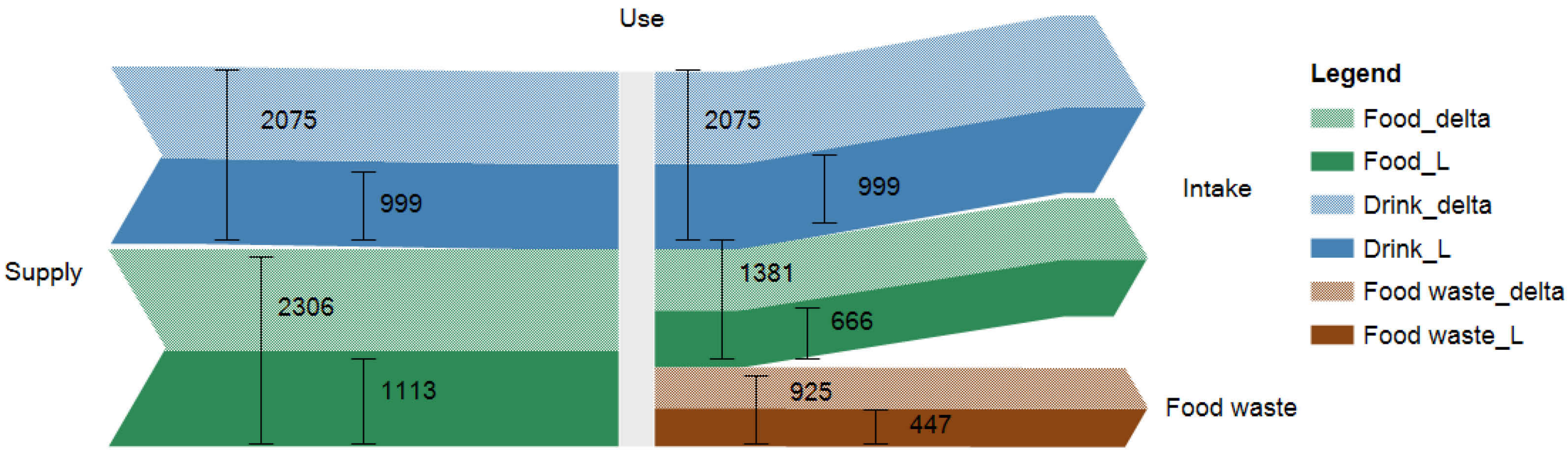
Note: [1] After application of coefficients (Table 25), wasted food and inedible parts amounted to 428 kt and 497 kt in FS1, and to 210 kt and 237 kt in FS2.

Figure 35. Food and drink flows related to out-of-home consumption of eating pop, Paris Petite Couronne, 2014, kilotons



Source: Table 30

Figure 36. Food and drink flows related to out-of-home consumption eating pop, Île-de-France, 2014, kilotons



Source : Table 31

Table 32. Food and drink flows related to out-of-home consumption calculated in FS1, household eating population and non-household eating population, Paris Petite Couronne and Ile-de-France, 2014, kilotons

	Household eating pop			Non-household eating pop			Distribution between populations
	Supply	Intake	Food waste	Supply	Intake	Food waste	Intake
Paris Petite Couronne							
Food	1,065	638	427	353	211	141	74/26
TOTAL drink	951	951	--	337	337	--	
TOTAL FOOD AND DRINK	2,016	1,589	427	690	548	141	
Ile de France							
Food	1,982	1,187	795	325	194	130	85/15
TOTAL drink	1,766	1,766	--	309	309	--	
TOTAL FOOD AND DRINK	3,748	2,953	795	634	504	130	

Drawing on the results of out-of-home consumption of food and drink as calculated in option FS1[164] (see Table 30 and Table 31), the composition of the eating population was essentially different between Paris Petite Couronne and Île-de-France, as Table 32 shows. The non-household eating population, that is, non-household residents and the additional population of commuters, tourists and excursionists, was responsible of a large quantity of out-of-home food and drink consumption in Paris Petite Couronne. It accounted for 548 kt food and drink intake compared to 1,589 kt for the household eating population, which represents a distribution of 26/74. In Île-de-France, the non-household eating population weighs much less, with 504 kt food and drink intake compared to 2,953 kt for the household population, which represents a distribution of 15/85. The different allocation between population types between Paris Petite Couronne and Île-de-France can be explained by the population of commuters. Commuters to Paris Petite Couronne, especially those from the Grande Couronne, alone accounted for 28% of the food and drink intake of the non-household eating population[165], entirely allocated to out-of-home consumption, in Paris Petite Couronne. By contrast, commuters to Île-de-France

[164] Only FS1 used the concept of the eating population as a starting point to calculate food and drink flows in out-of-home consumption. For this reason, only option FS1 yielded insight into the population structure concerned by out-of-home consumption. Option FS2, in contrast, used number of meals served in the social food service sector, but did not yield information about the target population.

[165] 189 kt and 17 kt for commuters from Grande Couronne and from outside of Île-de-France respectively, compared to food and drink intake of the additional population (597 kt) and the non-household resident population (134 kt) (see Chapter 3, Table 12).

accounted for only 2%[166] of the out-of-home food and drink intake of the non-household eating population. These results showed that conversely, households in both urban systems played an essential role in the food service sector, with 74% and 85% of out-of-home food and drink intake of the eating population in Paris Petite Couronne and Île-de-France, respectively (Table 32).

4.3.3. Integrated food consumption

A complete food flow diagram, according to the concept of inner-urban food flows shown in Figure 28, can be drawn for consumption when in-home and out-of-home consumption are integrated together. Integration of food flows was first achieved through the allocation of the food and drink intake between in-home and out-of-home consumption as the starting point of the inner-urban food flow quantification (see 4.2.1). Second, for additional supply and food waste flows, integration was achieved through the combination of the quantification options for households (HH1 and HH2) and for the food service sector (FS1 and FS2). This step yielded a range of results for supply, intake and waste flows of food and drink.

Overall, the total eating population had a significant share of out-of-home consumption. Food and drink intake out-of-home represented 32% and 30% of total food and drink intake, in Paris Petite Couronne and Île-de-France, respectively, calculated according to option FS1 (Table 33). The slightly higher share in Paris Petite Couronne can be explained by the higher share of the additional population, in particular of commuters from the *Grande Couronne* who alone accounted for 3% or 189 kt of the food and drink intake of the eating population (see Chapter 3, Table 11). The additional population, and the non-household population in general, essentially ate out of home (77% and 69% in Paris Petite Couronne and Île-de-France, respectively), thereby pulling the share of the eating population slightly upwards. Conversely, households consume 74% of their food and 73% of their drink in-home. The distribution between in-home and out-of-home intake was largely determined by the allocation coefficients defined in 4.2.1. We discuss the limits of this assumption in Section 4.4.1.

[166] 15 kt, see Chapter 3, Table 12

Table 33. Food and drink intake of the eating population, in-home and out-of-home consumption, Paris Petite Couronne and Île-de-France, 2014, kt and %

	Paris Petite Couronne			Île de France		
	Total	In-home	Out-of-home	Total	In-home	Out-of-home
Total eating population	6,730	4,582	2,148	11,580	8,115	3,472
	100	*68*	*32*	*100*	*70*	*30*
Household population	6,002	4,413	1,589	10,836	7,883	2,955
	100	*74*	*26*	*100*	*73*	*27*
Non-household population	729	169	559	749	232	517
	100	*23*	*77*	*100*	*31*	*69*

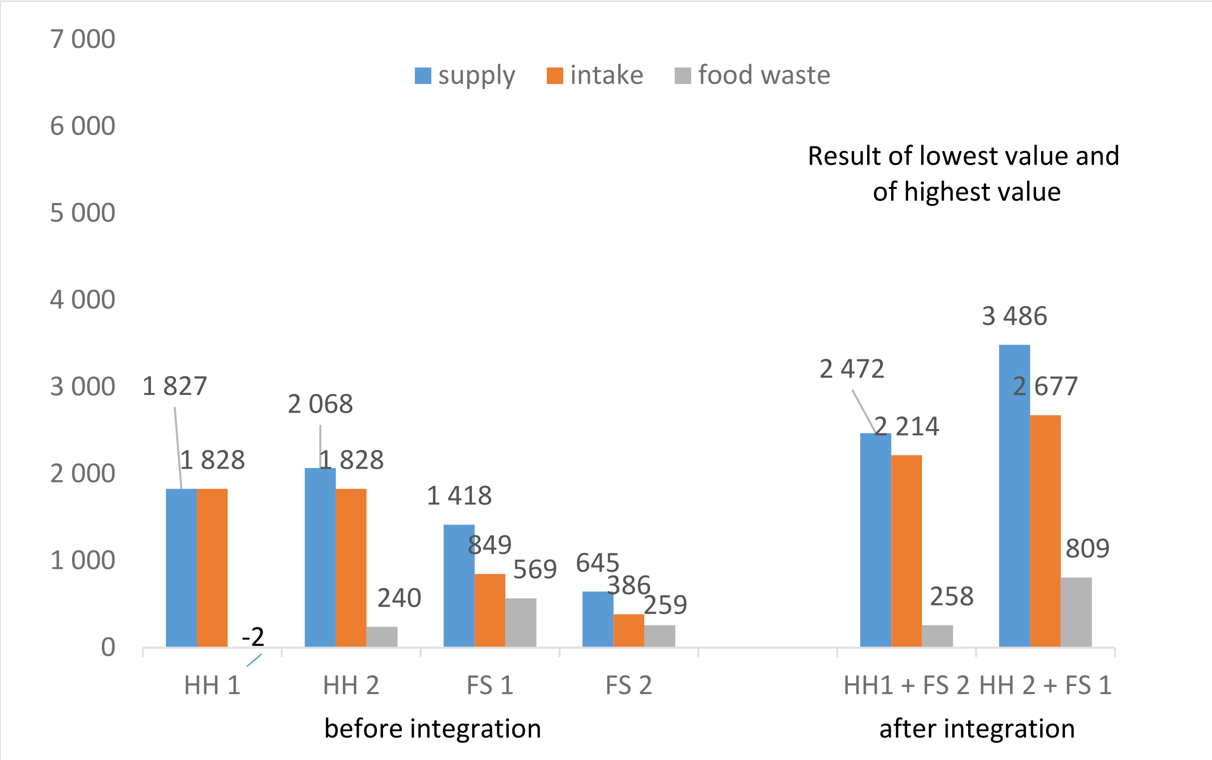
Source: author's calculations (see text)
Note: Due to computation, a slight difference appears with results of out-of-home intake of the eating population in Table 30 and Table 31. Total intake calculated for food and drink together generates slightly higher results (<1%) than when they are calculated separately and summed up. For Paris Petite Couronne for example, the food and drink out-of-home intake of the eating population amounted to 2,137 kt in Table 30 versus 2,148 kt in this table.

The further integration of food supply and food waste flows related to urban consumption is more complex than the allocation of in-home and out-of-home consumption because of the various quantification options in both sectors, totalling several combinations. A detailed analysis distinct for food and drink flows makes sense for food, but not for drink. The reason is that drink flows were modelled to a large extent without considering food waste (see 4.2.4), which reduces the analysis.

Figure 37 and Figure 38 show supply, intake and food waste quantities for food (excluding drink) for each of the quantification options for in-home and out-of-home consumption and, after integration, for the lowest and the highest value of the results of the four combinations, for Paris Petite Couronne and Île-de-France, respectively. The bar plot clearly shows how, in the case of Paris Petite Couronne, the negative difference (-140 kt) and the small difference (100 kt) between food purchase and intake according to quantification options HH1 and HH2 respectively, had a significant impact on the food waste quantities after integration. For Île-de-France, the overall picture is similar to that of Paris Petite Couronne, with higher quantities involved for all food flows. The difference between the lowest and the highest value of food flows after integration was large: 32% and 28% compared to the lowest level for food supply in Paris Petite Couronne and in Île-de-France, respectively, and 14% and 11% for food intake (Table 34). An explanation can be the big difference between the results from options FS1 and FS2 in out-of-home consumption: 85% and 71% in all flows (supply, intake and waste). Once integrated with food flows in in-home consumption, differences persist, but are less strong.

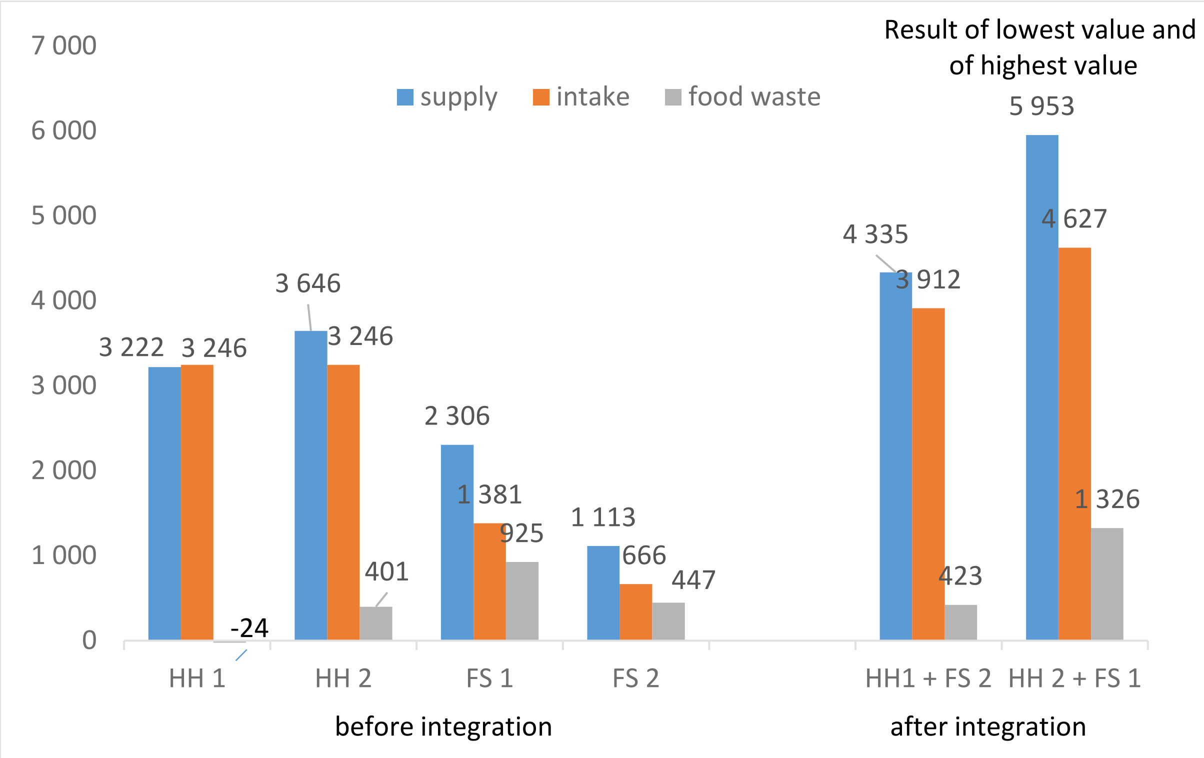
By contrast, the difference between food waste flows, once integrated, was massive, in both urban systems. They varied by a factor of around 2; in other words, the difference between them was 214% compared to the lowest result for Paris Petite Couronne and Île-de-France, respectively (Table 34). Food waste accounted for a very similar share compared to supply in both urban systems, with 10% of supply for the lowest and 22% for the highest value. Two reasons explain the wide range of food waste results after integration. First, the difference in the way food waste was quantified at in-home and out-of-home consumption can explain the wide range of results. For in-home consumption, food waste was quantified directly by calculating the difference between purchase and intake, whereas for out-of-home consumption, food waste was obtained by application of coefficients from the literature. A direct approach based on available data is preferable to the use of coefficients but was not possible for the two consumption sectors. Secondly, another reason for the low values of the range appeared to lie on the side of in-home consumption due to the close-to-zero and slightly negative values: - 1 kt and - 24 kt for food waste in HH1 in Paris Petite Couronne and Île-de-France, respectively. Negative food waste is however conceptually impossible and suggests that there are problems with the data for either purchase or intake (see discussion in 4.4.2 and 4.4.3). Nevertheless, together with food waste in HH2 (240 kt and 401 kt, respectively, in Paris Petite Couronne and Île-de-France), and once integrated with food flows from out-of-home consumption (Figure 37 and Figure 38), food waste from HH1 drove the results wide apart.

Figure 37. Food supply, intake and waste (excluding drink) for in-home and out-of-home consumption of the eating population, before and after integration, Paris Petite Couronne, 2014, kilotons



Source: Tables 4A.10, 4A.12 and 4A.14 in the Appendix to Chapter 4

Figure 38. Food supply, intake and waste (excluding drink) for in-home and out-of-home consumption, before and after integration, Île-de-France, 2014, kilotons



Source: Tables 4A.11, 4A.13 and 4A.15 in the Appendix to Chapter 4

The difference between the results is a little bigger for Paris Petite Couronne than for Île-de-France. The fact that Paris Petite Couronne has a higher proportion of out-of-home eating in the total food consumption of the eating population certainly plays a role (Table 33), in addition to the difference between options FS1 and FS2 in the food flow results of out-of-home consumption (Table 34). Together, the higher share of out-of-home consumption and the bigger difference between quantification options widens the range of the results of the integration.

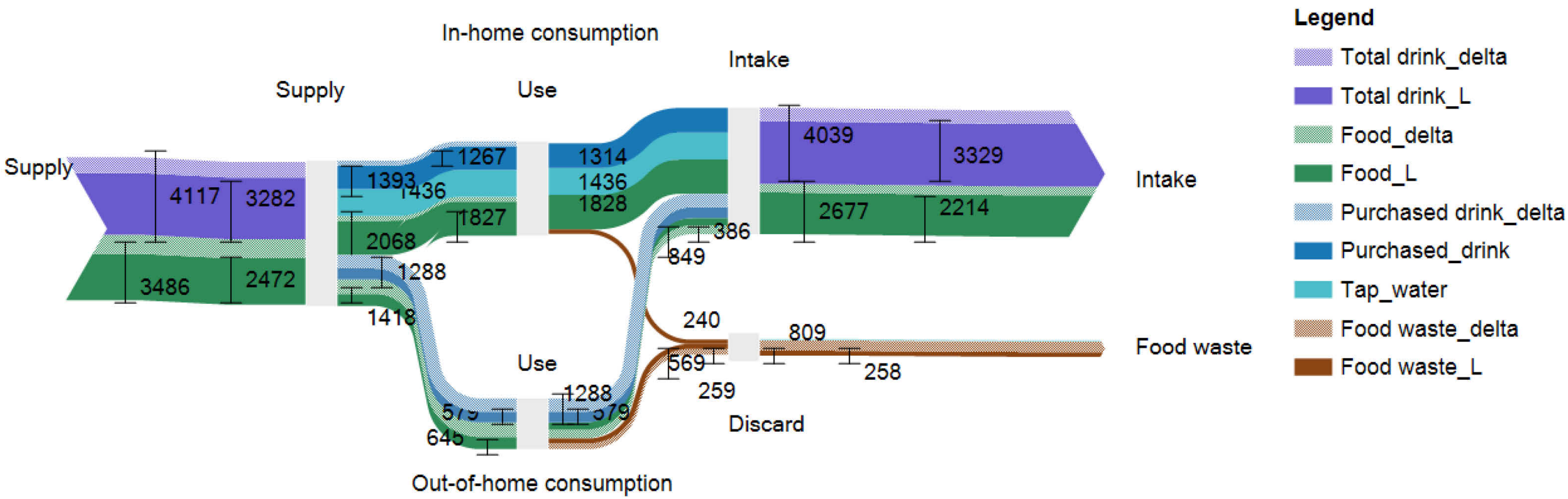
Sankey-diagrams in Figure 39 and Figure 40 show the integrated results for food and drink flows, for in-home and out-of-home food consumption of the eating population, for Paris Petite Couronne and Île-de-France, respectively [167].

[167] The complete results of the integration of food flows, drink flows and food and drink flows together are shown in the Appendix to Chapter 4, Tables 4A.10 to 4A.15. Due to a lack of drink waste data, the supply of tap water in in-home consumption and of drink in general in out-of-home consumption was modelled without waste in this study.

Table 34. Differences between quantification options for in-home and out-of-home consumption and results from integration, for food, in Paris Petite Couronne and Île-de-France, % of the lowest value

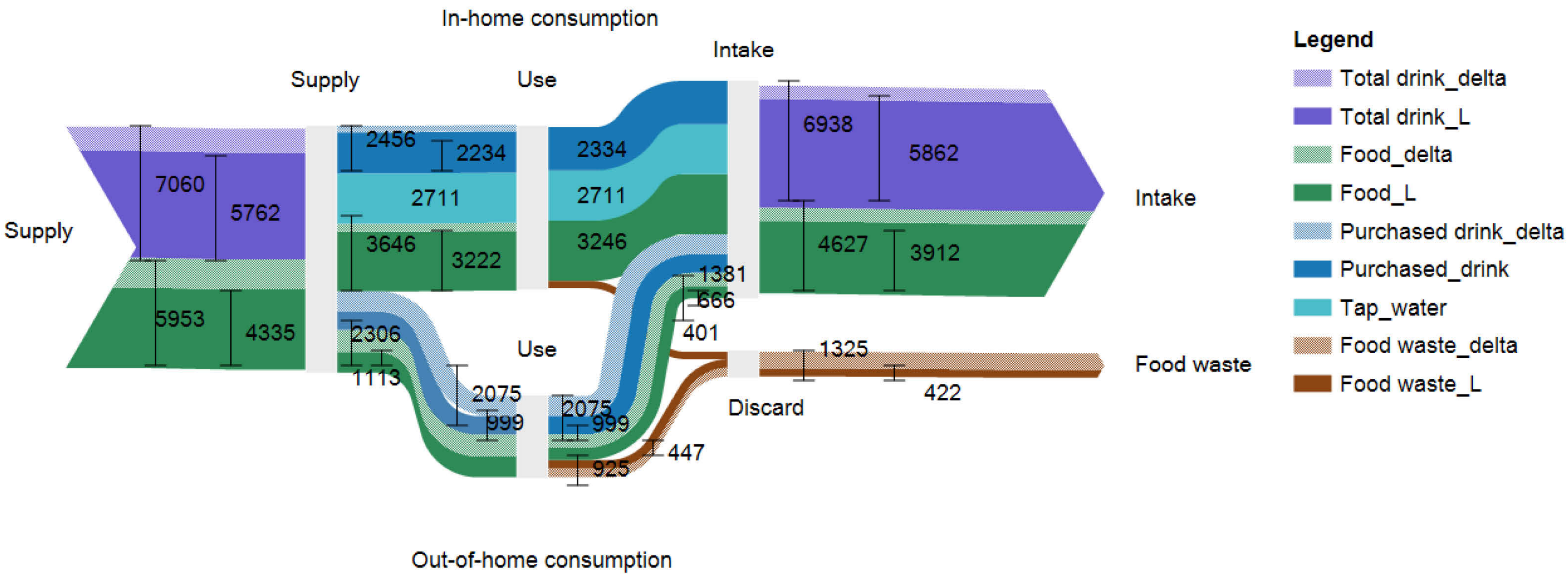
	Paris Petite Couronne		Île-de-France	
	In-home	**Out-of-home**	**In-home**	**Out-of-home**
	Difference between HH1 and HH2	Difference between FS1 and FS2	Difference between HH1 and HH2	Difference between FS1 and FS2
Supply	*13*	*119*	*13*	*107*
Intake	-		-	
Food waste	Partly negative		Partly negative	
Combined HH FS				
Total supply	*41*		*37*	
Total intake	*21*		*18*	
Total food waste	*214*		*214*	

Figure 39. Inner-urban food and drink flows, Paris Petite Couronne, 2014, kilotons



Source: author's calculations, see Tables A4.10, A4.12 and A.4.14 in Appendix to Chapter 4.
Note: For comfort of reading, 79 kt drink waste from in-home consumption and the negative difference of – 48 kt between purchase and intake, calculated according to option HH2, are omitted from the figure.

Figure 40. Inner-urban food and drink flows, Île-de-France, 2014, kilotons



Source: author's calculations, see Tables A4.11, A4.13 and A.4.15 in Appendix to Chapter 4 ;
Note: For comfort of reading, 122 kt drink waste from in-home consumption and the negative difference of – 24 kt of food and - 100 kt of drink between purchase and intake are omitted from the figure.

4.4. Discussion

4.4.1. Assumptions for modelling in-home and out-of-home consumption

The distinction between in-home and out-of-home intake of the eating population is pivotal in the inner-urban food flow model as most other food flows are directly derived from intake. In this study, 90% and 94% of the eating population of Paris Petite Couronne and Île-de-France, respectively, had their food intake allocated between in-home and out-of-home consumption, whereas only a small share of the population, for example commuters and people living in retirement homes and prisons, had their food intake exclusively out-of-home, in facilities of the food service sector[168].

The distinction is predominantly based on allocation coefficients obtained from one single study of national scope, the INCA 3 food intake survey (Anses, 2017). To adjust coefficients to the urban systems studied, the expense structure of in-home and out-of-home consumption was used. Adjusting was important since results of the Household budget survey from 2011 showed that Île-de-France households spent 26% more than French households for out-of-home consumption. The method of allocating has a massive impact on the distinction of both sectors in this study.

No study other than the national INCA 3 study was available to provide the allocation, in terms of mass, between in-home and out-of-home consumption of the population or parts of it. Furthermore, because of the national scope of the study, allocation coefficients available per age group are valid for this scope only.

Drawing on the results of the Household budget survey from 2011, application of a coefficient that reflects the expense structure of Île-de-France households compared to French households

[168] Adjusted allocation coefficients were applied to the food intake of three types of population: residents living in households, students in student homes, and young workers (see Table 21). Taken altogether, this population represents the majority of the eating population of Paris Petite Couronne and Île-de-France, with 90% and 94%, respectively (see Table 11 for the contribution of population types to the eating population). The difference between both proportions is explained by the fact that the resident population weighs higher (96%) in Île-de-France than in Paris Petite Couronne (91%), and inversely, the additional population, and especially commuters, who are assumed in this study to exclusively have food out-of-home, weigh lower.

was found to be a means to account for the specific context of the urban systems studied. The national accounts established by INSEE provide similar information about the expense structure but refer to a different scope and target population (e.g. inclusion of tourist expenses). For example, as cited in FranceAgriMer (2020), the national accounts report that 28% of all food expenditure in 2018 in France was directed to out-of-home consumption. By contrast, results from the Household budget survey for 2011 show 23% expenditure for eating out-of-home compared to total food and drink expenditure of households in France. The expense structure of Île-de-France households between in-home and out-of-home consumption cannot directly be used for allocation in terms of mass. For a comparable meal, expenses for eating out are higher than for in-home consumption, since wages, rent, and fees to run a restaurant are included in the costs of a meal. However, the target samples are different for the two types of surveys: level of individuals in intake surveys, as opposed to household level in Household budget surveys. Despite the difference between scope and target population, the expense structure of the Household budget survey was more appropriate to use for this study than the national accounts.

A sensitivity test clearly shows the sensitivity of the food flow results to a variation of the allocation coefficients for in-home and out-of-home consumption. To illustrate the impact, we put the focus on food only and exclude drink. The reason is that drink supply in the form of tap water is not covered by purchase data. The purpose of this sensitivity test is to evaluate the impact of changes of the allocation coefficient used for in-home consumption (variation of +/- 10%) on in-home food intake. We find an impact on the difference between household purchase and intake, that we use as a proxy for food waste.

As results show for Paris Petite Couronne (Table 35), varying the allocation coefficient of in-home consumption by – 10% and + 10% changes the proportion of food waste compared to purchase by a multiple when the purchase–intake difference is calculated with option HH1[169]. Since the purchase quantity initially equals intake in HH1, a decrease of intake by -10% lifts purchases above intake, therefore turning food waste positive (174 kt versus -1 kt). By contrast, an increase of intake by + 10% lifts intake above purchases and shifts food waste into a negative value (-178 kt versus -1 kt). In HH2, purchases lie 12% above intake in the baseline assumption, hence contributing to the share of food waste. Food intake decreases of 10% almost double the proportion of food waste, lifting it from 12% up to 20%, whereas increases of 10% minimize

[169] Options HH1 and HH2 refer to the source of purchase data used for the calculation of the purchase–intake difference. In option HH1, purchase data from the Kantar Worldpanel were used, whereas in option HH2, data from the household budget survey were used.

the proportion of food waste, reducing it to 3%. For Île-de-France, food waste results change in the same direction and magnitude when the share of in-home consumption varies by +/- 10% (Table 36).

Table 35. Sensitivity analysis of a variation of the allocation coefficient for in-home consumption of food, household eating population, Paris Petite Couronne, 2014

	Purchases[1]		Intake	Purchase – Intake (food waste)			
	Quantities (in kt)		Quantities (in kt)	Quantities (in kt) share of purchase, in % (in italics)		Per capita quantities[3, 4] (in kg/cap)	
	HH1	**HH2**		**HH1**	**HH2**	**HH1**	**HH2**
Baseline assumption	1,762	1,994	1,764	-2 *0*	230 *12*	0 0	40 34
- 10%			1,587	174 *10*	407 *20*	30 26	70 60
+ 10%			1,940	-178 *-10*	54 *3*	-31 -26	9 8

[1] data for food and drink purchases in HH1, from Kantar Worldpanel, in HH2, from INSEE Household budget survey
[3] normalized with household eating population
[4] normalized with legal population

Table 36. Sensitivity analysis of a variation of the allocation coefficient for in-home food consumption, household eating population, Île-de-France, 2014

	Purchases [1]		Intake	Purchase – Intake (food waste)			
	Quantities (in kt)		Quantities (in kt)	Quantities (in kt) share of purchase, in % (in italics)		Per capita quantities[3, 4] (in kg/cap)	
	HH1	**HH2**		**HH1**	**HH2**	**HH1**	**HH2**
Baseline assumption	3,132	3,545	3,159	-26 *-1*	386 *11*	-2 -2	36 32
- 10%			2,843	290 *9*	702 *20*	27 24	66 58
+ 10%			3,474	-342 *-11*	71 *2*	-32 -28	7 6

[1] data for food and drink purchases in HH1, from the Kantar Worldpanel, in HH2, from the INSEE Household budget survey
[3] normalized with household eating population
[4] normalized with legal population

The results from the sensitivity analysis suggest that the food flow results must be taken with caution, since small variations of +/-10% of the baseline allocation of in-home and out-of-home consumption have a massive impact on the food flow and food waste flow results. Although care was taken to adjust allocation coefficients to the situation of Île-de-France (but not to Paris Petite Couronne, due to a lack of data), the previously described limits (e.g. different scope and target population of the Household budget survey used for adjustment) might weigh on the approach.

A situation as in option HH1 of equal intake and purchase quantities of the eating population is artificial and signifies that either purchases are missing, or intake is too high. Both cases have already been partially discussed in the sections on the data sources. A third reason can be the one of limitations of the data used in HH1 and HH2, addressed in the following sub-section 4.4.2.

4.4.2. Limitations of data sources

In-home consumption

Despite differences in method and data provider, the data sources for HH1 and HH2 were supposed to provide data about total quantities of food and drink purchased for a given time period by a sample of households. Both data sources have limitations with respect to their use in this study. For the INSEE Household budget survey, the lack of information about purchase quantity in the case of 21% of purchased food and drink items (see 4.2.2) is the principal limitation of this data survey. Missing or inconsistent data and the solutions we found to overcome this limitation were likely to introduce a bias in the results which is hard to estimate. According to the manager in charge of this survey at INSEE[170], the purchase quantity data have not been analysed yet since the corresponding variables were introduced for the first time in the survey, in 2006. Hence, no reference is currently available compared to which the results in this study could be analyzed, despite first attempts undertaken by researchers and the *Direction de la recherche, des études, de l'évaluation et des statistiques* (DREES) of the French Ministry of Health and Social Affairs[171]. We informed the survey manager at INSEE about this piece of research as well as economist colleagues who work with the expenditure data from the survey. Once alternative approaches for imputation, for example the use of nearest neighbour (NN) imputation algorithms are tested, it would be interesting to compare results.

As for the household purchase data from Kantar Worldpanel, a private market research and consultancy company, an agreement with FranceAgriMer made it possible to obtain the Kantar

[170] Elvire Demoly, INSEE - DSDS, in charge of the household budget survey, personal communication, September 10th, 2019
[171] Elvire Demoly, INSEE - DSDS, in charge of the household budget survey, personal communication, April 17th, 2019

purchase data in a ready-to-use form. This meant however that it was not possible to return to the raw data to check or analyse them by our own means following questions or inconsistencies that arose in the process of the food flow quantification. The most intriguing point to investigate is the composition of the categories of bread and cereal and of other products (see Figure 31 and Figure 32). They stand out from the other categories as intake was higher than purchase quantities. Thus, they do not fit into the overall distribution of food categories when intake and purchase data are compared (see 4.3.1).

For bread and cereals, missing purchase data of products that do not carry a barcode is a major limitation. The problem of items not carrying a barcode is that purchases are not systematically reported by panellists. In contrast to other sectors, food items without a barcode in the bakery sector are rather the rule than the exception. This is why Kantar resolved the problem by not collecting purchase data in this sector for products without a barcode, to avoid the risk of obtaining inaccurate or approximate values. The situation is different in other specialized shops. Fishmongers, green groceries, and butcheries all sell food items without a barcode, but to a lesser extent than bakeries, which caused Kantar to consider that panellists manage to report the purchase quantities despite the absence of a barcode. For fruit and vegetables for example, green grocers, wet markets and farm shops total 26% of the purchase quantity of fruit and vegetables in Île-de-France (data 2014-2016). This is by far less than the share of traditional bakeries (58%) in the total purchase volume of bakery products. It is unclear, however, whether the compensation is sufficient in the category of bread of cereals and whether other categories also suffer from missing purchase data.

Overall, it seems that total quantity purchased by households is under-reported in the Kantar consumer panel, used for option HH1. Despite efforts undertaken in this study to correct purchase quantities for the products not covered by the data collection method, total quantities remained far below intake and purchase quantities from the Household budget survey, used for quantification option HH2.

Out-of-home consumption

It is hard to assess which of the quantification options yields results closer to reality. As results between both options vary widely[172], the problem is significant. Quantification option FS1 relied on allocation factors for out-of-home consumption of the national household population,

[172] They vary by 85% and 71% for Paris Petite Couronne and Île-de-France respectively, see Table 34.

obtained from the INCA 3 study and applied to the eating population. FS2 worked with absolute numbers of meals served in the social food service sector and then extrapolated to the total food service sector.

Whether the share of out-of-home consumption is overestimated for the Île-de-France and the Paris Petite Couronne eating population (FS1) or whether numbers of meals served are missing (FS2) is hard to say in a situation of overall lack of data about a city's food consumption. For FS1, there is evidence that the household population of Paris Petite Couronne and Île-de-France, which accounts for the major part of the eating population (Table 33 for food intake), spends more on eating out than do households of the national population taken as a whole. It is however hard to establish how higher expenditure on eating out translates into higher out-of-home food intake, in terms of mass. Paris Petite Couronne, in particular, and Île-de-France were characterized by a large number of commercial restaurants in 2018[173]. A rough estimate of the statistics yields a slightly higher restaurant density with roughly 3.3 units per thousand inhabitants, compared to the national number of 3.1 units (INSEE data cited in Fafih, n.d.). Supported by the large number of commercial restaurants in the area, the proportion of out-of-home consumption, in terms of mass, was assumed to be higher, in proportion to over-expenditure of Île-de-France households compared to French households. Disregarding price differences for eating out, between the region of the capital region and the provinces[174], this assumption potentially overestimates the relative share of out-of-home consumption in terms of mass, and over-emphasizes the weight of the food service sector's food flows in urban food. In the case of FS2, it is plausible that either the number of meals served in the social food service sector is underreported in the RESYTAL database, that adjustments to capture total food served, beyond meals, in the social sector was insufficient, or that the extrapolation to the total food service sector did not sufficiently cover the commercial food service sector. It is possible that numbers of meals were under-reported in the RESYTAL database (see 4.2.3) but it is hard to estimate the extent. Prisons for example are overpopulated in France and provide meals with much higher quantities than the reported capacity suggests. However, prisons are the smallest facility type in the social catering sector and cannot alone explain the low result in FS2. For some sectors such as school meals, large municipalities such as the City of Paris report

[173] Paris Petite Couronne in particular and Île-de-France are characterized by a high number, with roughly 25 000 and 31 000 commercial restaurants of any type (including fast food and food trucks) in 2018 (DRIAAF, extracted from regional statistics, transmitted December 16th, 2019).

[174] French culture has been coined by the divide, in people's social representation of the French population, between "Paris" standing for the centre of the centuries-old monarchy, and later of the bourgeoisie and the governing elite, and *"la province"* meaning the mostly rural hinterland of the French territory.

the numbers of meals served in public catering. But gathering the relevant numbers in a bottom-up approach, given the size of urban systems analysed in this study, always bears the risk of missing some. In fact, there is no information tool hosting centralized information about the social food service sector, including number of meals, types of establishments and supply chains involved, despite an urgent need to have a regional observation tool to track changes in the social food service sector[175]. Adjustments made to complete the number of meals with food served in other situations in the social food sector but not considered in the database, such as breakfast and snacks for example, might be inaccurate, but alone cannot explain the large difference with results from FS1. Lastly, it is plausible that the commercial food service sector was not sufficiently considered in this study. There is no way to estimate whether the distribution, valid at national level, of an equal proportion of 50% between the social and the commercial sectors of all meals taken out-of-home, respectively, applies to Paris Petite Couronne or to Île-de-France. Underestimating the commercial sector can reduce the proportion of overall out-of-home consumption in FS2 and lead to lower food and drink flows compared to quantification option FS1.

Food waste

We used secondary data to establish food waste coefficients for the food service sector as described in 4.2.4. The various data sources used for the calculation of a mean value for wasted food and for inedible parts were French study reports and one original data set. They provided mean values for wasted food in settings relevant to this study (primary school catering (Bigue, 2016), commercial restaurants (Moulinot Compost et Biogaz, 2015), and the general social and commercial food service sector). Unfortunately, information was not systematically provided by these studies to assess the overall quality of the data, for example standard deviation of the mean value or the number of measurements and sample size. To compensate for weaknesses of the studies' data input, not one value but the mean of several mean values of wasted food were used.

Only one study (Moulinot Compost et Biogaz, 2015), a study about commercial restaurants, provided information about the inedible parts of food waste as the study aim was to understand the generation and sorting of bio-waste. The particular feature of these restaurants was that they mostly prepared meals from raw products and therefore generated bigger quantities of bio-

[175] With respect to legal requirements, for example such as the EGAlim Act.

waste, compared to restaurants in the social catering or fast-food sector, which commonly use canned, frozen, and other ready-to-use ingredients. Applying this comparatively high value of inedible parts, that is, 150 g/meal compared to 275 g of total food waste per meal, to the entire food service sector in this study means a simplification of the heterogeneous situation of meal preparation in the social and commercial food service sector, and hence an overestimation of food waste quantities in this study. The use of processed ready-to-use vegetables in contrast to raw products varies with social catering facility types in Île-de-France[176]. Where inedible parts are generated depends on where the raw products are processed for either sale or meal preparation. This is also where the bio-waste is managed as it is usually managed locally. Hence, reference to the study by Moulinot (2015), which reports a high value of bio-waste from inedible parts in commercial restaurants, implies that food waste related to the food service sector occurs entirely within the urban system in this study, that is, within Paris Petite Couronne and Île-de-France. This leads to an overestimation of the generation of food waste from the inedible parts of food waste. However, the real situation is more heterogeneous. Despite a lack of detailed information about the supply chains for this sector, bio-waste occurring from processing is partly generated in the supplying areas which grow and process food for the food service sector. Urban food consumption generates waste not only in the urban system, but also partly in supplying areas. In analogy to supplying areas dedicated to food production, there are areas related to urban food consumption which absorb the waste, including waste generated remotely from the city. Since this waste generated in and remotely from cities is largely under-research, little is known about its destination and about the receiving areas involved.

4.4.3. Food waste as difference between purchase and intake

Taking the difference between purchase and intake as a rough estimate of food waste has several limitations. First, limitations of either purchase or intake data, or both at the same time, inevitably have consequences on this difference and restrict any possible interpretation of it as a proxy for food waste. Second, other parameters than food waste are part of the difference and must be considered.

[176] A study commissioned by the regional Ministry for Food and Agriculture in Île-de-France shows that fresh fruits and vegetables are served most in companies and the administration (more than 60% of the fruit and vegetable supply) and least in hospitals and retirement homes (48%), with school canteens inbetween. Conversely, canned vegetables make up 16% in the school canteens, but only 4% in companies and the administration (Driaaf, 2018).

Limitations of either purchase or intake data were previously discussed in 4.4.2. They relate to the data sources for household purchases which can suffer from under-reporting of food and drink purchase quantities. As discussed above, where missing quantities were known, purchase quantities were corrected in this study (e.g. for bread, *pâtisseries* and *viennoiserie*), but other missing quantities may remain unknown and may lead to underestimated household purchase quantities. Another type of limitation relates to the allocation between in-home and out-of-home consumption, as discussed in 4.4.1. Overestimation of in-home intake inevitably reduces the difference with amounts purchased, whereas underestimation increases the difference, therefore suggesting higher quantities of food waste. A brief simulation exercise in Table 35 and Table 36 has shown that the purchase–intake difference was very sensitive to variations in the in-home food intake.

Further parameters for the difference between purchase and intake can refer to mass variations, for example water variations in the preparation of food and storage variations. Purchases stored beyond the reference time of the study or food purchased prior to the reference time and then used for consumption has an impact on the purchase–intake difference for the reference period. Obviously, storage variations depend on individual domestic practices which are not generally known to a population. Moreover, we assumed that over the reference time of this one-year study, storage of food and removal from storage balanced each other out. This is because only food with low water content, such as flour, pasta, pulses, or canned and frozen food can be stored for a long time. Most other foods are perishable within days or weeks, and in any case in less than a year. For reasons of conservation, storage practices tend to play a bigger role for shorter periods, such as a week or a month. They were therefore not considered in this study.

Water variation depends on the composition of the diet, on food preparation and on cooking techniques which involve water evaporation or absorption. The water content varies with the cooking process. Usually dry cereal products, such as rice or pasta triple their mass, while frying meat or vegetables reduces it through evaporation. However, the INCA study specified that cereal products are considered as dry product, and therefore excluded water variation at cooking for this type of product (Anses, 2017). For the preparation of soup, I showed that the consideration of water addition is unclear in the purchase data of HH1 (see 4.3.1) and makes the interpretation of the purchase–intake difference for the category difficult. Although water variation appears relevant for some categories, the approach to food waste through the purchase–intake difference for all food and drink consumption as a whole does not require further adjustments.

Different from water variation during cooking but also related to water is the supply of tap water to drink, in addition to food and drink purchases from commercial circuits, that I use to compare supply and intake of total food and drink[177]. Poor estimation of tap water supply, which adds to purchases from commercial circuits, can also potentially count in the difference between purchase and intake, due to the distinction between tap water and purchased drinks in the daily drink intake per age group, performed above (see 4.2.5 and Table 7). While tap water supply data were retrieved directly from the tap water intake of the eating population, data on purchases of drink were obtained from purchase data in HH1 and HH2 and totally independently of choices concerning tap water. If half of all hot drinks were prepared with bottled water instead of with tap water, tap water intake would decrease and with it, tap water supply. As a consequence of the reduced tap water supply, food and drink quantities in HH1 and HH2 would also decrease, and widen the difference between purchase and intake even more. A lower contribution of tap water to household food and drink supply would not correct the negative difference between purchase and intake, on the contrary. Overall, a poor estimation of tap water versus purchased drink supply barely changes the difference between purchase and intake, and consequently of food waste.

Furthermore, inedible parts of food, notably for fruits and vegetables, such as peels or fruit skin, are part of food purchases but not of intake and therefore are naturally part of the difference, unless food is purchased pre-cut and ready-to-use without inedible parts[178]. The question of how to distinguish the edible and the inedible portion of food has been a lasting concern for public health and nutrition experts as nutrient intake from food obviously stems from what is eaten. Considerable efforts have been made to describe mass and water variations during the preparation of foods, according to the prevailing cooking and trimming techniques (Bognár, 2002; FAO/ INFOODS, 2012). The FAO has published guidelines for converting food items to edible portions as fresh weight, edible portions after cooking, inedible portions, and weight loss at cooking (FAO/ INFOODS, 2012). It informs its food composition databases with relevant coefficients[179]. From a food security perspective, the aim is to calculate nutrient composition from the wide diversity of foods consumed by a population and to compare it with nutritional intake references. This is why in the nutrition-related literature, mass and water variations refer to a detailed level of food categories, but are of no interest for the public health community

[177] For reasons of simplification, we refer to purchase versus intake and include the supply of tap water to drink.
[178] See also the discussion about food waste data in the food service sector under 4.4.2.
[179] http://www.fao.org/infoods/infoods/tables-and-databases/faoinfoods-databases/en/

when aggregated for a population. For the purpose of food metabolism studies, an average variation factor for the average French diet, based on water and mass variation per food category, would be useful. Knowing this factor would allow us to calculate the food waste estimate from the difference between purchase and intake data of a population. More generally, information about the mass variation along the supply chain, from the agricultural raw product to purchased food to the edible portion as fresh weight and cooked, can contribute to a better integration of consumption-based data into metabolism studies.

Lastly, food procured otherwise than through commercial retail outlets was not considered in household food supply and can potentially help to explain the negative difference between purchase and intake, at least for food. Gardening in private or shared gardens is a way to add vegetables, fruit and some other food to one's supply, at least for the time of the cultivation period in the temperate climate of Paris Île-de-France. Overall, in terms of mass, the INCA study suggests a small contribution of food produced by oneself or by someone close to the food supply of the French population. Roughly three quarters of participant children and adults reported having consumed food – mostly fruits, vegetables, potatoes and eggs –, from their own or someone close's production, picking, hunting or fishing, at least once in the twelve months before the survey. Three quarters of them had consumed such food at least once a week, but this was only the case in rural areas and regions other than Paris Île-de-France (Anses, 2017). The contribution of self-produced food is obviously more limited in the dense urban area of Paris Petite Couronne and part of Île-de-France. Nevertheless, with the increasing popularity of gardening and the fact that part of the population's food supply remains invisible to the gaze of both scientists and statistics, an estimate of households' own food production and contribution to their food supply would be interesting for different population types and areas in Île-de-France[180].

These various limitations and parameters influencing the difference between purchase–intake alone require caution in the interpretation of results. Additionally, negative values as they appeared for food and drink flows of Paris Petite Couronne and Île-de-France illustrate even more the complex interplay of parameters and the need to cross perspectives from other approaches to food waste.

[180] See Section 3.3.2, about an estimate of food production and contribution to food supply in private or shared gardens in Île-de-France through the TERRIBIO project.

4.4.4. Sectors not covered in the inner-urban food flow quantification

Data were insufficient for the sectors of the processing industry supplying both in-home and out-of-home consumption, wholesale and logistics. Some information for distribution to households and more generally to the general public was included in the section of in-home consumption, although a more detailed analysis was not possible.

For the processing industry sector, there appeared to be some possibilities at one point in the process of this study. Generally, food industry data about the material input and output at company or sector level is not publicly available. However, companies registered as classified facilities for the protection of the environment (*installations classées*) are legally obliged to report their material turnover in a database hosted at the Ministry of Ecological Transition[181]. The database of classified facilities shows a total of 22 facilities with "food industry" as a main activity, one facility with "food service", two facilities with "fishery and aquaculture" and nine facilities with "animal production, hunting and associated services". This is a far cry from the 665 food industry facilities counted by the regional Ministry of Food and Agriculture, the DRIAAF (DRIAAF Report 2015). It was beyond the scope of this study to further investigate the difference between the number of facilities. Considering the high number and the diversity of manufacturing industries in Île-de-France, it was not possible either to identify big players who could collect mass input and output flows and extrapolate them to the urban system. These considerations meant that the food processing sector was ignored in the inner-urban food flow quantification.

For the retail sector, there was an opportunity at one point to obtain mass data for the food supply from a big retail company which, together with four other brands, accounts for 50% of the total sales area for food shops of more than 300m^2 (IAU île-de-France, 2017). Unfortunately, despite contacts with the corporate responsibility manager and the logistic department of the group, the data never became available for this study. No other opportunity for quantifying food flows to and from the retail sector was available. For specialized food shops such as bakeries, butcheries, and green grocers, for example, the professional

[181] Every industrial and agricultural site which potentially is at the origin of a risk or causes pollution or significant nuisances for the health and safety of local communities must by law be classified as a facility for the purposes of protection of the environment (ICPE) (Ministry of Ecology, Sustainable Development and Energy, General Directorate for Risk Prevention). See for an overview chronological milestones in the elaboration of the legal framework of classified facilities for the protection of the environment (Ministry of Ecology, Sustainable Development and Energy General Directorate for Risk Prevention) http://www.driee.ile-de-france.developpement-durable.gouv.fr/IMG/pdf/14223_IIC_brochure_A5__EN_150421_.pdf

representation gathered under the CGAD[182] launched a survey in 2018 amongst its members to collect information about food waste. However, the low response rate and more generally the lack of understanding of the topic amongst the members[183] made the survey of no use for this study. As a result, the retail sector in its various forms was also excluded from the inner-urban food flow quantification. Only one piece of information based on food expenditure data provided an idea about the distribution of commercial supply chains in Île-de-France household purchases (4.2.2).

Due to the missing analysis of food flows in the processing and retail sectors, food surpluses and donations were not part of the analysis either as processing and retail are the two sectors that provide most of the donated food (Banque alimentaire de Paris et d'Ile de France, 2014). The absence of these flows in the analysis for 2014, the reference year of this study, was not as much of a loss as it would have been for more recent years, considering that the French policy framework for food waste reduction through donation was set up in 2016 only and has been strengthened gradually since then (see Chapter 5). A rough estimate based on the report of the charity Banque alimentaire (Banque alimentaire de Paris et d'Ile de France, 2014) and the number of needy people registered at a charity suggests that donations from surplus food did not exceed 2 kt in 2014.

[182] *Confédération Générale de l'Alimentation en Détail*
[183] Sandrine Bize, CGAD, personal communication, March 1st 2019

4.5. Summary

In this chapter, the analysis of inner-urban food flows was essentially focused on the consumption stage. It shed light on the respective roles of in-home and out-of-home consumption of the eating population. The food service sector as support for out-of-home consumption, and which concentrates 32% and 30% of food flows to consumption in Paris Petite Couronne and Île-de-France, respectively, is important yet has barely been characterized. Work reported in this chapter has shown that a wide range of various data sources were necessary as only a few official data sources directly provided food flow data per sector or enabled me to perform simple calculations (e.g. extrapolations to the urban system). Mass data were unavailable for food system sectors (distribution, food service, wholesale) at infra-national level. More generally, as aggregated and periodically produced data were unavailable, I was led to explore alternative ways for food flow quantification at the administrative levels of a region and a group of *départements*. For this reason, and unlike food flow quantification in Chapter 3, quantifying inner-urban flows was possible only through a bottom-up puzzle-like approach which could largely gain from improvements of data in the future.

Despite the data gaps, the food system approach showed its usefulness for the inner-urban food flow quantification in this study as it first guided the analysis sector-wise, focused on the consumption stage, and then allowed me to reconnect the sectors within the urban system. Now, in Chapter 5, the inner-urban flows from Chapter 4 will be integrated into the urban system flows from Chapter 3.

Chapter 5: General discussion

5.1. Particular features of the Paris Île-de-France food metabolism

When the food flow results from Chapter 3 and Chapter 4 are integrated into a single model, the result is the complete food metabolism including urban and inner-urban flows. Inner-urban flows were available in this study only at consumption stage. The Paris Île-de-France food metabolism has some particular features that became legible once insights on the role of in-home and out-of-home consumption had become available through Chapter 4. Three of them are analysed in the sub-sections of this chapter. First, the predominant role of import and export flows is striking, for Île-de-France to an even greater extent than for Paris Petite Couronne. Second, food consumption of the eating population is equal to or lower than that of the legal population. Out-of-home consumption plays an important role. Third, as regards food waste, disregarding questions raised by quantification methods and data, the overall picture of the metabolism shows a waste flow which is certainly linear but moderate in magnitude.

Following the analysis of these particular features of the Paris Île-de-France food metabolism, the question is addressed of how policy makers, from local to national and European level, are already addressing the challenges on the path towards a sustainable urban food system. In this analysis, the focus is deliberately put on food waste reduction and recycling, one amongst several other sustainability challenges. It corresponds to one of the study's aims, which is to enhance knowledge about the contribution of food loss and waste to the material intensity of urban systems, and about policy options to act on them. The analysis also widens the perspective on urban policy for food sustainability as it sheds light on antagonisms between food waste policy and other policy areas, often ignored as they do not pursue the same goals and are not managed by the same administration.

5.1.1. The complete food metabolism of Paris Île-de-France

Figure 41 and Figure 42 show the complete food metabolism of Paris Petite Couronne and Île-de-France, respectively, following the integration of inner-urban flows for consumption (Chapter 4) into the metabolism at urban system level (Chapter 3). Integration resulted in a complete flow scheme for urban and inner-urban food and drink flows, available for both urban systems.

There were several methodological points to consider for the integrated flow scheme compared to a separate quantification of urban and inner-urban flows. In the extension to Chapter 4, for out-of-home consumption, tap water and purchased drink were attributed to supply and intake flows of out-of-home consumption, in order to achieve the integration of drink flows. Only results for quantification option FS1 are shown for the sake of simplification. The simplification is not only visual, with fewer options for flows; it also lies in the fact that option FS1 is directly derived, through allocation, from the food and drink intake quantification of the eating population. This is why food and drink flows for out-of-home consumption calculated with FS1 conceptually fit into the model developed for the whole urban system. By contrast, food and drink flows calculated with FS2, which by a factor of 2 are smaller than the ones in FS1, leave a large gap in relation to total urban consumption. The differences between the methodological approaches used for flow quantification – absolute quantities reported and extrapolated versus allocation coefficients – raise the question of how to consider the resulting food flows for integration into the complete model. Unlike out-of-home consumption, the two quantification options used for in-home consumption were different in the data sources used, but not in the methodological approach (use of allocation coefficients). This is why results of both options are shown as optional in the figure. Negative values of the difference between purchase and intake are part of the complete model, but are not shown, as the quantities are very small compared to its scale (-1 kt and 26 kt for food and -46 kt and -99 kt for drink for Paris Petite Couronne and Île-de-France, respectively). Possible explanations for the negative difference between purchase and intake at the level of consumption are extensively discussed under Section 4.4.3., albeit not resolved.

In terms of results, in line with the law of conservation of matter[184], the system of inner-urban flows cannot have lower input and output flows than the urban system itself, nor higher inner-urban flows either. This would be inconsistent with the balance principle. Yet this is precisely what happens with the food flows related to urban consumption. Supply to the eating population is 154 kt and 195 kt higher in Paris Petite Couronne and Île-de-France, respectively, than food and drink flows (excluding tap water) that move through the processing, distribution and logistics stage. Furthermore, purchased drink imported and directed to consumption (1,272 kt

[184] See Method, Chapter 2, Section 2.2.

and 2,170 kt in Paris Petite Couronne and Île-de-France respectively) is lower than purchased drink supply to the eating population. An explanation can be the processing of solid ingredients into liquid food (soup, dairy products, etc.) or into beverages, using tap water as an ingredient. Tap water used as an ingredient is missing in the food flow quantification but would add to the processing stage if it was considered. This could not be done in the course of this study, as detailed information about processing activities per food category in the urban system would be required. Such information is not easy to access as we found out when exploring cereal processing in the cereal supply chain in Île-de-France (Section 3.2.2., Chapter 3).

Another inconsistency occurs with food waste quantified for the urban system (Chapter 3) and as part of inner-urban flows (Chapter 4), respectively. A detailed discussion of food waste flows in the integrated flow scheme, together with Sankey diagrams for food alone, follows in Section 5.1.4. Food waste quantified for the urban system for various types of waste, including drink waste (mixed household waste, business waste, separately collected bio-waste, used frying oil, agricultural food waste, and waste to the sewer) appeared to not be high enough (718 kt) in Paris Petite Couronne compared to food waste quantified for the consumption stage, when quantification options yielding high results for in-home and out-of-home consumption are retained (once combined, 809 kt for food and 79 kt for drink)[185]. Food system sectors (processing, distribution, logistics and wholesale) not covered in the inner-urban system analysis would also add sectoral food waste, and add to consumption waste which is already exceeding total food waste of the urban system. When quantification options for in-home and out-of-home consumption yielding low results are retained (once combined, 258 kt for food and -47 kt for drink, indicating a problem with purchase or intake drink flows), food waste quantified for the total urban system of Paris Paris Couronne (718 kt) appears as compatible or even too high compared to consumption food waste. It does nevertheless leave space for food waste from the additional food system sectors not covered in the analysis. However, the discussion about the various data sources and quantification approaches in Chapter 4 emphasizes severe limitations of some options. These options yield low food waste results, that is, for in-home consumption option HH1, related to the use of Kantar Worldpanel data for purchase quantities, and for out-of-home consumption option FS2, related to the number of meals in the social food service extrapolated to the total food service sector. The discussion leads to the conclusion that the different quantification options must not be considered as

[185] See Table A4.12 and Table A4.14 in the appendix to Chapter 4 for the complete data for the integrated food metabolism of Paris Petite Couronne.

equally appropriate for the analysis of the food metabolism and that at consumption stage, the higher food waste results appear as more plausible than do the lower food waste results.

The situation is similar in Île-de-France. When quantification options yielding high results for in-home and out-of-home consumption are retained (once combined, 1,326 kt for food and 122 kt for drink)[186], food waste quantified for the urban system (1,457 kt) appears as low considering that it includes all waste types of the system and even food waste from agriculture (161 kt). By contrast, when quantification options for in-home and out-of-home consumption yielding low results are retained (once combined, 423 kt for food and -100 kt for drink, indicating a problem with purchase or intake drink flows), food waste quantified for the total urban system of Île-de-France (1,457 kt) appears as compatible or only slightly too high compared to consumption food waste. Although the consumption sector is reputed for contributing the most to a system's total food waste (Lee and Willis, 2010; Stenmarck et al., 2016), the particularities of an urban system such as Île-de-France, which has heavy manufacturing and logistics sectors compared to Paris Petite Couronne, make it plausible that food waste from these sectors weighs heavily in the Île-de-France urban system as well. Once quantified, food waste from the manufacturing and logistics sectors would usefully add insights in food waste at the level of Île-de-France.

While food waste from manufacturing and logistics was missing in the inner-urban food flow analysis, underestimation of food waste at the level of the urban system could also have been a problem. Using a bottom-up approach as we did to gather statistics and other data sources for the different types of food waste implied the risk that parts of the flows remain poorly estimated, invisible and, as a consequence, ignored[187]. Food waste from business for example was identified as a type of food waste requiring further studies. Another example is home composting as an optional destination for food waste, different from mixed household waste collected by the public service, that is insufficiently considered. The benefit of the integration of inner-urban and urban flows in a complete flow scheme lies in the revelation of inconsistencies in the magnitude of the flows. Once integrated into the complete flow scheme, the inner-urban food waste flow from consumption proved to be consistent or inconsistent with the magnitude of food flows from the urban system, depending on the quantification options

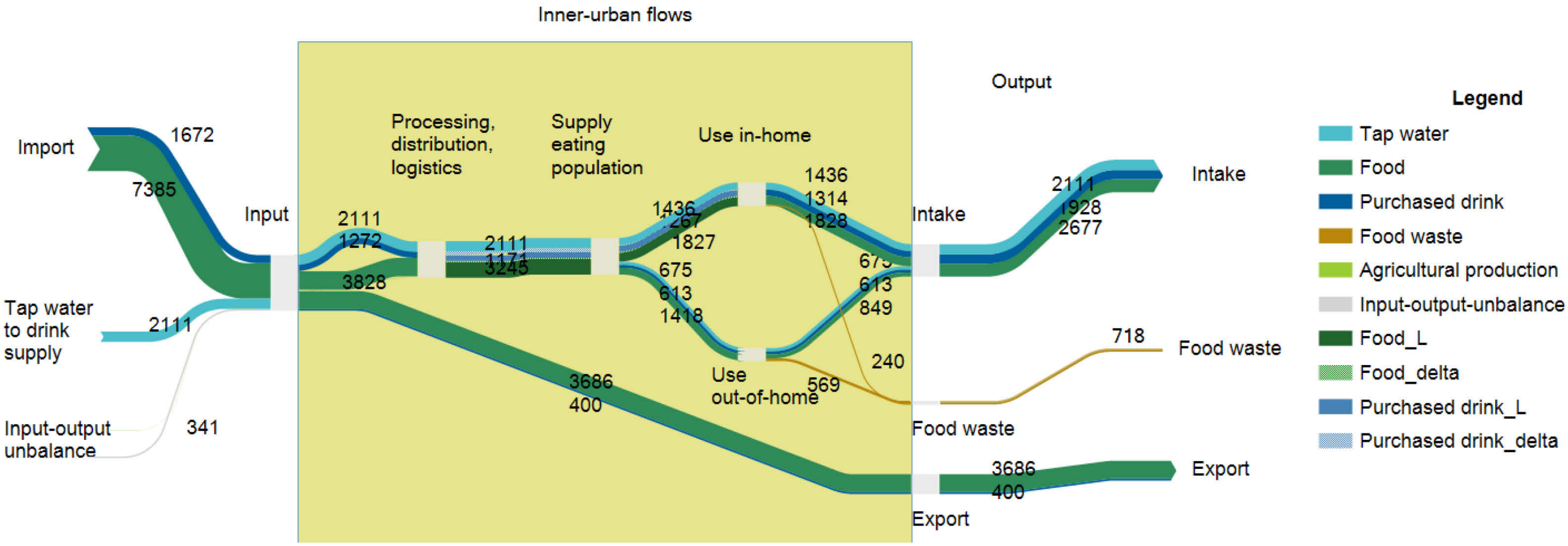
[186] See Table A4.13 and Table A4.15 in the appendix to Chapter 4 for the complete data for the integrated food metabolism of Île-de-France.

[187] Section 3.1 in Chapter 3 discusses the quality of the data used. The study expressed alerts following the statement of insufficient data and data quality about mass material flows, in particular in the field of food waste.

for consumption food waste that were retained. Lastly, in the case of Île-de-France, there is a huge imbalance between input and output flows of the urban system, amounting to 10,577 kt, which potentially can include food waste as well. It was not possible in the course of this study to disentangle possible material flows that together build this imbalance (see discussion part in Chapter 3). It is plausible, however, that food waste generated as part of inner-urban flows at stages other than consumption and not quantified as output flow from the system is part of the imbalance. There was no possibility though to quantify missing food waste flows in the course of this study.

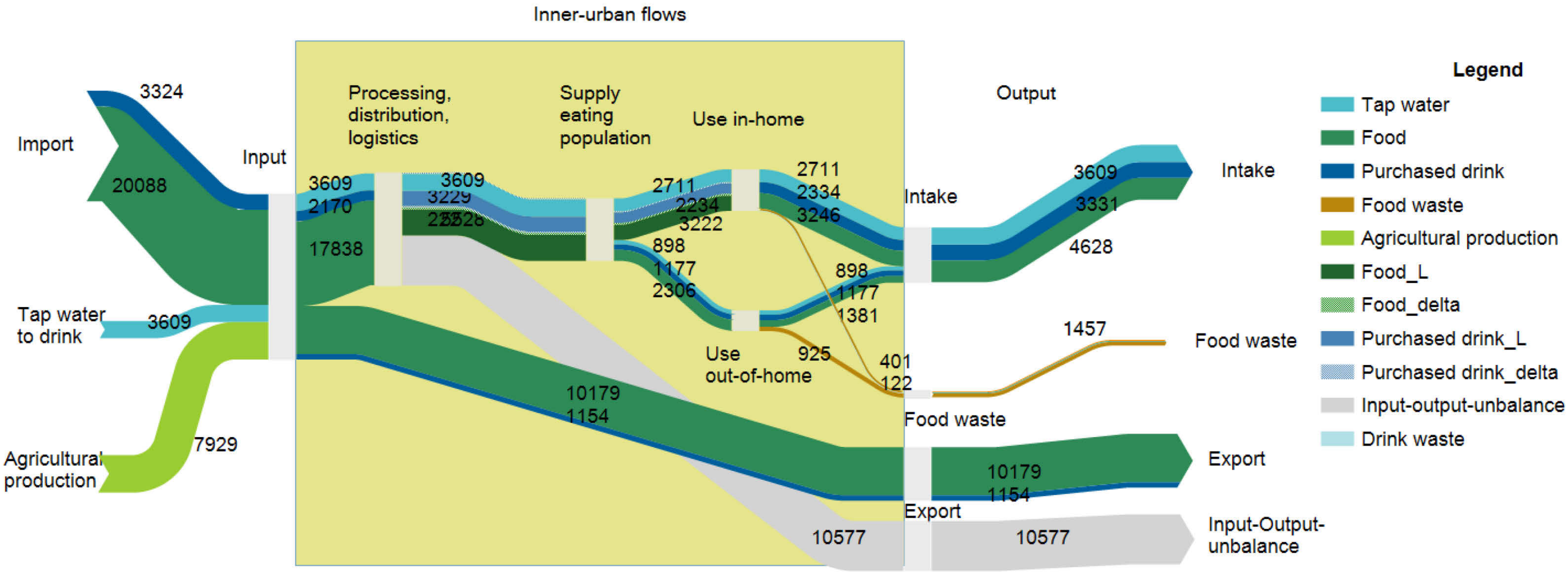
Another concern, already expressed in Chapter 4, is related to the different quantification approaches to food waste in in-home and out-of-home consumption, respectively. They tend to introduce a bias. A coefficient chosen too high (this study used a coefficient of 24% food waste) would overemphasize the food waste flow in out-of-home consumption. It could furthermore explain the high quantity of food waste at consumption stage compared to the magnitude of food waste generated in the urban system. By contrast, food waste generated at in-home consumption, as a proxy of the difference between purchase and intake, ends up with values that we consider as plausible in option HH2, but too low in option HH1, and overall low compared to food waste from out-of-home consumption. Compared to the food waste results of the urban system, the sector-wise food waste quantification has severe limitations, as discussed in more depth in 5.1.4. The food waste literature presented in the background Chapter 1 supports the idea that overall, the food waste results in this study are low.

Figure 41. Urban and inner-urban food and drink flows, Paris Petite Couronne, 2014, kilotons



Source: Table A4.12 and Table A4.14 in the appendix to Chapter 4, Table A3.4 in the appendix to Chapter 3; Note: Food and drink flows for out-of-home consumption calculated with option FS2 including food waste (259 kt of food), agricultural production (29 kt) and purchased drink waste (79 kt) from in-home consumption are not shown. For in-home consumption, the negative difference between purchase and intake (-1 kt of food, -47 kt of purchased drink) is not shown. Because the results of Chapter 3 and Chapter 4 have not been fully integrated, inner-urban food waste flows do not match urban system food waste (718 kt), disregarding unshown results.

Figure 42. Urban and inner-urban food and drink flows, Île-de-France, 2014, in kilotons



Source: Table A4.13 and Table A4.15 in the appendix to Chapter 4, Table A3.5 in the appendix to Chapter 3
Note: Food and drink flows for out-of-home consumption calculated with option FS2 are not shown. For in-home consumption, the negative difference between purchase and intake (-24 kt of food, -100 kt of purchased drink) is not shown. Because the results of Chapter 3 and Chapter 4 have not been fully integrated, inner-urban food waste flows do not match urban system food waste (1,457 kt), disregarding unshown results.

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5.1.2. A major trade dimension in the food metabolism

The Paris region has the feature of a major food hub through which huge food import and export flows passed in 2014. The study results reveal a metabolism that largely covers not only the urban food demand, which is already massive, but also a wider network of trade relationships in connection with other territories, in France and abroad. Billen and colleagues have shown that the Paris food metabolism is historically largely embedded and tightly webbed into a regional and supra-regional food metabolism (Billen et al., 2009; G. Billen et al., 2012; Gilles Billen et al., 2012; Chatzimpiros and Barles, 2013). The spatial embeddedness benefits not only the feeding dimension of the Paris Île-de-France food metabolism, but also the trade dimension.

Whether import flows or local agricultural production feed the food export flows cannot be answered through statistics. Nevertheless, considering the agricultural production sector in Île-de-France, it can be assumed that export is production-driven. This study, as all metabolism studies using a balance approach, does not allow us to track the pathways of food products from their origin to their destination. The material balance approach does not reveal how input and export flows actually connect to each other. The CREDOC, a French company specialized in the study and monitoring of the living conditions of the French, was charged by regional authorities with the study of the Île-de-France bread wheat supply chain, the predominant crop produced in Île-de-France, and has shown in a detailed flowchart that import and export flows concern both wheat and flour. In 2007, the region exported 60% of its bread wheat production, and exported another 60% of the derived flour. In turn, flour was imported at a share of 60% of the Île-de-France requirements for bread baking. The CREDOC study showed the complex import-export scheme of a product occurring at the various levels of processing, and the scant information available for its analysis. The situation is similarly unclear for other crops (other cereals, oil crops, etc.), but relatively clear for vegetables, fruit and some other products produced in Île-de-France and almost exclusively sold locally either on markets or to restaurants, and either via the wholesale market at Rungis or directly by the farmers.

The trade dimension of Paris Île-de-France is strengthened by two aspects. The capital region hosts “Rungis”, the short name for the national wholesale market (MIN) for fresh produce located 7 km south of Paris, in the municipality of Rungis, in the Val-de-Marne *département*. “Rungis” is the biggest wholesale market for fresh produce in the world. According to the annual report of Semmaris, the operating body, 1,720 kt of fresh produce (excluding flowers) arrived at Rungis to be marketed during the year of 2014. Compared to the food input, the quantity of 1,720 kt represents a small share, with 19% and 5% for Paris Petite Couronne and Île-de-France, respectively. Compared to the urban food intake (see Chapter 3, Table 12), the role of the "Rungis" market appears in a different light. With a share of 26% and 15% for Paris Petite Couronne and Île-de-France, respectively, "Rungis" appears as an important player for the food supply of the capital region. However, data for 2009 showed that one third was redirected to markets other than those of Île-de-France[188] (IAU île-de-France, 2012). According to the same study, "Rungis" contributes 40% of the fruit and vegetable consumption in Île-de-France, 30% of the fish and seafood consumption, 20% of meat products, and 5 to 10% of cheese.

The other aspect of the trade dimension is related to the role of the food processing industry. 902 companies and 1,408 production units are located in Île-de-France and have 22,037 employees, accounting for 4.3% of the sales turnover of the national food processing sector (DRIAAF, 2018). Paris Petite Couronne contributes with 864 production units and 13,316 employees. But these figures are not an accurate reflection of the situation. Some of the companies are headquarters without any production activity but with employees accounted for who actually work elsewhere. Other companies, especially the many small processors in advanced processing in a high-value market are not accounted for (DRIAAF, 2018). Whatever the exact number, the sector is only barely connected to the local agricultural production, and therefore is hardly anchored in its territory, with the exception of cereals and, to a lesser extent, of sugar beet processing. The baking industry with its local connection is amongst the largest food processing sectors in Île-de-France, in terms of number of production sites, although the beverage and meat processing industries, despite their few local connections, are important processors as well. The role of imports is particularly important for local processors as the connection to local agriculture is poor. The food service sector, supplied by a specialized processing industry, is heavily dependent on imports as local production is far from satisfying the sector's requirements in terms of quantity and quality.

This study's results reliably reflect the role of processing in the Paris Île-de-France food metabolism, particularly the distinction between first-stage processing in the cereal and beetroot sectors and second- or third-stage processing in other product categories. The massive input-output imbalance for Île-de-France (10,577 kt), amounting to one third of the input flow, can

[188] In 2009, two thirds of the produce in terms of value found its way to end users in Île-de-France, via independent retailers and restaurants as major clients, and some retailer groups' logistics platforms. Another 25% went to customers in the rest of France and the remaining 10% were exported (IAU île-de-France, 2012).

be almost entirely explained by the contribution of cereal (4,664 kt) and sugar beet processing (6,694 kt). As detailed in Chapter 3, possible explanations for the input-output imbalance refer to exports reported in a different product category, such as inedible parts or by-products from processing, and to output to nature in the sense of the EUROSTAT method, e.g. evaporated water, neither of which is covered by the quantification method of this study. The fact that the Paris Petite Couronne material balance is almost outbalanced suggests that there is little first-stage processing industry that removes large material flows from the balance, such as inedible parts or evaporated water, as is the case with cereal and sugar beet processing in Île-de-France. Small and highly specialized processing companies, located closer to the urban centre, tend to use semi-processed input material and do not generate massive amounts of by-products or water. Paris Petite Couronne and Île-de-France, characterized by different urban profiles, density and geography, both host important yet different types of food processing in the capital region which provides its food metabolism with a different profile.

5.1.3. Similar eating and legal populations

Unsurprisingly, Paris Île-de-France has a massive urban food demand related to its population of 12 million inhabitants. But despite the region's status as major tourist destination and vibrant economic hub in Europe, the additional population of tourists, excursionists and commuters accounted for only a small proportion of the eating population in this study (12% in Paris Petite Couronne, and 5% in Île-de-France). Their contribution was more than outbalanced by the residents' travelling and time spent away for personal or professional reasons, reducing residents' contribution to the eating population accordingly. The population of Île-de-France tends to travel more often, for longer and farther away than the population of other regions (IAU île-de-France, 2014). Its tourist activity therefore influenced the eating population as much as the presence of the additional population, resulting in a slightly lower eating population as a whole. The context of other cities with their population types, locations or wealth can yield very different results from those of this study. Few studies in the literature have explicitly reported on additional populations or parts thereof (Boyer et al., 2019; Niza et al., 2009). The eating population appears as a significant concept for urban metabolism studies as urban food demand based on the eating population is closer to the reality and provides a more reliable analysis of food flows and their implications for resource and energy use.

The concept should be tested empirically in the context of other cities with various profiles in future studies, under additional consideration of different diets and varying roles of out-of-home consumption. Tourist places such as ski and seaside resorts temporarily have an instant population that is many times bigger than its legal population. Commuter or "dormitary" towns, on the other hand, see large parts of their legal population commuting to other places for work and having their meals there, leaving the eating population diminished accordingly. By studying extreme cases, we then could see the range of results in which the eating population compared to the legal population operates, and discuss influencing parameters along with implications for the food metabolism. Insights in consumption-based scenarios in food metabolism studies would be valuable for designing and evaluating urban food policies, for instance involving diet change, or for exploring responses to extreme situations, such as a health crisis like the covid-19 pandemic involving a temporary limitation of populations' movements (more home office, less tourism).

Insight into the eating population can also help to target specific population types in terms of more sustainable food practices. Tourists or commuters tend to have different expectations or requirements from the resident population in terms of food and eating. A couple of years ago, for example, an initiative of the French railway company SNCF (and a local partner) launched stands with fruit and vegetable baskets for sale in train stations, at rush hour. This is an example where an offer from local farmers was tailored to meet the constraints of the commuting population. Using the concept of the eating population to know their numbers and their travelling and eating practices is an asset for taking action. Through the same concept, this study also estimated the part of out-of-home consumption in total urban food demand. With a share of 30% and 32% in Île-de-France and Paris Petite Couronne, respectively (Table 33), out-of-home consumption represents an important sector in size. With 74% and 85% of food and drink intake out-of-home in Paris Petite Couronne and Île-de-France (Table 32), respectively, the household eating population plays an essential role in driving the sector to more sustainable practices. More knowledge about the number of meals, origin and farming type of the food supply and organization and management guidelines with respect to sustainability, such as seasonality or vegetarian options, would be relevant when it comes to tailoring more sustainable food systems.

5.1.4. Partly hidden food waste flows at urban system level

We used varied approaches to estimate food waste flows in this study, according to the level of analysis. While food waste flows were derived from waste statistics and reports for the urban system as a whole (Chapter 3), food waste was estimated with different methods at consumption stage (Chapter 4). For in-home consumption, an input-output mass balance approach was used based on food and drink purchase and intake data. For out-of-home consumption, food waste was estimated through coefficients.

As noted above with regard to the overall results, the different approaches to quantification, the data sources and the system boundaries they referred to could explain that food waste quantified for the urban system appeared to be low compared to food waste quantified for the consumption stage, with in-home and out-of-home combined. The reason is that for the urban system, the quantification covers food waste of the additional food system sectors prior to consumption (see discussion, Section 5.1.1).

Because of these different approaches, the comparison between results at individual stages of the food system is also difficult to establish. Table 37 presents an overview of these food waste results. Only waste flows for food, not drink, could be calculated at the level of households and businesses. The reason is the lack of data on drink waste disposed of in the sewage system and not the solid waste management system. The food waste results are linked to the complex typology of waste and the possibilities for their quantification (Figure 15). For example, food waste results for households, calculated in Chapter 3, included business waste (restaurants and shops) collected together with household waste (OMR) by the public service sector. The results therefore cannot be compared directly with the results obtained for households per mass balance, in Chapter 4. At business stage, the situation is even more complex. In Chapter 3, business food waste refers to food waste collected from companies by the private waste sector (DAE). The part of business food waste collected together with household waste, which was impossible to quantify in this study, is part of the household waste data. Finally, there is food waste collected separately as bio-waste, almost exclusively from businesses at the time of the study. This means that a comprehensive quantification of business food waste would require us to sum up these three fractions, of which information about the fraction collected by the public service is not however available. In Chapter 4, only waste from the food service sector could be considered as business waste, and not waste from the retail and processing industry, for which data were unavailable. Overall, not even when food waste quantities at all stages from Chapter 3 and Chapter 4 are added together is the total comparable. Despite these shortcomings, the overview presented in Table 37 gives a rough idea about the range of food waste quantities, at a minimum, at household and business stage. The results show for Paris Petite Couronne 591 kt food waste, excluding food loss at production, at household and business stage, obtained in Chapter 3, and 809 kt or 499 kt, at the stage of consumption, but excluding processing and retail businesses. For Île-de-France, the results are 1,082 kt and 1,326 kt or 847 kt respectively. Results of a negative difference between purchase and intake, shown in brackets in Table 37, are not being considered in the analysis of food waste as they would introduce a bias and do not enable further insights in addition to those discussed in Chapter 4.

Table 37. Food waste (excluding drink), in kilotons, 2014

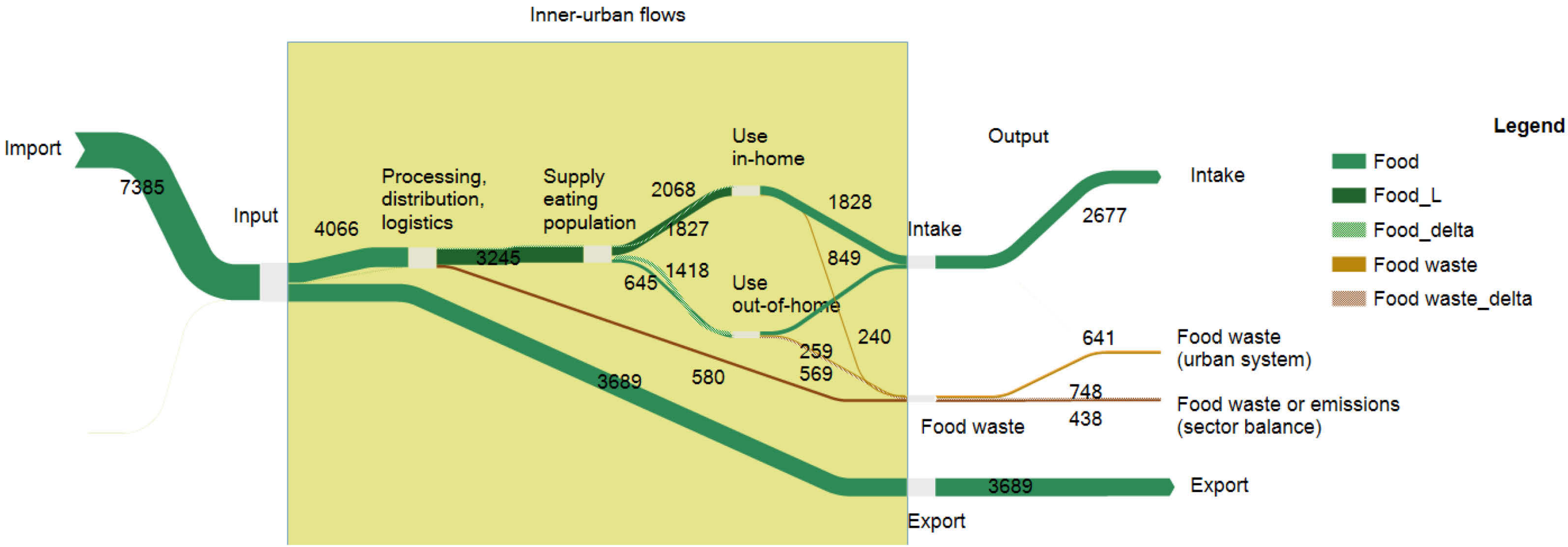
	Paris Petite Couronne		Île-de-France	
	System level	Consumption level[7]	System level	Consumption level[7]
At household stage	402[1]	(-1) / 230	792[1]	(-26) / 386
At food service stage	--	569 / 259		925 / 447
At business stage[4]	153[2]	--	235[2]	--
In separately collected bio-waste[3]	36	--	55	--
TOTAL FOOD WASTE at household and food service /business stage	591	(568) / (258) / 809 / 499[5]	1,082	(901) / (422) / 1326 / 847[5]
TOTAL FOOD WASTE excl. production stage	640		1,111	
TOTAL FOOD WASTE incl. production stage	641		1,272	
Share of food waste excl. production (in %) of food supply[6]	18	23 / 16	19	22 / 15
Annual per capita food waste excl. production (kg/cap/y)[8, 9]	96 95	121 / 74 120 / 74	98 92	117 / 75 110 / 70
Share of food waste incl. production (in %) of food supply[6]	19	--	22	--
Annual per capita food waste incl. production (kg/cap/y)[8,9]	96 95	--	112 106	--

Source: see text in Chapter 3 for the system level, and Chapter 4 for the consumption level
[1] Contains business waste collected together with household waste by the public service sector.
[2] This estimate reported in the regional planning tool (Conseil Régional Ile-de-France, 2019) relates to business waste that is neither collected with household waste nor separately collected as bio-waste, but collected with mixed business waste.

[3] Essentially collected from businesses (school catering, markets, etc.).
[4] Including food waste from the food service sector.
[5] Four combinations obtained from two quantification options per food system component (two data sources for the mass balance in in-home consumption, coefficients and one data source in out-of-home consumption).
[6] Share refers to food supply built from food intake (excluding drink) plus food waste; food intake was 2,677 kt and 4,628 kt for Paris Petite Couronne and Île-de-France respectively (see Figure 41 and Figure 42); not shown for negative difference between purchase and intake.
[7] Numbers in brackets result or are calculated from a negative difference between purchase and intake.
[8] Normalized with eating population; not shown for negative difference between purchase and intake.
[9] Normalized with legal population; not shown for negative difference between purchase and intake.

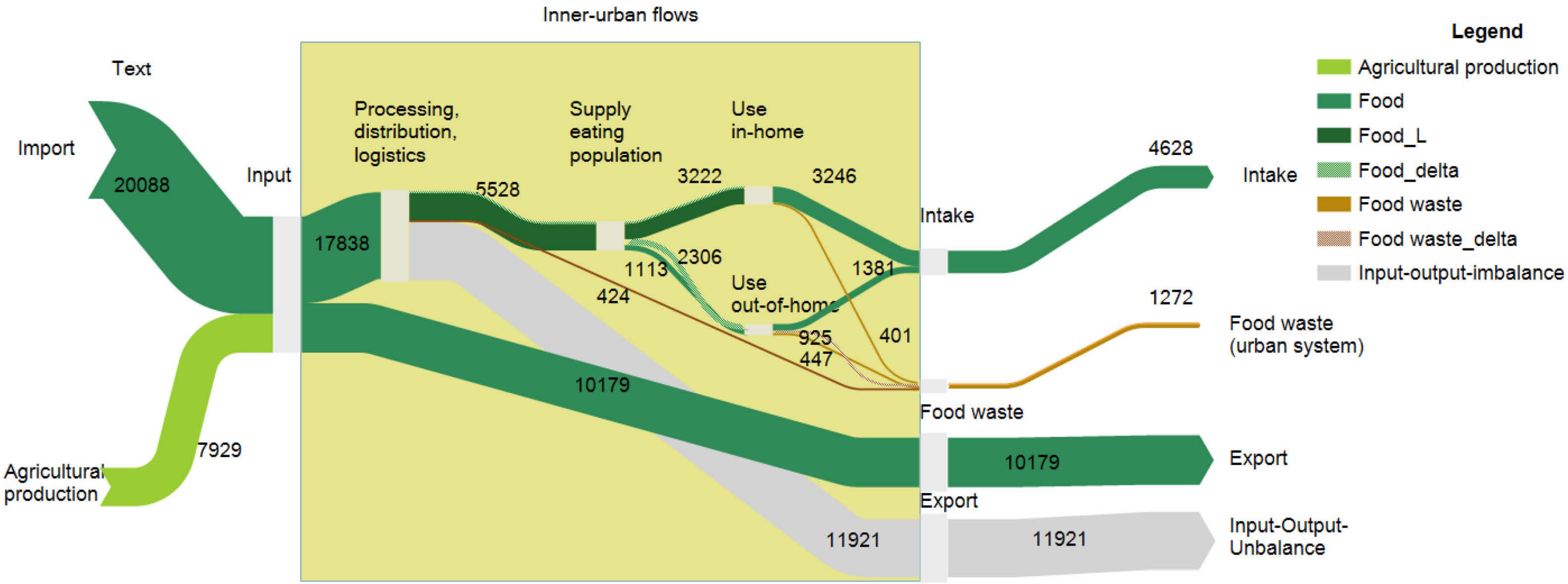
Figure 43 and Figure 44 show the complete flow scheme for food flows, excluding drink, in order to visualize the results of a sector-wise food waste analysis at the urban and inner-urban level, for Paris Petite Couronne and Île-de-France respectively.

Figure 43. Urban and inner-urban food flows (excluding drink), Paris Petite Couronne, 2014, kilotons



Source: Table A4.12 in the appendix to Chapter 4, Table A3.4 in the appendix to Chapter 3.
Note: Agricultural production (29 kt) not shown. For in-home consumption, negative difference between purchase and intake (-1 kt of food) not shown. Missing flow (438 kt or 748 kt depending on option in out-of-home food waste) appears in order to balance food flows prior to consumption and adds to food waste quantified for the urban system or to emissions (water?).

Figure 44. Urban and inner-urban food flows (excluding drink), Île-de-France, 2014, kilotons



Source: Table A4.13 in the appendix to Chapter 4, Table A3.5 in the appendix to Chapter 3.
Note: For in-home consumption, negative difference between purchase and intake (-24 kt of food) not shown. Missing flow (424 kt) appears in the case of low result of out-of-home food waste (447 kt) in order to balance food flows prior to consumption. In the case of high quantities of out-of-home food waste, food waste at urban system level is missing (54 kt) (not shown). It adds to food waste quantified for the urban system or to emissions (water?).

When normalized with the eating population, which most reliably reflects the population involved in generating the food waste in Table 37, per capita food waste (excluding food loss at agriculture) amounted to a similar range of results between Paris Petite Couronne and Île-de-France. Calculated for the urban system in Chapter 3, per capita food waste amounted to 96 kg/cap/y and 98 kg/cap/y for Paris Petite Couronne and Île-de-France, respectively. These results lie in the middle of the results calculated in Chapter 4, that is, per capita food waste of 121 or 74 kg/cap/y and 117 or 75 kg/cap/y for Paris Petite Couronne and Île-de-France, respectively, for the quantification options retained (excluding options with a negative difference between purchase and intake).

Although the results between the urban systems were close, they are nevertheless different from two points of view. First, a difference appears to lie in the role of the eating population. While Île-de-France has an eating population that is 6% smaller than its legal population, Paris Petite Couronne's legal and eating population are nearly equal (see 3.2.1). A smaller eating than legal population drives per capita food waste higher for results normalized with eating than with legal population. This is the case in Île-de-France, where the difference between the results according to normalization (98 and 92 kg/cap/y normalized with eating and with legal population, respectively) illustrates a food system that has fewer permanent eaters over the year than residents, and is organized along these lines (role of out-of-home consumption etc.). For Paris Petite Couronne, per capita food waste is almost equal, whatever the population used for normalization (96 and 95 kg/cap/y). The second difference lies in the contribution of food loss from agricultural production to total food waste of the urban system. Food loss played a role in Île-de-France because of extensive agricultural production in this system, whereas both are negligeable in Paris Petite Couronne. Food loss at this stage is a specific fraction in total food waste as it is not managed by a waste management system but is to a large extent dispersed to agricultural land. For this reason, it makes sense to distinguish food waste results excluding and including food loss at agricultural production. For Île-de-France, total per capita food waste is 14% higher when food loss is considered, that is, 112 versus 98 kg/cap/y (normalized with eating population).

Putting the results into perspective for the purposes of demonstration required me to choose where to lay the focus of analysis. A territorial approach, as applied in this study, is meaningful when the focus is on the management of emissions, such as waste flows, at the level of an urban system. Territorial emissions are often indicative of the economic structure of a system (Pichler et al., 2017). At the urban system level in this study, for example, food waste accounted for 7%

and 5% compared to the total food and drink input, excluding tap water, for Paris Petite Couronne and Île-de-France, respectively. Part of the input and output flows, however, are not related to urban food demand, but are transit flows. This is why a consumption-based approach is relevant to use. It includes emissions occurring outside of the system and says more about the food system performance in our case and the influence of urban consumption patterns. A consumption-based approach is not altered by the magnitude of export and import flows that move through a system and do not contribute to consumption. Since food waste at household and business stage predominantly concerns urban food demand, and not food export and import, food intake and food waste summed up are taken as supply to urban demand. For further discussion of the food waste results of this study, I chose a consumption-based approach within the limits of the urban system, based on the urban food demand, and called it a "territorial consumption-based approach". To consider and exclude non-consumption-related food flows for which we assume little food waste, this "in-between" approach appears to be a good solution. The metabolic profile, for example a high import/export and high processing activity involving high material throughput, must be considered when a share of food waste is calculated for an urban system.

Based on this data, summarized in Table 37, we calculated a share of food waste in food supply. We distinguished food waste as a total of household and business (food service sector for data from Chapter 4), and food waste including agricultural production. The latter was added on the basis of data from chapter three, to allow for comparison with studies covering the whole food system.

The share of food waste gives an idea of how the food system performs in relation to urban food demand, although the idea can only be a rough one, for several reasons. The results lie in a wide range due to the different quantification approaches and data sources. Furthermore, food waste at business stage, obtained in Chapter 3, normally includes food waste that is directly related not to urban food demand but to processing and distribution for food export. Therefore, the calculated share of food waste could be overestimated for food waste that is not generated in relation to urban demand. It should be considered, however, that the data base of food waste in mixed business waste is very poor, as discussed in Chapter 3. It is consequently difficult to estimate how much of the food waste in business waste, calculated in Chapter 3, is not comparable to food waste calculated in Chapter 4.

The share of food waste, excluding food loss from agricultural production, lies in a range of 18%, calculated in Chapter 3, and 16% or 23% for Paris Petite Couronne, and of 19% and 15% or 22% for Île-de-France (Table 37). Including food loss at agricultural production, the share of food waste rises to 22% for Île-de-France, but remains at 19% for Paris Petite Couronne, where agricultural production is negligeable. The wide range in which the food waste results of this study lie, fits with the large discrepancies in per capita urban food waste that we found in the literature of urban metabolism studies (see Figure 27) characterized by different approaches to method and data, opposing notably the use of waste statistics and balance approaches.

Many food metabolism studies chose substance flows, in particular nitrogen and phosphorous (Esculier et al., 2019; Forkes, 2007; Svirejeva-Hopkins et al., 2011). Since nitrogen content depends on protein content, which is variable across foods (e.g. high in meat, cheese, eggs, pulses, and low in fruit, vegetables, potatoes, and milk), nitrogen flows from diet do not relate direct to fresh weight mass flows and cannot be used to compare the results of this study.

A couple of studies can be used as references as they calculated, or allow us to easily calculate, the share of food waste related to food supply in a context similar to this study. The most detailed one is the study from Codoban and Kennedy (Codoban and Kennedy, 2008), who report a 26% difference in terms of fresh weight, called food loss in this study, between food available in stores and food consumed, including purchased drink but excluding tap water to drink. While food consumption in their study is similar to that in this study (2,266 g/d/capita versus 2,047 g/d for one adult), the difference between quantities of food available in stores and quantities purchased in this study is significant.

As I did in this study, Boyer et al. (2019) used household purchase data to model urban food demand and did not look at food waste specifically. The study was carried out for several cities in India with partly insufficient diets, which makes the comparison with results of this study difficult. Other studies, not referring to food metabolism or to urban systems, quantified food waste and related them to food supply. At the country level, a study from the French agency for ecological transition, Ademe, obtained a share of 19% of food waste compared to food produced, covering all stages from agricultural production to consumption (Income Consulting AK2C, 2016). At the level of Europe, Stenmarck et al. (2016) show a share of 20%, or 173 kg/cap/y food waste out of 895 kg/cap/y food produced. At household level, the share of wasted food, which is only a small percentage of all food waste, was 6% (Income Consulting AK2C, 2016) whereas food waste including both fractions accounted for 12% and 11% of food purchases, according to option HH2 for Paris Petite Couronne and Île-de-France in this study (and a negative difference in option HH1). The small number of studies makes it hard to put results of this study into perspective.

Overall, progress has been achieved in the quantification of food waste at the urban system level, thanks to some investigations in so far little explored quantification approaches and data sources. Disregarding the questions raised by quantification methods and data, the overall picture of the metabolism in Paris Île-de-France shows a waste flow which is certainly linear but moderate in magnitude. It is similar in magnitude to food waste in other food systems at urban or supra-urban level, in the Western world. The consumption stage, including households and the food service sector, make up the overwhelming part of food waste in this study, as confirmed by the literature (FAO, 2019; Stenmarck et al., 2016; WRAP, 2018), but leaving little margin for food waste generated prior to consumption, as the mass balance approach to food flows in the urban system reveals. The most difficult aspect in the quantification of food waste remains access to food waste mass data or mass data of food and drink flows in general.

5.2. A policy perspective on food waste in the Paris Île-de-France food metabolism

Food waste flows quantified for 2014, the reference year of this study, were barely impacted by policies at that time in France. At most, the topic had merely begun to become a matter of public interest, raised through national communication and information campaigns. Action towards food waste reduction has gradually begun to be implemented since the early years of this decade. At the initiative of NGOs, policy at various administrative levels was followed by businesses which committed rapidly to a topic that can be described as particularly consensual in its aims and strategic for stakeholders' image (Cloteau and Mourad, 2016). Food waste quantities in this study can therefore be considered a starting point for the future assessment of their evolution, for Paris Petite Couronne and Île-de-France. However, because of the current insufficient data base, specifically lacking periodically produced statistics or access to any other representative data, difficulties in monitoring food waste are expected to persist in the future. There is likewise no point for comparison with the food waste in the past.

Beyond this background, the potential impact on food waste of national and local policy designed and implemented in recent years would need to be analysed. Broadly, two types of action targeting food waste can be distinguished: food waste reduction, also termed prevention, and food waste recycling.

Food waste reduction has a direct impact on the quantity of food used by society and hence on the overall food metabolism of a population. By definition, wasted food in food waste (see Chapter 2, Section 1.1.2) can be prevented or avoided and reduces the quantity of food used, if relevant action is taken. Hence, food waste reduction means food waste prevention and concerns wasted food.

The inedible parts of food, on the other hand, that naturally are parts of food and arise when food is processed and prepared for eating, such as vegetable peels, eggshells, meat trimmings or bones, can at best be usefully recycled but not prevented. As they are often mixed with wasted food, mainly in the processing and consumption stage, the two are usually handled together. Policy towards food waste recycling aims at redirecting food waste towards uses that are considered valuable for society. Inspired by the European waste hierarchy from the 2008 European directive on waste (European Commission, 2008), the French legislator has translated priority uses into law (Journal Officiel de la Republique Française, 2016). After food waste prevention, they include in decreasing order of priority, surplus processing or redistribution, use as animal feed, and organic recycling through composting and anaerobic digestion. In recent years, scholarly and citizen-driven considerations informed the idea of reconsidering inedible parts as something that could be edible or be made edible (Coles and Hallett, 2012). Suggestions of cooking ideas and recipes, partly rooted in older cooking traditions, have been flourishing in social media, in zero food waste cooking books, and in discourse by NGOs (Henderson, 2004).

The following part of this chapter shows how policy has been designed to act on food waste reduction and recycling in various fields and administrative levels in Paris Île-de-France. While food policy is the natural home of problems concerning food, waste policy is the natural home of problems concerning waste (Bradshaw, 2018). Food waste builds the linkage between the two, even if it more often is embraced by waste policy than by food policy. As a part of urban bio-waste and an abundant renewable resource, food waste has moreover come into the focus of energy policy. The detailed analysis in the following sections shows that much of this policy could well serve no purpose, given the poorly coordinated landscape of administrative responsibilities.

5.2.1. Limited policy impact on food waste reduction

The results of the food metabolism of Paris Île-de-France suggest that there is ample potential for food waste prevention, given the size of the waste flow and its share compared to the supply[189] of the eating population. Studies showing that it is common to find food in waste bins in households, restaurants, and shops (Betz et al., 2015; Evans, 2012, 2011; Swaffield et al., 2018) point towards potential for food waste prevention. Waste composition analysis in household bins estimates the amount of wasted food at household stage, including business waste collected together, at approximately 25 kg/cap/y (see Chapter 3, Table 10). This would mean that roughly 300 kt of wasted food, or 20% of the total food waste, would be disposed of by households and small businesses alone, in Île-de-France, disregarding further potential in the other food system sectors, such as the food service sector and retailing. Hence, a minimum of 300 kt of food could potentially have been saved and waste avoided in 2014, had preventive action been taken at the time.

[189] Supply of the eating population has been built from intake and food waste and does not include import-export flows.

5.2.2. A rationale of commitment and best practice supported by law at national level

Table 38 shows the main policy references and the nature and content of the policy instruments at national level, for France, since food waste became known as a topic in the early years of the decade. The nature of the policy instruments was assigned according to the classification suggested by Lascoumes and Le Galès (2007) who distinguish five major types of instruments: legislative and regulatory, economic and fiscal, agreement-based and incentive-based, information-based and communication-based, and standards and best practices.

Table 38. Main policy references directly or indirectly targeting food waste prevention, the nature and content of policy instruments and their target, for France, at national level, from 2009 to 2020

Year	Reference of text	Nature of policy instrument	Content	Target sector	Mechanism of prevention
2009 -	Ademe campaign "*Halte au gaspillage*"	Communication	Awareness raising campaign	General public	Consumer behaviour change
2010	Law n° 2010-874 of 27 July 2010 for the modernization of agriculture	Legislative, Fiscal	Legal framework for food aid including tax reduction for food donation to charity	Business	Food redistribution to charity for food aid
2013	National pact against food waste	Communication, Agreement, Incentives, Regulatory	Action programme; working groups on scheduling, food donation, food waste measurement and other National target (halving food waste by 2025 compared to 2013).	Business, General public	Consumer behaviour change, Stakeholder engagement, Voluntary commitments
2014-2018	National food program	Communication, Incentives	Awareness raising, promotion of initiatives	Civil society (NGOs), Local authorities, Businesses, General public	Consumer behaviour change, Social innovation support
2014-2020	National waste prevention plan	Communication, agreement, Incentives, Regulatory	Aligned with the National Pact against Food Waste	Businesses, General public	Consumer behaviour change, Stakeholder engagement, Voluntary commitments
2015	Law n° 2015-992 Energy transition for green growth	Legislative	Mandatory action plan against food waste backed by an initial diagnostic analysis in the public food service sector (from Sept 2016 on)	Food service sector	Management
2016	Law n° 2016-138 of 11 February 2016 for	Legislative	Prohibition of the destruction of unsold food that can still be consumed;	Retailers	Redistribution to charity for food aid;

	combating food waste, called "Garot Act"		obligation for the retail sector to contract with charity for donation; integration of the topic in the Education Code *		Consumer behaviour change, Skills
2018	Law n° 2018-938 of 30 October 2018 for balanced commercial relationships in the agri-food sector and healthy, sustainable food to all, so-called "EGALim Act"	Legislative	Extension of mandatory donation to include the social food service sector and processing industry; extension of mandatory action plan against food waste in the private social food service sector; promotion of "gourmet bags" to restaurants; creation of a national "zero waste" challenge in secondary and high schools; explanation to consumers of the significance of use-by dates	Food service sector, processing industry	Redistribution to charity for food aid; Behaviour change through education and awareness raising
2020	Law n° 2020-105 from February 10th 2020 for combating waste and for a circular economy, so-called "AGEC Act"	Legislative	Obligation to donate unsold food in wholesale sector; strengthening of the quality of food donation; fine for the destruction of unsold food; improved data labelling Revised national target: halving food waste in the retail and social food service sectors by to 2025 compared to 2015; by 2030 in the consumption, agricultural production, processing and commercial catering sectors	Local authorities, Businesses, General public	Redistribution to charity for food aid; Behaviour change through education
2017-2020	National pact against food waste 2nd edition	Agreement, Incentives	Working groups on improvements in scheduling, food donation, food waste measurement and other	Businesses, General public	Stakeholder engagement and voluntary commitments
2019-2023	National food program	Incentives	Extension of the provisions of the Garot Act to include the institutional catering	Civil society (NGOs), Local authorities,	Consumer behaviour change, Social innovation support

			and agrifood sectors; promotion of “gourmet bags” to restaurants creation of a national “zero waste” challenge in secondary and high schools; improved explanation to consumers of the significance of use-by dates on food products	Businesses, General public	

* Integration into the Education Code did not succeed; the law has not been applied in this respect.

Table 38 shows that awareness raising campaigns conducted by the Ademe and the Ministry of Food and Agriculture, within its national food program, have been an established part of the policy at the end of the decade. Another flagship measure of the French food waste policy is the national pact against food waste led by the Ministry of Food and Agriculture. Meetings of multi-stakeholder working groups around relevant policy topics such as measurement and monitoring, date setting, or food donation, started as early as 2012 and gave stakeholders, including businesses, civil society representatives and the administration, an arena to share their analysis of the topic and defend their position.

Several laws addressing food waste shape the French political landscape, with the law number 2016-139, the so-called "Garot Act", being entirely dedicated to this aim. Several laws support the redistribution of unsold food to charity in one way or another, either through mandatory contracting with charities ("Garot Act") or with the food service sector ("EGAlim Act"), or by allowing a tax reduction for donated food (law nr 2010-874), or by ensuring the food's quality. Issues of education and training about food waste are also addressed in the Garot Act and were planned to be integrated into the Education Code, although that did not happen[190]. Apart from these flagship measures, the administration was concerned to clarify requirements for date marking and to implement food waste measurements and monitoring.

French food waste policy as a whole has been coined by the "Garot Act", the exemplary first law against food waste, passed in 2016. Although the preceding stakeholder working groups and awareness campaigns were by far less symbolic, they played an important role on the way towards the first law.

5.2.3. Little coordination between authorities and services organized to prevent food waste at local level

At local level, different types of local authorities or their distinct services are in charge of waste prevention, through a variety of approaches. There are the executives of the waste services, with local authorities at the intercommunal level (*établissements publics de coopération intercommunale*, EPCI) in charge of waste collection, and others in charge of waste treatment

[190] Education programmes turned out to be more difficult to change than initially thought when the law was initiated.

which they can execute themselves or delegate. There are local government agencies (*établissements publics territoriaux*, EPT) of the Greater Paris Metropolis set up in 2016 as part of the recent territorial reforms to bundle tasks and services. Waste management falls within the scope of their competencies. The regional government is in charge of a comprehensive waste planning tool for the region *(plan régional de prévention et de gestion des déchets, PRPGD)*, while the EPCI and EPT are required to elaborate one for household waste reduction within their ambit *(programme local de prévention des déchets ménagers et assimilés, PLPDMA)*. Elementary school canteens and municipal markets are under the responsibility of municipalities, while middle school (*collège*) and high school (*lycée*) canteens are managed by the *départements* and the region, respectively.

Table 39 shows the main policy references and content at local level, directly or indirectly targeting food waste prevention.

Table 39. Main policy references directly or indirectly targeting food waste prevention, at local level, from 2009 to 2020

Level	Year	Reference of text	Authority in charge	Content	Target sector
regional	2013	Regional plan to combat food waste	Île-de-France regional government	Support for food donation and anaerobic digestion, facilitating and promoting action in schools and business	Local authorities, food industry via action by the Region's promotion office CERVIA
	2019	Regional waste prevention and management plan (PRPGD)	Île-de-France regional government	Synergy building between existing policies; changes in public procurement of the social food service sector	Local authorities in charge of waste services (collection and treatment)[191]
intercommunal	2015	White paper on the circular economy of Greater Paris	Greater Paris Metropolis	Intervention in school canteens and municipal markets	Local authorities (municipalities)
	2016-2020	Local household waste prevention	City of Paris and other local government	For the City of Paris: one of 13 actions, see plan to combat food waste	Intercommunal local authority, local NGOs

[191] In 2020, as a result of a decline in their number in the course of the reform of the public services' territorial organization, there were 66 authorities in charge of waste collection and/or its treatment in Île-de-France. Fifteen of them were in charge of both, 40 of collection alone, and 11 of treatment alone (Sauques, 2020).

		programme (PLPDMA)	agencies (EPT)		
municipal	2015	Plan to combat food waste	City of Paris	13 actions structured around three axes and transversally: food waste reduction in the municipal food service sector, involvement of shops, restaurants and municipal markets; awareness-raising of citizens; actions for the recovery-processing-redistribution of unsold items; the promotion of short supply chains and bulk sale; characterization and quantification campaigns	Actors of school and other municipal canteens; general public; shops, restaurant; waste service
	2017-2020	Paris circular economy plan	City of Paris	See the Plan to combat food waste	See the Plan to combat food waste
	2011-2015	*Programme Local de Prévention des Déchets* (PLPD)	City of Paris	One of 13 actions, see Plan to combat food waste	Local authority (municipality)

Regions have the particular role of designing waste management planning. Waste management planning means providing an overview of waste prevention and recycling measures already planned or to be planned and supporting their implementation by the executing local agencies. The work covers an inventory of waste types, amounts and requirements for management put into perspective with available management facilities, future trends and challenges, and need for infrastructure, brought together in a regional waste prevention and management plan (*PRPGD*). The plan, published in May 2019 by the regional government of Île-de-France (Conseil Régional Ile-de-France, 2019), is considered a working document for coordinating action of local authorities involved in waste prevention and management. To meet the national food waste reduction target, the plan mainly suggests building synergy at a regional level between existing policies (Ministries of Food and Agriculture, of Solidarity and Health, the Ademe) within a regional agency addressing food waste reduction. Local authorities in charge of local programmes for household waste prevention (PLPDMA) should take action against food waste with reference to a regional food plan (*plan régional de l'alimentation*) coordinated by the Île-de-France government. Furthermore, innovation support and integration of food waste reduction targets and higher quality food into public procurement of the social food service sector should enable concrete action.

The White Paper on the circular economy of Greater Paris, a joint publication by the City of Paris and the regional branch of Ademe, proposes a unifying strategy to develop the circular economy and to test its principles in the context of Greater Paris (City of Paris, 2016). Referring to the French energy transition law of 2015, the White Paper advocates for 65 initiatives elaborated in working groups with stakeholders. Food waste reduction was one of the topics to be addressed specifically in dedicated working group. Local authorities, businesses and citizens should cooperate around action in school canteens and municipal markets. A couple of instruments are put forward, from awareness-raising to logistic support for the use of incentives and clauses in contracts with canteen restaurants or market managers. The working group has made detailed proposals to reduce food waste mainly oriented towards redistribution of surplus[192].

Local authorities at intercommunal level in charge of waste collection have a particular role to play as they are the executives of waste management and the closest in contact with the local population, although they are not always well known to the general public. They are legally required by the energy transition law of 2015 to establish a local household waste prevention programme (PLPDMA). From a legal point of view, this is different from any local waste prevention plans that local authorities, especially municipalities at the time they were in charge of waste collection, may previously have established on a voluntary basis. The PLPDMA must plan the measures to meet the national target of a 10% reduction of household and related waste (DMA) between 2010 and 2020, as fixed by the Energy Transition Law of 2015. Food waste

[192] The detailed proposals made by the participants are as follows: include transformation and packaging costs to facilitate the donation of unsold food; use existing equipment for the (re)packaging or processing of unsold foodstuffs; develop one or more shared platforms for the collection of food donations; privilege local logistics chains by adapting and diversifying transport modes for donated food products; develop food aid distribution areas, promoting social and intergenerational diversity; raise awareness about food waste depending on the various audiences; and define the conditions for setting up a transversal network of ideas, interactions and work across Greater Paris, for those contributing to the fight against food waste.
Other proposals mentioned included: have detailed and shared knowledge of food waste data throughout the chain, and of current measures to combat this phenomenon (prerequisite); offer a positive image of redistribution and food aid, particularly by focusing specifically on the related vocabulary (prerequisite); attach importance to donors and their products; develop activities to convert food surpluses using mobile equipment on production or sale sites.

reduction is one of the flagship areas in local household waste prevention programmes. Funding for local NGOs is available to implement innovative action towards households and businesses. In Île-de-France, six such programmes were adopted by 1 July 2018, covering 23% of the local population. Conversely, the majority of the population does not yet have a plan.

The City of Paris, with its unique status as a municipality and EPT *Territoire 1 (T1)*[193] in charge of waste collection and treatment is largely committed towards food waste reduction through various municipal plans (plan to combat food waste, sustainable food plan, Paris circular economy plan 2017-2020) and a local household waste prevention programme (PLPDMA). The plan to combat food waste (2015) is a central plan in this field, to which the other plans refer. It works through the mobilization of the administration, in particular of municipal and school canteens and municipal food markets, as well as the mobilization of actors, via actions for the recovery-processing-redistribution of unsold items, the promotion of short supply chains, and bulk selling. The plan contains a range of thirteen actions led by the city, a result of consultation with dozens of local and public actors, involving the food service sector, shops, food markets and citizens. In 2017, 22 organizations working towards surplus food redistribution received support from the City of Paris (19 in 2016)[194].

In line with the Energy Transition Law from 2015, local authorities are required to engage in food waste reduction in the public food service sector. These are municipalities with regard to elementary school canteens and other municipal canteens they are in charge of. In the same way, the *départements* and the region must address food waste in the middle schools (*collèges*) and high schools (*lycées*) they are in charge of, respectively. For local authorities, the public food service sector is the one prominent area where they can directly intervene with regard to a population's food. However, even if an authority is in charge of both services, the public food service and the waste service, they are usually managed in distinct services – municipal (in the case of Paris) or intercommunal or regional – which often do not work together.

To summarize, at local level, food waste is addressed with a strong focus on awareness raising campaigns and educational tools, such as cooking workshops, which is a common point with national programmes. Additionally, there is a strong focus on local authorities' intervention, for example in school canteens, at municipal markets, and through support for charities' food

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[193] See Chapter 3, 1.1.4 Food waste, for a more detailed description of the territorial organization regarding waste in the Île-de-France region.
[194] https://www.paris.fr/pages/reduire-et-recycler-ses-dechets-114#districts-21lcl7r7vx-14

redistribution. Overall, the picture of local action against food waste in Île-de-France is one of scattered initiatives. Local authorities at various administrative levels have launched several policy plans and programmes, but have poorly interconnected them. In charge of these tasks by law, each one has launched its own plan or programme with little coordination and poor synergy with the others. Moreover, the recent territorial reforms (the “NOTRe” Law) and the changing attribution of tasks (waste collection, planning) in the course of the decade have left local authorities with profound uncertainties about the implications of the reforms. This unintelligible situation has probably not either helped to support more coordinated innovative approaches towards waste prevention and has increased the distance from the local population even more.

5.2.4. Carrots with no sticks: poor coordination to address food waste

Overall, policy has rather limited potential to act on food waste reduction in France. The governance of food flows in modern food systems is largely in the hands of the industrialized business sector (Bognon and Marty, 2015). There is also the fact that it is generally difficult to act on household and business practices for a topic like food waste, that relates to the field of environmental and social responsibility, but constitutes no immediate threat to consumer health and environmental protection. It is clear that in fields that are top priority for a population, such as food safety and food supply, policy action is by no means comparable regarding the resources, policy instruments, monitoring and reporting of the results. Furthermore, food policy in France traditionally is rather a responsibility of national policy, while local authorities have much more limited potential to act directly (Bognon, 2017, 2014; Bognon and Marty, 2015). Thus, they mainly act on the public food service sector and municipal markets, or indirectly through supporting measures.

The above analysis shows that national food waste reduction policy largely makes use of agreement and communication instruments to initiate commitments by businesses and behaviour changes in the general public. Communication, consultation and negotiation with stakeholders play a major role, as illustrated by the national pact against food waste and by the awareness raising campaigns run by the Ademe and the Ministry of Food and Agriculture for many years. Referring to “new public policy instruments” as they reflect a new understanding of political relations, they are designed to mobilize stakeholders and prompt voluntary action, in contrast to traditional interventionist instruments of the “command and control” type (legislative and regulatory, as well as economic and fiscal) (Lascoumes and Le Galès, 2007).

Some authors question the efficiency of such "soft" policy instruments in the field of waste prevention (Johansson and Corvellec, 2018), in opposition to constraining ones. For food waste in particular, they advocate for the introduction of more coercive measures such as taxes and bans (Priefer et al., 2016). But such claims tend to ignore the role that these soft policy instruments can play to make more traditional constraining ones, such as bans and obligations, acceptable. The effect of a period preceding the French laws, in the form of roundtable discussions with stakeholders via the national pact, must not be underestimated here.

Although France is widely known for passing laws against food waste, being the first country, in 2016, and one of the few ones to ban food destruction and to make contracting with charity mandatory, it undeniably chose a soft way, as the overall French food waste policy is hardly coercive and fines are rarely applied [195] (Melchior and Garot, 2019). It does however demonstrate "best practice" and socially desirable changes towards responsible corporate behaviour (Cloteau and Mourad, 2016). Actual food waste quantities and achieved reduction are not being monitored, which confirms a means-oriented and not a target-oriented policy. As an example, food redistribution executes a legal obligation to contract with charity, irrespective of any proof of efficiency of this measure. The obligation involves neither a minimum quantity of unsold items to be donated, nor a regular frequency. There is no guarantee of requirements either that qualify food for donation and protect charity against the risk of ending up as the waste managers of the donors. In this context, the quantitative target of halving food waste by 2025 as part of the 2013 national pact seems to serve more as a means for stakeholder mobilization than as a genuine target for monitoring.

At both national and local level, French food waste policy geared towards food waste reduction is designed around three main types of action: awareness-raising; supporting the redistribution of unsold food to charity; and implementing best practice in the public food service sector.

Awareness-raising among the public at large is generally considered a necessary but insufficient means to stimulate change in food waste practices. The "attitude-behaviour gap" explains that intention to reduce food waste, built from awareness, seldom induces change in practice (Schanes et al., 2018). The scientific literature holds many examples of studies showing that people holding environmental attitudes and values actually do not translate them into

[195] The recent circular economy law n°2020-105 increased the fine, from €450 to €1,500 maximum, for retailers who failed to sign a contract for food donation to charity. Destruction of unsold food items is liable to a fine of €10,000 instead of €3,750.

environmental behaviour (Boulstridge and Carrigan, 2000; Vermeir and Verbeke, 2006). This is a very real concern as information and communication for awareness-raising and education are used by government as the only means to address households, that is, the sector which contributes the most to food waste. Little is being done to act on food practices other than "end-of-pipe" initiatives. The food system could also be reorganized upstream, for instance in the production and retail stages, to foster food-saving practices in households. In this respect, policy fields with conflicting goals towards food waste reduction also need to be revised, as analysed in detail in Sub-section 5.2.4.

Redistribution of unsold food to charity stands out as the predominant means to address food waste. It is increasingly becoming a legal requirement in the retail, food service, and industry processing sectors. However, redistribution does not prevent the generation of surplus food. It could even be a facilitator for businesses to get rid of unsold items without paying for their treatment as waste. Donation is moreover encouraged by means of a tax incentive, which makes it financially beneficial for donors[196]. Undeniably, policy has had an impact on donation. A recent study on retailers (Comerso and Ipsos, 2019) found that quantities increased by approximately 30 percent in 2017, and the percentage of supermarkets donating unsold food rose from 66 percent prior to 2016, to more than 90 percent in 2018. However, it remains unclear how much food in total remains unsold and how much of it constitutes donation, which again confirms a means-oriented policy.

While it is important to improve the organization of food aid and access to it by the needy, the question of whether food donation from surplus food is an appropriate means to do so is a matter of debate. A French parliamentary task force set up to analyse the effects of the French law that made donation mandatory for retailers, concluded that the law has been successful in fostering food donation, but has failed to encourage a policy of food waste prevention: "It's not about offsetting the excess of our society of overconsumption. It's about avoiding excess in the first place" (Melchior and Garot, 2019). As suggested by the waste hierarchy and confirmed in a recent literature review (Redlingshöfer et al., 2020), the biggest environmental benefit lies in food waste prevention not redistribution, as food production and related resource consumption and environmental impacts would concomitantly be avoided. Critique of the food donation policy comes from the academic arena as regards the social impact. Food aid, which is entirely

[196] Article 238 bis of the French tax code stipulates that 60% of the food's inventory value is tax deductable, up to a total of 0.05% of the business turnover.

organized by charity in France, works mostly with donations and makes it dependent on donated food, including from surplus. And yet, the redistribution of surplus should at best become obsolete through efficient prevention policy. Food aid and food waste therefore are tied up in a paradoxical relationship (Darmon et al., 2020). Initially planned for people in situations of emergency and complementary to support for social and occupational inclusion, food aid today appears as the only support for people in need, which makes them dependent and denies them personal liberty and dignity in their limited life choices. As Dominique Paturel (2018) put it, food aid not only maintains people in a state of dependency but additionally supports the rationale of mass food production and distribution, which in turn contributes to the suffering of those who do not succeed in this system, such as impoverished farmers.

In view of the overall policy in place, it is difficult to assess the impact at this stage and to perform ex-post policy evaluation. Food waste monitoring is challenging, since the currently available data do not allow it to be carried out at national or local level[197]. It is therefore not possible to state whether food waste has decreased in relation to public and private action since 2014. Furthermore, food waste prevention can be measured only in comparison with the waste arising between two points of time (Sakai et al., 2017; Yano and Sakai, 2016), and not directly. Outside of any such comparison, measuring food waste prevention has an intrinsic problem. All food that does not end up elsewhere than in people's stomach then counts as prevented food waste. And yet, this should be the normal course of things. Food waste prevention paradoxically appears as the result of directing food to its priority destination, that is, feeding people, which implies a high risk of confusion in monitoring.

While suggestions and ideas for food waste reduction flourish, little evidence and few studies are available in the literature about policy intervention that works. A recent study reviewed seventeen studies in the academic literature – thirteen of which used measurement – that analysed intervention for food waste prevention at the consumption and consumer stage of the supply chain (Reynolds et al., 2019). While changes in the size or type of plates were shown to be effective in the food service sector, and changes in nutritional guidelines in schools, little or

[197] One of the working groups of the national pact analysed the feasibility and elaborated guidelines for sector-wise food waste quantification, at national level (Gouthière, 2019). They informed the preparation of a national food waste monitoring program that was mandatory for member states since the revision of the EU waste directive (European Comission, 2018). The Ministry of Ecological Transition is currently preparing this work following the delegated act on a common methodology and minimum quality requirements for the uniform measurement of levels of food waste, a non-legislative act adopted by the European Commission to amend or supplement legislation, which laid the foundations for EU member states (European Commission, 2019). Coordinated efforts should make it possible to obtain required data from private companies per sector.

no robust evidence was provided for in-home intervention. Information campaigns, the most prominent type of intervention targeting households, were shown to be effective with up to 28% food waste reduction in a small sample size intervention. The study concluded on a significant evidence gap, suggesting a difficulty for policy makers to take evidence-based decisions.

The scientific literature has moreover described several barriers to placing food waste prevention as a priority compared to ways of handling food waste and managing waste streams, as I have shown in a recent literature review (Redlingshöfer et al., 2020). The barriers identified range from difficulties in defining and measuring prevention (as it is generally difficult to measure what is physically avoided), to difficulties in securing public support and participation (food waste prevention can reduce diversity and assortment in meal services) and to conflicting organizational and policy goals (prevention conflicts with goals for bio-waste recycling and for higher consumption of healthy foods following nutrition policies)[198].

Small-scale experiments such as examples of school canteens have shown how to drastically decrease food waste [199] while making successful waste prevention part of an integrated approach to a healthier and more sustainable meal service. The public food service with school and municipal canteens is a prominent sector, and the only one, where local authorities have the necessary responsibilities to effectively act on food policy. The implementation of best practice in food waste prevention through public procurement policy, such as the introduction of clauses into contracts with restaurant managers, are a simple means of intervention for local authorities. However, at the level of an entire city or even a region, large-scale food waste prevention must go beyond the public food service sector and can be effective only when businesses and households are involved.

5.2.5. Urban bio-waste as a bonanza for introducing circularity into food systems

As the results of this study show, the urban food metabolism of Paris Île-de-France has a strongly linear form, with all food flows currently contributing to linearity. On the one side, supply through imports and local production enter the system, while on the other side, food intake and export leave it. The linear dimension of the food metabolism is strongly reinforced

[198] See Sub-section 5.2.4 on conflicting goals between food waste reduction policies.

[199] To a level of 32 grams per meal in the case of Mouans-Sartoux (https://mead-mouans-sartoux.fr/la-fin-du-gaspillage) compared to the national average of 120 g / meal, see the literature on quantitative food waste results in Section 0.

when export flows are large compared to intake, which is the case at the level of both Paris Petite Couronne and Île-de-France [200]. Food waste flows, albeit much smaller, currently reinforce the linearity of the urban food metabolism, as more than 90% of the food waste is incinerated or landfilled (excluding food loss at agriculture). Not only does waste elimination add environmental emissions to already embedded upstream emissions, it also removes the material basis for introducing circularity in the metabolism through waste recycling. From a food material perspective, potential for closing material cycles and engaging with a less linear form of metabolism essentially lies in material reuse, for example for animal feed, or in organic food waste recycling that serves as fertilizer and soil amendment [201]. The use for biogas production has much less potential from both a material and an energy perspective (low energy efficiency), even though it falls within the framework of renewable energy policy.

Results from the Paris Île-de-France food metabolism show that composting and anaerobic digestion of food waste were hardly practised in 2014. Organic management of food waste, collected separately as bio-waste, accounts for only 5% of solid food waste from households and businesses in Île-de-France, and 6% in Paris Petite Couronne, as the results of this study show (Table 37). Accounting additionally for food loss in agriculture – that we assume returns to the soil and contributes to closing nutrient cycles [202] – and for spent cooking oil recycled as fuel [203], the total share of food waste being recycled rose to 17% in Île-de-France and to 8% in Paris Petite Couronne. The difference is explained by the contribution of food loss in agriculture, a sector contributing little to the food metabolism in Paris Petite Couronne in contrast to that in Île-de-France. The contribution of domestic or neighbourhood composting is difficult to assess, but is estimated to contribute little.

In 2014, waste recycling policy, as laid down in the European waste directive (2008) and translated into French law, was extended to address bio-waste in particular and hence to develop

[200] See Table 12, Chapter 3
[201] By contrast, ample potential for closing nutrient loops lies at the extreme ends of the supply chain, at farm stage through the use of manure (Billen et al., 2014) and at post-consumption stage, in the use of urine (Esculier, 2018), both as fertilizer in crop production.
[202] Like any other organic matter, food loss ploughed under returns nutrients to the soil and contributes to closing biogeochemical cycles. We nevertheless expect that this contribution is modest as the average food loss quantities are small compared to other organic input (plant residues etc.). Furthermore, losses to the environment might occur in the course of the degradation process, in contrast to composting or anaerobic digestion. To conclude, food loss left in the field must strictly speaking be considered a circular flow. Circularity however is not necessarily synonymous with benefit. The FUSIONS framework for example does not acknowledge as a productive use surplus food ploughed under or left in the field, and qualifies both situations as food waste (Östergren et al., 2014).
[203] Use as fuel is a technical combustion process which releases CO_2 and H_20 into the air. We cannot speak of material recycling here.

productive uses of it. Other policies targeting renewable energy systems identified the same bio-waste, notably from cities where this urban waste is easier to access, collect and treat. Table 40 and Table 41 summarize waste and energy policies and their key measures relating to bio-waste, including food waste, at national and local level. These policies targeting bio-waste to recycle are running in parallel with the policies aimed at food waste reduction, with food or bio-waste as a linkage.

Table 40. Main policy references directly or indirectly targeting recycling of bio-waste including food waste, at national level, from 2010 to 2020

Year	Reference of text	Content	Target sector
2012	Law n° 2010-788 of 12 July 2010, on National Commitment for the Environment ("Grenelle II Law")	Mandatory separate collection of bio-waste and used frying oil for big producers	Distribution, food service sector
2015	Law n° 2015-992 of 17 August 2015 on Energy Transition for Green Growth (TECV):	Generalize the sorting of bio-waste at source for all producers	All waste producers including households

Table 41. Main policy references directly or indirectly targeting recycling of bio-waste including food waste, at local level, from 2010 to 2020

Level	Year	Reference of text	Local authority	Target	Target sector
Regional	2019	Regional plan of waste prevention and management (PRPGD)	Île-de-France region	Material and organic recycling reaching a share of 55% by 2020, 60% by 2025 and 65% by 2031.	Local authorities
	2019	Regional biomass planning scheme (SRB)	Île-de-France region	Overview of biomass production and destination in Île-de-France	Local authorities
Intercommunal	2015	White paper on the circular economy of Greater Paris	Greater Paris Metropolis	Separate bio-waste collection on municipal markets and canteens, and on household food waste, support to neighbourhood composting	Local authorities
Municipal	2016	Composting plan	City of Paris	Development of composting of different types (apartment houses, public buildings, neighbourhood, and private household)	Different services of the City of Paris, local associations
	2017-2019	Paris circular economy plan	City of Paris	Collection of household food waste in the 2nd and 12th *arrondissements* starting in 2017, throughout Paris by 2020, and production of compost	
	2019	Climate Air and Energy plan	City of Paris	Development of composting in apartment houses (1000 composters by 2020), centralized composting in facilities of different sizes and use for farmers, anaerobic digestion facilities of different sizes for biogas production, awareness-raising programmes in after-school programmes	Waste service of the City of Paris, Syctom, school canteen service (*caisses des écoles*)

In 2014, separate collection and treatment of bio-waste, which by definition includes food waste, was still scarcely performed, although law n° 2010-788 of 12 July 2010, on National

Commitment for the Environment, also referred to as the "Grenelle II Law", had laid the legal foundation for requiring big producers of bio-waste to separate it and have it collected for organic recycling[204]. The mains sectors concerned are the distribution and the food service sectors. Threshold levels of annual bio-waste production, fixed at 120 t per year in 2012 and progressively decreasing to 10 t per year in 2016, determine whether establishments fall under this obligation (decree of 12 July 2012). By 2014, producers of at least 40 t of bio-waste generated per year were concerned, as were retailers with a sales surface of 2000 m^2, based on an average of 20 kg per m^2 per year (Ademe, 2013). For the food service sector, canteens serving at least 1,357 meals per day, 220 days a year (average food waste 134 g / meal) were concerned (Ademe, 2013). There is no estimate of the quantities that should have been collected at that time, based on the number of establishments at the level of Île-de-France. A study for France in 2019 (Comerso and Ipsos, 2019) found that 59% of medium and large retailers (above 400 m^2) reported that they did not recycle their bio-waste. However, if all hypermarkets recorded in Île-de-France (181 according to the data base BDCom of the Paris Urbanism Agency Apur) had their bio-waste collected, based on an estimate of 11 kt in total and 60 tons per year (Ademe, 2013), they would have contributed one fifth to the total separately collected quantity of 55 kt in Île-de-France. This seems plausible since hypermarkets which normally generate bio-waste above the annual threshold quantity of 2014 tend to have bio-waste recycling implemented very early, compared to smaller shops and restaurants[205]. The remaining quantity of separately collected bio-waste would then have been filled by supermarkets and the social food service sector, such as schools and hospitals.

Restaurants, concerned from 2016 on, seem to be confronted with major barriers, and therefore only barely comply with the obligation (Palierse and Robert, 2018). One representative of the FNADE, the national professional organization of activities for the environment, pointed out the high cost of separate bio-waste collection and treatment which, to date, is predominantly carried out by private companies[206]. By comparison, the collection and treatment fees for mixed household and related waste are very low[207] when access to the public service of waste

[204] https://www.optigede.ademe.fr/outils-gros-producteurs-dechets-organiques

[205] Small quantities of business waste are often accepted by the public waste collection sector. Presumably, the remaining business waste contains bigger quantities per unit.

[206] €300 per tonne, according to two sources (Conseil Régional Ile-de-France, 2018; Palierse and Robert, 2018). A national monitoring tool for the cost of waste management by the public waste service showed that in 2014, total cost of bio-waste management collected from households, door-to-door, was between 225 and 559 €/tonne for 50% of the sample of 36 local authorities covering a population of 1.1 million inhabitants (ADEME et al., 2018). With the exception of one local authority (CA Cergy), there was no public service bio-waste collection in Île-de-France in 2014.

[207] Calculated as tax on surface TEOM (see Section 3.1.4), amounting to several hundred euros per year.

collection and treatment is available, especially when the quantity and composition of business waste is close to household waste. When access to the public service is not available, private waste companies may accept bio-waste collected in mixed business waste (DAE) and charge a lower price per tonne. This is found in sectors such as the food service sector, although sorting and separate collection are mandatory by law. They are expected to be controlled and, where applicable, will be penalized more consistently in the future. In this context, it remains to be seen if and how the political sign sent out by the government's fiscal reform to make landfilling and incineration more expensive in the five years to come[208] impacts business waste practices towards waste reduction and recycling. Further barriers to bio-waste sorting lie in the field of logistics and handling[209].

With the perspective of generalizing bio-waste sorting to all producers including households (law 2015 TECV), by 2025, advanced to 2023 by recent law[210], initiatives have been under test to reduce the bio-waste part of mixed household waste. The promotion of in-home and neighbourhood composting by local authorities has helped to make composting techniques known and to train households. The benefits of on-site management of bio-waste, which is often performed with low-tech equipment, is the fact that transport and the need for large-scale treatment infrastructure are avoided, and has an impact on costs[211]. It is important to emphasize here that local authorities consider on-site management by households as waste reduction, namely a decrease in waste quantities to collect and to direct to waste management infrastructure, whereas in the use hierarchy of waste policy and in food policy, waste reduction means reduction at source or prevention.

The Syctom has provided extensive support to participating local government EPT agencies within its scope. There are currently several experimentations for bio-waste sorting, collection and centralized treatment with local government agencies (EPT). However, little is known about the quality and fate of the compost obtained by households. Some form of professionalization and steady support would be beneficial for successful running of

[208] The tax for polluting activities (*taxe générale sur les activités polluantes*, TGAP) has been decided to increase notably through the finance law for 2019, therefore increasing the total cost of waste treatment. Between 2020 and 2025, for landfilling, the tax will increase from a range between 17 to 41 €/tonne up to 65 €/tonne, and for incineration, from between 3-1 5€ up to 15-25 € (Journal Officiel, 2018). We could however not find the average cost of the collection and treatment of mixed business waste including tax for Île-de-France.
[209] FNADE, S. Roussel, personal communication, 21 November 2017.
[210] Law n° 2020-105 from 10 February 2020 for combating waste and for a circular economy
[211] Local authorities in charge of waste treatment have a direct interest in reducing bio-waste quantities to collect and treat as it is costly and not problem-free to have a waste-treatment building accepted by local residents in dense urban areas such as Paris and the Petite Couronne.

composting initiatives. Recent guidelines for successful bio-waste sorting, recently published for local authorities (ADEME et al., 2018), emphasized the benefit of considering various options, for both on-site and centralized bio-waste treatment, depending on the type of neighbourhood and together with the use of monetary incentives.

Progress in the management of bio-waste is being reported by the City of Paris these past years, but was in its early stages in the year 2014, the reference of this study. In 2015, approximately 300 tons of bio-waste were avoided through composting on 422 composting sites at the foot of buildings (including 222 in collective housing and 200 on public sites), as well as 6 neighbourhood compost bins. 116 tons of organic waste was collected in 2015 for food markets and municipal canteens (European Commission, 2017) Intermediate reporting (2017-2018) of the circular economy plan of the City of Paris shows progress since. 3.5 kg bio-waste per inhabitant and year were collected in 2017 in the 2nd and 12th *arrondissements.* This result must be put into perspective with the approximately 25 kg of wasted food and 60 kg of food waste per inhabitant per year thrown into the waste bin, as suggested by household waste composition analysis[212]. Recovery of unsold fruits and vegetables from 53 municipal markets amounted to 1,450 tonnes. For household composting, the Syctom has organized the donation of 1,500 worm composters to households. All in all, the results show that bio-waste sorting and organic management is still in its early stages, despite visibility given to these initiatives in the circular economy discourse (see Table 40).

Countless urban agriculture and gardening projects in Paris and the neighbouring *départements* use composted bio-waste from households and business activities in the neighbourhood. Small companies spring up around the business idea, producing compost for sale from neighbourhood bio-waste. School gardens often have a composting site for educational purposes and for bio-waste reduction from school canteens.

Despite the many ongoing initiatives in food waste recycling, for which it is difficult to estimate the quantities involved at the local level, the food metabolism of Paris Île-de-France unfailingly reflects the difficulties of urban societies to turn to a circular scheme. In 2014, composting and anaerobic digestion captured 6% of solid food waste from households and businesses together, in Paris Petite Couronne and only 5% in Île-de-France (see Table 37), although this share is likely to increase in the near future under the effect of recent policies. Infrastructure of organic

[212] As described in Chapter 3, 1.1.4 food waste.

recycling appropriate for food waste, which requires additional safety procedures with respect to pathogens, is largely insufficient in Île-de-France (Conseil Régional Ile-de-France, 2019; ORDIF, 2016). A much larger capacity is required to meet the policy target. How much bio-waste collected by private waste management companies is handled outside of Île-de-France, in treatment facilities of *départments* close by, is unclear but the phenomenon exists (Roussel S, personal comm.[213]).

In parallel, food or bio-waste recycling is in the focus of urban policy other than waste policy. An inventory of the various types and quantities of biomass including organic waste of any type was recently drawn up at the level of Île-de-France (*Schéma régional biomasse*) with a view to estimating their potential for renewable energy production (Région Île-de-France et al., 2019). Actually, urban policies increasingly promote local energy production, as the case of Paris' Climate Air and Energy Plan illustrates (Ville de Paris, 2019). The political signal sent out by local governments is to increase energy supply rather than to reduce energy demand, by shifting to thus far unexploited renewable sources, including urban food waste. Unless amended by material efficiency goals, such strategies will deprive the urban population of one of the rare means, organic recycling, to act favourably on biogeochemical cycles, in particular on the strongly disrupted nitrogen and phosphorus cycles (Barles, 2019).

5.2.6. Conflicting goals between policies

Policies in fields unrelated to the aim of food waste reduction can have conflicting goals, as they can stimulate food waste generation as an unintentional but sometimes tolerated side effect. This is why an efficient food waste reduction policy must not stop at the border of dedicated food waste policy but be careful about consistency with other policy fields in working towards the common goal of food waste reduction. The design of policy instruments for example must not directly or indirectly incentivize food waste generation in any field. Through an integrated trans-sectoral approach, policy measures which create such incentives can then be corrected. The challenge of such an integrated trans-sectoral approach is coordination. Coordination deficits already detected at the local and regional governance level of Paris Île-de-France as a case study (see 5.2.1.2) are not less common at the higher level of legislative power, at national or supra-national level in the case of the EU.

[213] FNADE, S. Roussel, personal communication, 21 November 2017.

In the scientific literature, scarce attention has been granted to policy interactions directly or indirectly impacting food waste generation and management. For the European case, available insights are mainly the merit of two EU-funded projects, preceded by the study of Waarts et al. (2011). These authors provided an overview of the obstacles in legislation and regulations to food waste reduction mentioned by supply chain actors (Waarts et al., 2011). Regulation of food information was one cause leading to food waste, with short expiration dates, differing ones for the same type of product, and a lack of clarity about what can be done with the item once the date has passed. Because of product liability, traders are careful not to take any risk and they remove food from the shelves early. Another cause of food waste was related to hygiene rules in the food service sector. The two-hour guarantee, part of the hygiene codes of the EU Hygiene Package[214], is considered partly too severe. But exemption from it requires extensive research and better information in a field where no business actor would take a risk.

A first review of EU legislation and policies impacting food waste generation was part of the FUSIONS project (Vittuari et al., 2015). Based on 52 policy acts assessed in 2014, the project found that as many as seven different policy areas, or Directorates General in EU jargon, were concerned by food waste reduction, from agricultural policy, fisheries, consumer protection and health, industrial policy and internal market, to environment, energy and taxation. Policy acts considered by experts as having the largest contribution to food waste generation were those framing food information (risk of confusion between date stamps, leading to food waste), hygiene rules (partly excessively binding and disproportionate to practical needs), and marketing standards (aesthetic criteria and size of food). Conversely, policy acts considered as having the largest contribution to food waste reduction were those framing the integration of food loss and waste goals into waste policy (achieved in the revised waste framework directive n°851-2018), and use of taxation to encourage donation and free redistribution of surplus.

The FUSIONS follow-up project REFRESH identified opportunities for improvement through more consistency in key policy areas. It furthermore added particular attention to areas where policy is required to adapt the framing so that the focus is maintained on the priority order of prevention first, then reuse and then recycling, defined in EU waste laws (European Commission, 2008). Hygiene and food safety rules leave much room for interpretation, potentially leading to food waste when the flexibility margin provided by the European hygiene

[214] Products which normally need to be stored refrigerated, may be offered for sale for a maximum of two hours and must afterwards be thrown away, whether packaged or unpackaged (Waarts et al., 2011).

package is not well understood. These rules would benefit from more coherent interpretation and application. The use of surplus food for animal feed can be facilitated through clear safety guidelines. Renewable energy policy should not incentivize use of food for energy. Unfair trading practices between retailers and suppliers leading to food waste can be moderated through increased transparency and more balanced power relationships, without harming suppliers.

The call for an integrated policy framework to tackle food waste at EU level has grown louder over the years (Eriksson et al., 2020; Garske et al., 2020; Waarts et al., 2011). But not only better policy coordination is lacking; impact assessments in terms of reduced quantities of food waste are also required. Making food waste policy measurable and monitorable would help to identify priorities between the manifold policy acts and to determine efficiencies, or the lack thereof, in food waste reduction. In parallel, work is underway to improve individual policy acts. For example, a revision of EU date setting rules is underway in a dedicated working group of the EU platform on food losses and food waste[215]. Amendments to EU food hygiene rules, some of which relate to food donation, are currently being assessed with an aim to facilitate redistribution of food whilst ensuring its safety for consumers.

Further examples of conflicting goals in relation to food waste can be an issue of national policy not linked to legislation at EU level, or even of local policy. Without systematically having empirical data at hand to support a positive relation to food waste, the exercise of "thinking" the relationship can help to design more integrated policies towards the wider goal of sustainable food systems. One example of conflicting goals with food waste reduction can be found in national food policy. School lunch has a crucial role to play for children of needy families, as it may be the only nutritious meal for the day for them (CNA, 2017). School lunch has a role in the education about food and experiences of taste, diversity, and food cultures from a perspective of public health and prevention of overweight, as the Ministry of Food and Agriculture acknowledges[216]. It is often also a precondition for parents whose workplace is far from their home, which is the case of the majority of the working population today and in the near future at least, despite possible changes in working practices prompted during the Covid-19 pandemic[217].

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[215] https://ec.europa.eu/food/safety/food_waste/eu_actions/eu-platform_en

[216] https://www.education.gouv.fr/la-restauration-scolaire-6254

[217] In 2018, 5.2% of employed persons aged 15 to 64 in the European Union, and 6.6% in France, usually worked from home (Eurostat, 2020). From 2020, home office work was on a sudden steep rise in France due to the Covid-

Besides the extensive food safety rules laid down in the European hygiene package and transposed to national law (Ministère de l'alimentation de l'agriculture et de la pêche, 2009), national policy frames the nutritional quality of school meals. Policy act n° 2011-1227 of 30 September 2011 requires a defined frequency of use of food items over a cycle of 20 consecutive meals (Journal Officiel de la Republique Française, 2011a, 2011b), in line with the national programme for nutrition and health (PNNS) and the national food plan (PNA). The frequency is defined according to recommended intake of vitamins, minerals, fibres and the limitation of salt and sugar. For example, due to their fibre and vitamin content, at least ten out of 20 consecutive meals must contain raw vegetables or fresh fruit, ten meals cooked vegetables, and at least eight meals fruits for dessert. Conversely, to reduce sugar, a maximum of four sugar-rich desserts (> 20 g per portion) with a minimum fat content of 15% is allowed. These requirements challenge the managing authority of school canteens to serve meals of appropriate composition, while making them varied, tasty and attractive for children and teenagers. However, there is room for flexibility, defined by law in the policy act n° 2011-1227 (Journal Officiel de la Republique Française, 2011a) in particular for the portion sizes[218]. This flexibility is an important but insufficient aspect as, since 2007, the permanent working group on public procurement in the social food service sector [219] has gradually introduced specifications about nutritional quality in the public food service, endorsing the ongoing legislation change at that time. However, the guidelines, published in 2011, went much too far as they included clear-cut recommendations about frequencies and portion sizes of meal components per age group *(Groupe d'étude des marchés de restauration collective et nutrition* (GEM-RCN), 2015). Although not complying with the aim of a GEM working group, neither the Ministry of Food and Agriculture nor the Ministry of Finances, both members of the working group, fulfilled their assigned role as a regulator in the change of direction in the work of the GEM-RCN.

Though not mandatory, from then on managing authorities, restaurant managers and the food service industry have taken these recommendations, and the portion sizes in particular, into

19 pandemic. During the general population lockdown from 16 March to 11 May 2020, 42% of the French working population was working in a home office, according to a study from the Ademe (6t bureau de recherche pour l'Ademe, 2020), while prior to the Covid-19 pandemic, 12.5% of the working population worked from home once a week and another 4.8% once a month. It is still unclear at this stage what has remained part of new working practices beyond the pandemic.

[218] Policy act n° 2011-1227 specifies the possibility to adjust portion size by +/- 10%.

[219] In French, the group is called *Groupe d'étude des marchés de restauration collective et nutrition (GEM-RCN).* Public procurement working groups exist for various fields concerned by public procurement. They are organized by the finance ministry to specify requirements and guidelines for public procurers.

account when contracting. It is a matter of convenience to follow clear-cut meal-based portion sizes in the planning of the food to prepare, deliver and serve. Adjusting standardized portion sizes to actual consumption in a perspective of food waste reduction has not been in the scope of the managers' considerations until recently. On the contrary, additional buffer quantities are sometimes included.

The most recent attempt to regularize a flexible management of school meal composition comes from the EGAlim Act, Article 29 (Journal officiel de la république française, 2018), which must be followed by a revision process of the Policy Act 2011-1227 related to the nutritional quality of school lunches[220]. Previous efforts to clarify the legal framework ended up only in simple information documents[221], for which it is unclear whether they had any reach at all in the way contracts were written in the public food service sector.

Apart from the problem of misuse of the GEM-RCN as a much too strict and possibly waste-generating reference, the introduction of nutritional quality aspects into France's school meal legislation has its own potential for food waste generation. However, public health objectives also require policy action to be taken, ideally in an integrated approach towards a common aim of sustainable food.

Several studies report a high level of food waste in the social food service sector in various countries, including Switzerland, Sweden, Finland, and France: approximately 20% of the handled food (Betz et al., 2015; Engström and Carlsson-Kanyama, 2004; Eriksson et al., 2017; Silvennoinen et al., 2015) or even more than 25% (Bigue, 2016)[222]. They suggest portion size and large overproduction of meals a major cause of food waste. A mismatch between portion size and appetite was mentioned by Betz et al. (2015) as the principle cause, followed by several causes related to taste. The study of Sebbane and Costa (2018) found these same situational causes to be negatively correlated to food waste, whereas visual appearance and temperature were not. Side dishes in the form of vegetables and staple foods such as pasta, rice or potatoes make up the biggest part (Bigue, 2016; Silvennoinen et al., 2015). In a study on elementary school canteens in France, Bigue (2016) found that on average, 42% of the side dishes prepared to be served for lunch, a large share of which were vegetables, were wasted. All other

[220] The newly introduced experimentation with a weekly vegetarian meal in school canteens can only be in line with legislation and unambiguous for the management authorities when Policy Act 2011-1227 is revised accordingly.
[221] For example a short note from a regional delegation of the Ministry of Food and Agriculture (Draaf Rhône-Alpes, n.d.).
[222] See Section 0

components, including bread, dessert, starter, were wasted at a share of between 26% and 29% (Bigue, 2016), suggesting an overall portion size problem.

With the recent policy targeting the food service sector, food waste is expected to gradually decrease in the coming years[223]. The development of surplus redistribution does not tackle the origin of surplus generation nor problems with taste, but it can prompt a more ambitious strategy to address the problem at source. High levels of food waste in school canteens are particularly regrettable as increasing use of products responding to sustainability criteria is being made, in line with municipalities' sustainable food strategies[224]. With a minimum of 50%, of which at least 20% is labelled organic, the use of sustainable food products will be generalized from January 2022 on, as required by the EGAlim Act (Journal officiel de la république française, 2018). As sustainable food products are usually more expensive et require adjustment in the management and cost calculation of the school lunch service, food waste reduction can move into focus precisely for the reason of monetary savings. Conversely, efforts in the sustainable transformation of school catering do not automatically prevent food from being wasted when all other things remain equal.

School lunch is a good example to illustrate where health and sustainability requirements would benefit from being coordinated and integrated into a joint plan. Considerations of portion size, variety and frequency of meal components and sustainability criteria could be usefully completed by thoughts about taste. While managing authorities have multiple budget, legal and management requirements to comply with, the margin for the improvement of additional aspects such as taste appears limited. Yet satisfaction with canteen meals is often reported by respondents as being low. Furthermore, the national food policy expects children to be educated to taste, in a positive sense. One difficulty for canteen managers might be that there is no objective assessment tool for taste and therefore no means in public procurement to refer to taste. Relying on children's expectations towards taste within the framework of budget, legal and managing requirements of school meals might require further studies. Indirect criteria can possibly be used, such as seasonality for fresh fruits and vegetables, or the type of preservation of semi-processed vegetables (canned, frozen or under vacuum). But general statements about the link between taste and other characteristics of food are hard to establish. Together with more

[223] See Section 5.2.1
[224] For example, a 50% target by 2020 set in the Sustainable food plan of the municipality of Paris (Mairie de Paris, 2015) or a 60% target of the municipality of Fontenay-sous-bois (94), with 50% already achieved in 2019 (Ville de Fontenay-sous-bois, n.d.)

flexible portioning, further research to include taste criteria into public procurement can help to reduce food waste in the social food service sector.

The identification and analysis of other conflicting policy goals requires dedicated research. One other policy field to investigate at local level could be the profile of shops in an urban planning perspective. Planners and nutritionists in the United States became aware of its potential role for unhealthy food choices and called areas of poor food choices “food deserts” (Hilmers et al., 2012). It could be of interest to analyse whether there is a link between a predominant access to particular types of shops and domestic food waste.

It is undeniably challenging to develop an overview of all possible interactions between the different policy fields directly or indirectly impacting food waste. Conflicting policy goals at national level add to a multi-level policy landscape that is already highly complex.

5.3. Summary

Food waste reduction has the potential to decrease the intensity of food use in the urban food metabolism. In the case of household food waste, less than half is wasted food and could to some degree be prevented, thereby decreasing food metabolism intensity. However, the analysis of policy shows a picture of poorly coordinated approaches to food waste reduction, first between different policy fields (food, waste, etc.), and second within policy fields. The risk is that approaches to food waste reduction remain ineffective, as shown in the case of intervention towards an increase in the nutritional quality of school lunch. Coordination has proved to be necessary to anticipate any impact from policy on the generation of food waste.

In the field of waste, poor coordination is a problem as responsibilities or tasks related to waste (planning, prevention, collection and treatment) have been delegated by law to local authorities at very different administrative levels. Initiated by authorities at the various administrative levels and fields of responsibility, they do not seem to be sufficiently connected to one another to build stimulus and synergies. Worse, there is a risk that much of the effort has been in vain – something which is difficult to assess as there is no operational food waste monitoring available for the scale of an urban system. The regional government for example, which plans at the regional level, is far from executing any waste collection or even treatment, nor can it directly act on waste prevention, with the exception of the public food service sector for high school canteens (*lycée*), a distinct service under the region’s responsibility. Moreover, food waste is addressed primarily from a waste-oriented, end-of-pipe perspective, by services which are experts of waste once it has been produced but which know little about the situations and determinants at its origin. Waste that is hardly identified, characterized and quantified, as shown for business food waste and potentially further waste in the form of missing food flows, seems to slip through the system of responsibilities and tasks.

It would make sense to develop instead a food approach to food waste (Redlingshöfer et al., 2020), and to have food policy collaborate more extensively with waste and other policies (consumption, urban planning, etc.) towards this common goal. Food waste addressed by food policy has largely been built so far on awareness-raising campaigns, support for redistribution of surplus food, and best practice in the public food service sector. However, while it is uncertain whether this policy has had any impact at all, the question of how to efficiently coordinate efforts remains unanswered. The relevant question now is therefore about the conditions to set to transform the food system as a whole towards sufficiency and frugality, in such a way that households and businesses change their use of food and generate less surplus and waste. Inevitably, to change societies' material use requires an understanding of the cultural and social context in which this use takes place, and in which industrialized societies grow. Applied to food, Chapter 6 takes a cultural and social science perspective on societies' material uses of food, focusing on food waste, and provides insights into the conditions that made questions of use and un-use of food come to the surface.

Considerations to improve the urban food metabolism as simply as possible lead to food waste recycling. Policies in the field of waste recycling, the circular economy and the emerging bio-economy have increasingly set the conditions to capture household and business food waste. Especially in the case of inedible food parts, there lies a chance for local policy to introduce at least some degree of circularity in an otherwise strongly linear food metabolism. While being tagged as contributing to sustainable urban systems, these policies do however potentially risk hampering food waste prevention. This could be the case when the conditions they offer for making use of waste are more appealing or financially beneficial than those for preventing waste, in the case not only of businesses but also of households. This is of particular concern since reduced material use through food waste reduction, involving reduced resource use and environmental impacts, has high potential for the sustainable transition of cities.

Articulating food waste reduction and recycling is a challenge insofar as the failure of the former fuels the success of the second. In other words, strategies for composting and anaerobic digestion of food and bio-waste require steady, not decreasing waste streams, given the size and cost of infrastructure. This is where waste policies, in theory, pursue conflicting goals, but in practice, they do not seem to be impeded. There might be an issue of the representations that policy actors have about food waste. As long as food waste is primarily seen as requiring management, or even more, is increasingly considered a resource, there is a risk that in the long run food waste reduction efforts turn out to be in vain.

Chapter 6: Cultural and social embeddedness of the urban food metabolism: understanding and transforming society's relation to food

Our analysis of the social metabolism of food for the urban systems of Paris Île-de-France revealed novel insights about its organization. Firstly, several activity sectors taken together have a large place in the organization within the urban systems. Food consumption to a large extent takes place out of home, which implies there is a dedicated food service sector and a food industry serving the upstream stages of food processing, distribution and preparation. The food industry could however not be analysed within this study. Secondly, food waste is generated in these different sectors but is well hidden within the general waste system, which makes it difficult to establish a link between the food system and the waste system, or to even to integrate the two.

Highlighting the phenomenon of food waste, and of wasted food in particular, raises the question of how to explain this specific feature of the food metabolism in its present form. As Chapter 2 has shown, the cultural and social science perspective is a relevant contribution to answering this question, as cultural and social factors have always shaped human societies' relationship to food and the use they made of it. Adopting this perspective in this chapter means looking at explanations of the food waste phenomenon seen in a context of society's use of food, materialized in food waste flows and revealed in the urban food metabolism of the case study. How can the cultural social context in which food and food waste flows are produced in the case study be described? Adopting this perspective means locating the urban food metabolism of a society in a setting of cultural and social conditions favouring or reinforcing food waste. The aim is to understand the mechanisms of the cultural social embeddedness that contribute to explaining how food waste flows in the social metabolism of food come into existence.

The approach to food waste as a cultural and social phenomenon opens perspectives for change, as insights from the analysis of social metabolism can be used to transform it in turn (Fischer-Kowalski and Rotmans, 2009). Applied to this study, the transformation of the metabolism, in line with the goals of sustainable food systems, aims towards a more sustainable use of food and in particular to reducing the non-use of food, in the form of food waste. Any intervention and transformation of the social metabolism can only be successful, in the long run, when considered through the cultural and social prism. How does the cultural social context enable or constrain envisioned transformation of society's food use? This approach refers to the conceptual model of society–nature interaction developed by the Vienna Social Ecology School (Fischer-Kowalski and Rotmans, 2009; Fischer-Kowalski and Weisz, 1999). As Fischer-Kowalski and Weisz (2016: 19) put it: "intervention within society must refer to cultural meaning", pointing out that unsustainable development, and within it unsustainable material use, is a problem of society and not a problem of nature. It must therefore be addressed with a language that is audible to society and that refers to societies' value system or culture.

Cultural and social embeddedness in this chapter refers to the ways in which food and food waste flows are produced in the social metabolism of food. The term embeddedness was introduced by Polanyi (1944) but has become popular in the social sciences since Granovetter (1985) used it to link economic activity with the structure of social relations. While much of the literature remained focused on embeddedness of economic activity, we used a broader approach, similar to the work from Boons and Howard-Grenville (2009). In their approach to the social embeddedness of industrial ecology, they contextualized organizational activity in this field more broadly than in explanations of rationality, efficiency and intentionality. In this study, the cultural and social embeddedness of the urban food metabolism contextualized food waste practices with respect to value systems, representations and norms at the collective level of society, and with respect to interaction with individuals, groups, organizations and institutions[225]. The emphasis lies on cultural embeddedness rather than other forms of social embeddedness, such as cognitive, structural, political[226] or spatial and temporal embeddedness (Boons and Howard-Grenville, 2009; Zukin and DiMaggio, 1990). Cultural embeddedness is one aspect because food waste is seen in this study as a cultural phenomenon and a result of cultural processes. Social embeddedness is another aspect, because food waste is the result of social practices, although the term is often used as an umbrella term for other types of embeddedness. This is why cultural and social embeddedness are preferred in this study in its distinct form. This choice is in line with the positioning of this thesis.

[225] The doctoral studies lie in the department of Cultural History and Theory at Humboldt University in Berlin. This department focuses on the historical and material-oriented analysis of European cultures from antiquity to the present.
[226] Chapter 5 provides some insight into political embeddedness of the urban food metabolism with respect to food waste

I analysed various strands of the humanities and the social sciences and their respective theoretical frameworks for a contribution to explain how the relation between food and society can explain the food waste phenomenon in industrialized societies. This chapter deals with the cultural and social dimension of food waste practices in households, acknowledging households as main contributors. It is organized in two parts following the introduction. The first part shows how the humanities and then the social sciences have addressed humans' relationship to food, and the role played by the subject of food waste. In the second part, the insights gained from the humanities and social science literature are discussed and yield in new avenues for research about food system transformation and food waste reduction. This exploration is guided by questions on how the material–cultural interplay acts on food waste generation, how food waste can be reduced and what makes household food waste practices change.

It may seem surprising to find a chapter with a literature review at the end of a study. The reason is that this literature about the food–society relationship serves for the discussion about a possible transformation of the urban food metabolism following the combined food system–material flow analysis. In this case, the review has not served for the definition of the research proposition, for which another body of literature was used (see 1.2.3).

6.1. Food waste in the humanities and social sciences

6.1.1. Food in anthropological movements from the end of the 19th to the mid-20th century

From an early stage, major socio-anthropological movements were interested in food and eating practices, but they addressed them from different epistemological positions, with different viewpoints and explanatory models. Traditionally, cultural anthropology has had an interest in food because of its central role in many cultures and the symbolic, materialistic, and economic perspectives which are relevant to anthropological research (Counihan and Van Esterik, 1997). Late 19th-century anthropology and ethnology addressed, above all, religious and supernatural aspects of food consumption, such as prohibitions, rites and rules related to religion and magic, and remained focused on indigenous communities (Frazer, 1890; Smith, 1889). From the 1930s onwards, the humanities and social sciences gradually began to open up towards wider functions of food than strictly religious ones (see the functionalist perspective), and to acknowledge the role of food in the organization of industrialized societies. Three principal socio-anthropological movements begun to address the topic of food and food practices.

The functionalism perspective

British ethnology of functionalism[227] turned away from religious aspects and for the first time considered food and eating practices, field studies at hand, as genuine socializing activities. Radcliff-Brown pointed to the food-getting process as “the most important social activity” (1922: 227; in Poulain 2017: 137). Audrey Richards acknowledged the importance of cultural and social aspects of food in her seminal work “Hunger and work in a savage tribe” (1932), a founding text in the emerging anthropology of food. Contrary to the scientific community to which she belonged, Richards insisted from the start on the need to link the cultural aspects of food with the biophysical requirements of human eaters. This position was unusual at the time, when French sociologist Émile Durkheim’s notion of the autonomy of the social held sway, with the premise that “the social can only be explained by the social” (Durkheim, 1894: 156).

The culturalism perspective

The anthropology of the culturalism movement, which spread from the 1930s onwards in the US, was particularly interested in the wide variability of attitudes, practices, and techniques related to food (Ashley et al., 2004). Mead, at times secretary of the Committee of Food Habits, in the US, was the anthropologist who had done the most work on food in this field. According to the culturalist conception, food habits are transmitted within a group or community through a learning process framed by their society and their culture. Referring to the aspect of culture, food habits are defined as “the way in which individuals or groups of individuals, in response to social and cultural processes select, consume and utilize portions of the available food supply” (Guthe and Mead, 1945: 13). The culturalist perspective points to the influences from the cultural system but has not considered interaction of food practices with the biological constraints and requirements of human eaters. Culturalism tends towards humans making their history, and this is a humanist approach. Criticized for being “too general” (Mennell et al., 1992, in Poulain, 2017: 130), the culturalism movement had little influence in social sciences’ research on food.

[227] Functionalism adopts the position that human phenomena are similar to machines endowed with functional units, referring to the notions of “system” and “structure” (Dortier, 2009). Approaches of functionalism applied to food have in common that they associate with any aspect of a food culture a function which can be explained by extra-cultural or material phenomena, such as biological or physical. Proponents of functionalism, for example Harris (1985) and the cultural materialism he defined, explained food preferences and avoidances with costs and benefits, and the results of an adaptation process for the purpose of subsistence (Ashley et al. 2004).

In France, social anthropologist Leroi-Gourhan addressed food from the perspective of "consumption techniques" and anchored food topics in studies about material culture (Leroi-Gourhan, 1945, 1943). He developed analytical methods to classify activities using techniques to organize the manufacturing of objects, such as tools, which enabled the acquisition of goods for basic needs such as food, clothing and housing. He considered techniques, a characteristic of humankind, as a link in the culture–nature relationship between human society and the natural world.

The structuralism perspective

While culturalism puts emphasis mainly on individual personal doing, the structuralist perspective emphasizes the structural features of society. Structuralism is an intellectual movement, developed from the mid-20th century, that seeks to understand and explain social reality in terms of social structures. Theories of structuralism focus on structural form as an organizing principle underlying whole cultures and societies. The main premise is therefore that conditions and settings have a strong influence on defining culture (Ashley et al., 2004).

One prominent structuralist scholar who worked on food is anthropologist Mary Douglas. She was at the origin of anthropological modernism, a dominant movement in British anthropology from the 1920s to the 1980s, through her work on everyday culture. The mundane, everyday practices and cultural habits came into focus as they revealed "the fundamental and the universal in human culture" (Hendel, 2008: 4). This change in focus was a shift away from narratives of cultural ascent, great events and heroic protagonists that were found in evolutionary theories. "The triumphal narratives of human ascent from primitive superstition to modern Western science" made way to anthropological modernism (Hendel, 2008: 3). The complexity of other, non-Western cultures was now seen as equal and was acknowledged as such.

Mary Douglas' book *Purity and danger* (1966) analyses concepts of ritual purity and pollution, and shows that the concept is in the core of religious classification. Food classification is part of this classification. Based on her own research on the people of Lele, located in the Basongo area of the Democratic Republic of the Congo, she identified a symbolic classification system that uses couples of contrasting characteristics (dirty/clean, human/animal, male/female, village/woods, etc.) according to which food is classified, although the classification obeys a more complex structure than that. Anthropologists have consistently endeavoured to understand the rules that different cultures adopt in terms of approving or prohibiting particular foodstuffs. Mary Douglas' analysis of Hebrew dietary laws (Douglas, 1975, 1966) explained the taboo of pork in the Jewish food culture in cultural terms, referring to texts from the Bible. In her study of the biblical dietary prohibitions, she impugns the evolutionary model in which irrational magic (including ritual) belongs to the primitive stages of humanity, in contrast to the sacramental theology of modern Western religion, which belongs to a more advanced stage of reason and morality. In doing so, she shows that ritual has its reasons, which are not at all irrational, and that modern religion likewise has symbolic actions; indeed, "it is impossible to have social relations without symbolic acts." Douglas maintained that food prohibitions represent a means of creating order within the theology of the times (1966). With this position, she made an essential move towards anthropological modernism. Her work was opposed by proponents of cultural materialism, for example by Marvin Harris who affirmed that taboos result from adaptation to a purpose of subsistence (Harris, 1985).

Claude Lévi-Strauss was the most prominent representative of structuralism in French anthropology. Unlike other anthropologists and sociologists who shared structural approaches to human phenomena, Lévi-Strauss aimed to develop a structural method and demonstrate its performance through the analyses conducted in various fields, such as cooking. His work does not look at the variability and particularities of cultural practices, as does that of Mary Douglas and other anthropologists. His work is more generic when it comes to the identification of empirical categories and their relationship to one another, which operate in the human mind in any culture. Lévi-Strauss built on Saussures' structuralist analysis of language[228] to analyse constituents of cuisine by means of oppositions. His aim was to corraborate a twofold claim of the structuralist approach: first, that taking the example of cooking, "divergent cultural phenomena enjoy common structural features" (Ashley et al., 2004: 29), and second, that the opposition between nature and culture "holds a privileged position within this common structure" (Ashley et al., 2004: 33). He has become famous for the culinary triangle built from the three fundamental categories: "the raw, the cooked and the rotten". Cooking as an act of mediation can be seen to consist of mediatory activities between a series of binary oppositions such as heaven/earth, life/death, nature/culture (Lévi-Strauss, 1965). The process of cooking can thus be seen as mediating between nature, represented by the raw, and culture, represented

[228] Structuralism originated with Ferdinand de Saussure for whom "meaning stems from difference". Although Saussure worked on language, not food, he was interested in the deep structure and the form of language, and less in its content, understood as the common rules that communication obeys. Difference then stems from connotations and association of meaning that are given to words by social groups (Ashley et al., 2004).

by the cooked, therefore “the cooked is a cultural transformation of the raw, whereas the rotten is a natural transformation”[229] (Lévi-Strauss, 1965: 20).

The nature/culture opposition is central in Lévi-Strauss’ analysis, to which he added further binary oppositions and tested them in a variety of cultures in different contexts. As with language in Saussures’ analysis, cooking obeys rules in a given culture that build common structure and are fixed at an unconscious level. This does not mean, however, that the nature/culture opposition is present as an organizing principle in any food culture. It can be more or less identifiable for some food-related issues, demonstrated in Ashley et al. (2004), or it can be under social construction and changing over time.

In brief, research about food practices in the humanities developed within a fragmented landscape of various movements and research perspectives. A central debate within these movements appears to be around the question of the respective roles of cultural versus biophysical aspects, or nature versus culture, in the way food choices were made. This is evidenced in the debate between Harris’ cultural materialism and Douglas’ modern anthropology. Phenomena of discard, refusal or rejection of food, once acknowledged and accepted in the respective food cultures of groups and communities, were seldom addressed. Likewise, little if any attention was paid to phenomena of removal or rejection of parts of foodstuff, referring to the notion of inedibility (see Chapter 2). In other words, issues of food ending up uneaten – to avoid the abundance-connoted term food waste – did not receive attention in the anthropology-dominated literature[230] addressing food in the period from the late 19th to the mid-20th century.

6.1.2. Food in sociological research from the mid-20th century onwards

Food in sociology has an eventful history, for it was not recognized as a field of interest in its own right for a long time. The various sociological traditions tended to ignore food (Paulitz and Winter, 2018; Poulain, 2017), partly because of it being so commonplace in daily repetitive routines, and partly because sociologists, in the French sociological tradition, disagreed about

[229] *"Le cuit est une transformation culturelle du cru, tandis que le pourri en est une transformation naturelle."*
[230] Evans et al. (2013) point to the importance of the non-academic literature from the mid-eighteenth century on to illustrate that food leftovers in households were an issue of concern already at that time. Cookery books and household management manuals provided abundant advice on how to re-use food leftovers and minimize waste, referring to the moral virtues of thrift and frugality in the household realm.

the status of food as a theoretical object, due to unclear limits between the social and the biological dimensions (Poulain, 2017). Tensions arose through a debate about the epistemological status of social fact, according to Durkheim and Mauss. Durkheim (1894), loyal to the autonomy of the social, referred to social fact as the practices most possibly explainable by society[231] and excluded food practices as non-eligible. “Each individual drinks, sleeps, eats, or employs his reason, and society has every interest in seeing that these functions are regularly exercised. If therefore these facts were social ones, sociology would possess no subject matter peculiarly its own, and its domain would be confused with that of biology and psychology”[232] (Durkheim, 1982: 50). Mauss, though, saw in food practices the articulation of biological–material, social and psychological dimensions, and therefore a perfect example of what he called a “total social fact” (Mauss, 1925). Sociology found an interest in food, but framed by other society-relevant sociologies (i.e. rural sociology, sociology of work, mobility, health and illness). There was and maybe even today there is no sociology of food, as it is not feasible to establish a sociology of food seeing food through a singular lens (Poulain, 2017), although attempts at articulation do exist. Current work in a sociology or socio-anthropology of food recognizes itself in dealing with the ways in which societies engage in and organize the double space of freedom that becomes available to them once the biological constraints of the body are satisfied and the use of the possibilities of a milieu are decided upon. A socio-anthropology of food is interested in interactions between the biological, the ecological and the social, thus rooted in the social sciences and opened to interdisciplinarity (Poulain, 2017: 244).

Chronologically, since the 1960s the humanities and social sciences in the English-speaking and French-speaking scientific communities have increasingly turned to food as a research field, while struggling to have food acknowledged as a research object because of its “trivial” nature (Boni, 2019). It did help that in the 1970s daily practices and routines finally came within the focus of scholars in what was termed the “sociology of everyday life” (De Certeau, 1980; Douglas, 1970) – a turn that also proved to be beneficial for the food waste topic in the waste literature[233]. In the Anglo-Saxon literature a turn to a sociology of food began with work by

[231] Durkheim defined social facts as “consisting of manners of acting or thinking, distinguishable through their special characteristic of being capable of exercising a coercive influence on the consciousness of individuals” (Durkheim, 1982: 43). Practices related to food and cooking, including all culinary techniques, were considered to be too close to the biological-physical-chemical characteristics of food stuffs, and therefore excluded.

[232] The original text was published in French. "*Chaque individu boit, dort, mange, raisonne et la société a tout intérêt à ce que ces fonctions s'exercent régulièrement. Si donc ces faits étaient sociaux, la sociologie n'aurait pas d'objet qui lui fût propre, et son domaine se confondrait avec celui de la biologie et de la psychologie* (Durkheim, 1894: 35)."

[233] Raymond Williams, a prominent representative of culturalism and a major contributor to the emergence of cultural studies, argued that culture is lived and commonplace, and not an elite construct. In “Culture is Ordinary”,

Murcott (1983), Mennell, Murcoot and Van Otterloo (1992), McIntosh (1996) and Beadsworth and Keil (1997).

In France, a sociology of food emerged within a sociology of consumption. Sociological work on the determinants of food consumption developed from the 1960s on, after Halbwachs had laid the foundations with seminal work on the working classes' food consumption (Halbwachs, 1912). An early advocate of the importance of the cultural and material context of social practices was Bourdieu, with his theory of the habitus as part of a sociology of taste. "Taste" must be understood as a socially constructed normative system of practices and representations, reproduced within a culture of classes carrying their own habitus, or "systems of dispositions", for example popular taste in distinction to the taste of the French bourgeoisie or luxury taste (Bourdieu, 1979). The very nature of taste however stems from the freedom of choice that is possible only in a living context of material abundance: without material abundance, no choice, no taste. The significance of the difference in taste lies in the affluent class' pretension in showing and maintaining their dominant position towards popular classes by "distinction", as termed by Bourdieu (1979). Food was one of several practices analysed in Bourdieu's work on "distinction" (Bourdieu, 1979). Practices related to leftovers and uneaten food were not specifically addressed in Bourdieu's work, although his rationale of social distinction could be of interest for the analysis of food waste in relation to social class and to a "freedom to waste".

The emerging consumption society and the distinguishing function of consumption was a central topic in Baudrillard's work, yet not specific to food (Baudrillard, 1970). Baudrillard, in his studies of the cultural and economic dimensions of the consumption society from the 1960s on, gave wastage (*gaspillage*) in general the meaning of abundance and wealth.

A sociology of food, in France, was stimulated when access to large data samples became possible through two national surveys: the Household budget survey launched in 1956, and the food consumption survey in 1964. Moulin (1975), for example, analysed how the "consumption society" impacts food practices in a context of abundance, looking at the consumption of different foods across social groups. Contemporary food practices and their relation to the implementation of norms, to life trajectories and to social differences are being researched

later titled "Culture and Society" (1958), he related culture to a set of expressive practices, such as print, cinema and television, but did not relate it to food culture.

extensively by sociologists in France, using both quantitative and qualitative methods (Cardon et al., 2019; Régnier et al., 2006).

German-speaking sociology also ignored food for a long time. The first seminal work was by Barlösius (1999) and Setzwein (1997), as well as an interdisciplinary team of scientists who defined a cultural perspective "Eating, a topic of culture" (*Kulturthema Essen*) (Wierlacher et al., 1993). Until then, academic work on food was largely dominated by the natural sciences, with food and nutrition science at the front. In the United States, interdisciplinary food studies were established as a distinct scientific field that developed between 2000 and 2010, rooted in cultural studies, an area of academic work at the interface between the humanities and the social sciences[234]. In parallel, in French-speaking sociology, a socio-anthropology began to be established. These movements are still ongoing.

Within this eventful history of sociology focused on food, there is again the question of where to locate research about food waste practices. Evans et al. (2013) point to the fact that food waste has for a long time been neglected by sociology. The reasons for this "invisibility of food waste" (Evans et al., 2013) can be found in the difficulties in sociology to acknowledge food in everyday life as a research domain in its own right, and in the vanishing of concerns around food scarcity in the course of major transformations of agriculture and the food industry since the mid-20th century. Another reason is certainly that centralized data collection about food consumption [235], of much interest for a sociology of food building on the heritage of a sociology of consumption, did not cover food waste practices[236]. Although scholars increasingly directed attention to thus far neglected everyday practices in households, waste still remained "out of sight, out of mind" (Melosi, 2005: 17) even to scholars in the social sciences.

A rapid turn towards the topic of food waste as the result of practices in household settings occurred as soon as the food waste issue had emerged in the public and political sphere, in the mid-noughties[237]. Despite the recent entry of food waste into sociological work, there is a rapidly growing body of research interested in household food waste practices and the

[234] Cultural studies are an area of academic work, strongly developed in the United States at the interface between the social sciences and the humanities. Cultural studies research relationships between power structures and everyday practices of social and cultural reproduction, resistance, and transformation (Ashley et al., 2004).
[235] Household budget or food intake surveys, see Chapter 4.
[236] The lack of household food waste data persists today in France, with the consequence that only rough estimates of food waste are used for founding policy. Cloteau and Mourad speak of the institutionalization of a figure (20 kg of food waste per person per year) that from then on was difficult to change (Cloteau and Mourad, 2016).
[237] The food waste topic emerged in the work of NGOs and international organizations in the mid-noughties and from then on stimulated research in many different scientific fields.

determinants of food waste generation. Scholars rapidly grasped this complex issue and the many different aspects involved, from cultural and social aspects (values and the value of food perceived as low because of low prices, desire for freedom of choice, wish for variety, lack of acceptance of imperfect food, diversity of food preferences in households, and others) to material or structural aspects (household size, income, diverse preferences, unpredictable eating patterns through mobility and occupation, etc.) (see Hebrok and Boks, 2017; Schanes et al., 2018 for a systematic review).

Social scientists soon turned to food waste as an issue stemming from practices. They criticized the fact that household food consumption and related activities were often considered as a matter of individual action in a private domain where personal behaviour changes were possible (Evans et al., 2012; Southerton and Yates, 2015). But complex issues such as food waste in households can usefully be studied with theories which relate practices to broader societal processes, such as changing norms, and to the material world (Evans et al., 2012; Southerton and Yates, 2015). Empirical work underpins the viewpoint from which changing norms are broader societal processes leading to the generation of food waste. Date labelling, for example, often pointed to as being badly understood by consumers, initially served as an internal stock control mechanism. Today, date labelling on food with short shelf life is seen as an indicator of quality and freshness, both of which are highly valued qualities for food but which are also a challenge with regard to its preparation and consumption over time (Milne, 2012). On the one hand, the normative demand for eating fresh food, equated with healthy food, has become an important driver of food waste (Evans et al., 2019). On the other, cultural conventions such as of frugality and thrift, seen as driving food waste reduction, are not necessarily related to changing norms towards sustainability. Those norms are more likely to be generated through personal experience, as shown by Evans (2011) in the case of the elderly who were inclined to use leftovers and reuse goods, without adhering to sustainability. More generally, societal demands and cultural values appear to have competing and conflicting influence in shaping household food practices, and to act on food waste.

6.2. The cultural invisibility of waste in the humanities and social science literature

Waste topics have raised limited interest within the social sciences in the past but have gained momentum in the last two decades. Waste formerly appeared rather as the "shadow" – to remain close to the metaphor of invisibility used by Evans et al. (2013) – of processes and relations that were sociologically interesting rather than appearing as an object of inquiry per se. This limited interest by the social sciences sounds familiar, in analogy to the struggle for acknowledgement of food as a research topic. Both food and waste distinctly had a hard stand in the social sciences. One reason could be that food and waste both share situations of an ordinary and everyday nature, barely attractive as a science topic (see previous section 6.1.). Moreover, they are so obviously part of the way industrial societies work that this could explain why waste has been of little interest for a long time.

Environmental historians have shown that the notion of waste did not emerge in human history until the late 19th century in the particular context of European and North American cities. There was no urban waste as long as urban residues and human excreta were systematically recycled and used as an irreplaceable source of fertilizer for agriculture and material input for industry (Barles, 2005; Marald, 2002; Melosi, 2005). Reuse and recycling of used things, illustrated by the *chiffonnier* (ragpicker) in France, played an important role not only for cities' material metabolism in response to an increasing demand, but also for reasons pertaining to hygiene and cleanliness. While cities depended on the countryside for their food supply, the countryside conversely required nutrient flows from cities, thereby building a system of mutual exchange (see Section 1.2.2.1 for a more detailed description of the urban chemistry approach). With the increasing use of synthetic fertilizer by agriculture from 1880 on, urban residues and human excreta were no longer of use, and from then on were seen as something bothersome, to get rid of, which turned it into waste. This change in perspective, from residues to waste, was fostered by the rapid spread of hygienism, putting waste in a new light of disturbance, annoyance and even danger to public health.

In *Waste and Want* (1999), Susan Strasser described the processes through which disposal was separated from production, consumption and use at the turn to the 20th century in the United States. At the time, few things were thrown away, and much was repaired, reused, redirected to other uses. Sewing clothes was a widespread skill; close to 50% of the population knew how to sew. Few things were sold wrapped, and most food, cleaning products and hardware were sold as bulk. Food scraps were boiled to soup or fed to domestic animals such as chickens. Despite widespread reuse and recycling practices, the trend was towards disposal in a dedicated waste system. Municipal officials pointed to their efforts to provide garbage collection and made waste appear as a public problem by stating that one quarter to one third of municipal waste was from households (Strasser, 1999: 12).

Interest in used things for reuse and recycling waned in tandem with an increase in purchasing power which enabled households to buy new things. Wasting as such became a driving force for progress in the manufacturing industry (Jarrige and Le Roux, 2020). Consumption peaked in the post-World War II decade when it was experienced as a form of relief from material constraints and tight budgets. Unlike in the past, wasting conveyed a feeling of freedom and social acceptance to the new consumers of increasingly affluent societies. This feeling prevailed in the second half of the 20th century, far removed from ecological or social concerns (Baudrillard, 1970; Galbraith, 2017).

Some authors saw waste as something dynamic that needed to be understood with respect to historical, social and cultural contexts. Mary Douglas was pioneering in this approach when she drew attention to the cultural categorization between dirt and not dirt, describing dirt as a cultural construct and as "matter out of place" (1966). From the 1970s on, William Rathje defined as garbology the research stream that used archaeological methods to study garbage. His work was subsequently published with Murphy (Rathje and Murphy, 1992). According to him, the study of garbage yields insight into the culture of the societies that produce it. Michael Thompson's Rubbish Theory (1979) suggested that analysing waste helps to understand how value is socially controlled. Value is not a fixed characteristic of things, but changeable, including the fact that zero-value things such as rubbish can become valuable again. Thompson developed a dynamic theory of rubbish to explain that rubbish is necessary to allow for value changes. In France, at the same time (1972), Jean Gouhier coined the term "rudologie" (Gouhier, 1972).

Key sociological contributions to waste scholarship are Martin O'Brien's *A crisis of Waste* (2008) and Zsuzsa Gille's *From the Cult of Waste to the Trash Heap of History* (2007). Institutions and conventions determine what waste is considered valuable and the ways in which their production and distribution is managed, represented and politicized. Waste is neither just a given nor a simple outcome of policy. Differing definitions of waste express different regimes which vary across space and time[238]. Gille coined the notion of "waste regimes" which means that waste constitutes a social relationship, and as such should be studied as something produced materially and conceptually by profoundly social relations (Gille, 2007). Gille's work suggests

[238] This resonates strongly with the ongoing debate over food waste definitions which opposes a waste or resource efficiency approach to a food security approach, and which only recently produced a sort of hybrid definition as a compromise. See Section 2.1.1 on food waste.

that the invisibility of waste in sociological thought is a reflection of its invisibility in popular and political imagination.

Further contributions to understanding waste in contemporary societies are Gay Hawkin's *The Ethics of Waste* (2006), John Scanlan's *On Garbage* (2005), and work from Nick Gregson (2010). Until recently, waste dealt with in part of the social sciences was seen as a niche problem of a rather practical nature. Emphasis was put on questions of governing and policy which had their home in environmental policy and planning, and on evaluating waste policies and their consequences. A typical concern related to waste policies of past decades was to assess the potential for recovering waste materials through recycling. These research orientations were based on waste seen as having particular traits and conceptualized as follows (Evans et al., 2013):

- Waste is worthless, needs to be distanced or converted into value via technological or organizational innovation,
- Waste is a fixed and self-evident category, an innate property or characteristic,
- The fact that things are designated as waste without further consideration of their nature is given by the imperatives of waste management. According to Gregson and Crang (2010: 1027) "that which is managed as waste is waste, and that which is waste is what is managed",
- Waste is located end-of-pipe, it is final by-products and outputs in linear processes of production.

Furthermore, waste was connoted as a risk. Environmental discourse, loaded with alarming and moralizing appeals, characterized publications about waste (Hawkins, 2006). Evidence of social inequalities with respect to exposure and proximity to waste was provided by research under the topic of environmental justice. Social order symbolized by processes of distancing and hiding waste from the societies that produced them, at least from the upper classes, was reported in Melosi (2005)[239]. In summary, waste was considered as a practical problem of management and policy.

[239] Massive amounts of waste and overflowing rubbish bins in Paris illustrated that social order was being disturbed in early 2020 as a result of the striking public waste management service. From late 2019 to early 2020, large-scale demonstrations and strikes attended the public services' opposition to the government's reform project of the French pension system, just before the Covid-19 crisis that had the relevant public service staff return to their jobs. https://www.lepoint.fr/societe/la-greve-fait-deborder-les-poubelles-a-paris-et-marseille-03-02-2020-2360996_23.php .

The discourse about waste and the conversion of waste to a resource where an output flow of waste appears as an input flow to another system has been the leitmotiv in environmental waste policy. It promises a solution not only to industrial societies' waste problem but also to the strongly criticized resource-intensive capitalist production and consumption model (EEA, n.d.; UNEP and ISWA, 2015). In his book *Homo Detritus*, Monsaingeon (2017) has argued that this turn in the waste discourse tends to deceive public opinion by suggesting there are good ways (recycling) and bad ways (landfilling, burning, etc.) of handling waste, when actually both are dead-ends providing no solution to the massive waste problem of contemporary societies. For food waste, the scientific literature likewise focusses on a "waste approach to food waste", although handling food as waste has limited potential to reduce the environmental impacts of food waste. This contradicts the current discourse, as shown in the literature review carried out and published in the course of my PhD research (Redlingshöfer et al., 2020). The review opens perspectives to discuss how a "food approach to food waste" can instead be implemented to strengthen food waste prevention, the best performing action to reduce environmental impacts.

To conclude, waste remained invisible for a long time from a social sciences perspective, as did food waste. A keen interest in the topic and consequently new perspectives were witnessed from the noughties on.

6.3. Avenues for future research on a material – cultural approach to food waste

Little insight is available on food waste and food waste practices from the early developments of the humanities' and social sciences' interest in food, in the late 19th century and over the course of the 20th century. The core debate of ethnological, anthropological and sociological studies, and later interdisciplinary food studies, is commonly the question of how social-cultural aspects and biophysical aspects interact in the determination of food practices. This literature scarcely questions the rationale of food waste and food waste practices. Compendiums by Poulain (2017) and Fischler (2001), to cite only two, make no mention whatsoever of food waste. The phenomenon of leaving food uneaten in households, by far incommensurable with the situation today, raised very little interest among researchers studying food practices. Likewise, the social science literature addressing waste did not address food waste either. One explanation is that wasted food was not an issue at the time, in the late 19th century and over the course of the 20th century when the humanities' and social sciences began to work on food.

The last famine in Europe dates back to the mid-19th century in Ireland[240]. Food scarcity in the 20th century in Europe was a purely situational problem (e.g. times of war), outside of which there was enough food. Moreover, food became increasingly available as the post-war food system industrialized, specialized, and delocalized production, transformation and distribution systems and thereby massively increasing the supply of food.

Based on the literature review in the first part, a set of questions revolves around the central issues of how the interplay between cultural and material determinants acts on the organization of food practices and food waste generation. While cultural, social, material and structural determinants were found to be relevant (Hebrok and Boks, 2017; Schanes et al., 2018b; Southerton and Yates, 2015), how they connect to one another and form a pattern in the organization of food practices is still a matter for research (Gojard and Véron, 2018). Considering the complex interplay of determinants, it becomes clear that food waste can be fully understood only within the wider set of social and cultural processes and related moral and cultural tensions, at the multiple levels from households to society. Boulet et al. (2020) recently developed a novel multi-level framework of food waste in households that organized the various determinants at micro (individual), meso (household), and macro (external to the household) levels. The authors argue that interactions between the determinants are key to the generation of food waste. The recent sociological literature referring to social practice theory helps us to understand household food waste practices in a broader than individual perspective, by referring to normative systems, cultural processes, and material systems (Evans, 2012). While being partly dependent on the material world, such as the food system and its components, food waste practices act on it in turn.

Social practice theory appears as a promising theory framework to link social practices to the material world. It seeks to understand and explain practices of everyday life interconnected with a material system, based on the idea that materials and practices are mutually constituted and densely interwoven (Shove, 2017). The idea that humans, artefacts, organisms and things of nature are variously but unavoidably enmeshed in social life (Schatzki, 2010) has the potential

[240] The Great Famine, also called Irish Potato Famine, Great Irish Famine, or Famine of 1845–49, occurred in Ireland in the years 1845–49 when the potato crop failed due to the late blight disease (*Phytophthora infestans)* in successive years. In France, the last famine dates back to 1741-1742. Nowadays, industrialized countries are food abundant, given that the average per capita food availability was above 3500 kilocalories per day in France and in Germany, for example, which is roughly 60% above the average nutritional requirement of 2200 kcal (FAOstat, n.d.). Abundance at the country level does not mean that the entire population is food secure. According to various sources, France counts a population which does not have adequate access to food of between 8 million (Anses, 2017) and 13 million (Ipsos, 2018), with 5 million (2018) having access to food aid (Morvan and Wanecq, 2019).

to stimulate a food waste literature that is deemed useful for the analysis of the social food metabolism developed in this study. Food-related activities, from food production to consumption, taking place in specialized food system sectors, are closely linked to the reproduction and transformation of food practices. In turn, the food practices shape the material relationship between the society and its environment, reflected in the social metabolism. In this respect, social practice theory has a role to play to enrich our understanding of the social embeddedness of social metabolism. In fact, this is relevant not only for food use but for any material and energy used by society, as Shove and Walker (2014) show with respect to household energy demand.

A second set of questions turns around the central issues of how food waste can be reduced and what makes household food waste practices change. In the humanities and sociologies, the culture–nature interaction that is applied in the conceptual model of society–nature interaction from the Vienna Social Ecology School (Fischer-Kowalski and Rotmans, 2009; Fischer-Kowalski and Weisz, 1999), appears as a framework of analysis for food practices. Assuming that food waste practices are the subject of a culture–nature opposition and that the material dimension has become the one of oversupply, like the situation in industrialized countries these past decades, one question is inevitable: how can a cultural understanding of the necessity to reduce food waste be strengthened, when the context is one of oversupply, with food perceived as abundant and accessible at least by a large part of society (cultural dimension), and when the relation between food waste and environmental impacts on the planet's ecosystems are not perceived (nature dimension)? When oversupply characterizes societies' experience with food, does it influence society's relationship to food because of people's feeling of abundance or because of the perceived material system in the form of specialized food system sectors? How can practices of sparing, careful, and efficient food use be fostered in a context of oversupply? What social processes would drive cultural skills and cultural understanding of the avoidance of food waste, through reuse of leftovers for example?

As anthropological work has amply shown, the selection of foods, and the distinction between edible and inedible resources from nature, is made on the basis of cultural and social representations and the imaginary of a culture, embedded in a value system, and not primarily according to physiological requirements (Fischler, 1988). When this is so for food, what does it mean for food once considered edible and transformed from a natural product, but discarded later, such as plate waste and meal leftovers? And what would that have as a consequence in a perspective of reuse of leftovers to avoid food waste? Does food waste have a cultural meaning to a society, and what would be the mechanisms to explain the meaning of food waste?

6.4. Conclusions

A metabolism's social embeddedness sums up the cultural and social conditions that shape the material and energy flows produced by a society. To understand the diversity of determinants which act on the way societies use or do not use food, the humanities and the social sciences have progressively engaged with food as a research subject – as shown in the literature review of the first part of this thesis. In some recent work, a few avenues for research stand out. Application of the theory of social practice – acknowledged as a promising framework for the understanding of food practices and conditions for change – to individuals' food practices in different settings would benefit our understanding of social metabolism. For example, we would have more insight into why consumers, either in households or in the food service sector, are the main contributors to food waste. We would also better understand how, from a linear flow standpoint, the material world in the form of food system sectors and activities shapes food practices and leads to food waste.

On the one hand, it is surprising that human societies consider as waste large quantities of material in the food system. The results of the Île-de-France case study in particular show a massive, unidentified material flow that raises questions about why this flow remains invisible to statistics and unaddressed by policy. At consumption stage, awareness has been built, data collected and policy implemented to reduce food waste for only the past decade. On the other hand, the literature reviewed in Chapter 6 provides some first important insights into why humans as a society are wasting (changing priorities, affluence-driven sign of social distinction, etc.) and, more importantly, why food waste has for a long time been a blind spot in academia and in the public arena (with the exception of times of scarcity and war).

Overall, material flows in social metabolism studies become more legible when they are analysed as "embedded", from a perspective of practices and of actors and their respective value systems and norms. While the social science literature that seeks to understand the generation of food waste from this perspective is growing, further research is nevertheless required to achieve its integration into the analysis of the embeddedness of the metabolism.

Conclusions and avenues for research

The starting point for this thesis was the statement that the food systems of industrialized societies are unsustainable. Cities are particularly concerned as they concentrate population and societal challenges related to urban food consumption and to the food system organization supporting it.

Food system transformation to a more sustainable regime requires profound change in the way societies interact with the biosphere. However, the physical relationship between urban societies and the biophysical world in the form of material and energy flows remains fairly opaque and invisible to decision makers and institutions, as the scientific literature presented in Chapter 1 has shown.

Social metabolism, that is, the socially organized throughput of energy and material of a society, reflects these society–biosphere interactions and opens possibilities to analyse their transformation. Food metabolism, one component of social metabolism, reflects the unsustainable nature of industrialized societies' food systems. The linear organization of the metabolism is a threat to the biosphere and ultimately to humankind, but so is the metabolisms' intensity. The massive generation of food waste, described for industrialized societies in the recent literature, adds to both intensity and linearity of the metabolism but has not yet been studied in the framework of urban metabolism studies. This is where this thesis comes into play.

Based on the aim of my research – to analyse urban society's food metabolism with respect to food waste –, the central research question and three propositions, developed hereafter, guided the design of this study. As described in Chapter 2, detailed analysis of the social metabolism required me to build an original method, including a quantitative tool for the flow analysis, which was itself hybrid as it was combined with a food systems approach. This flow analysis, covered in Chapter 3, characterized and quantified the food and food waste flows that enter and exit a city, according to the main input and output flows but disregarding specific food system sectors. Paris Petite Couronne and Île-de-France were taken as case studies. The sector-wise food system approach was useful for the analysis, in Chapter 4, of inner-urban flows of food and food waste as they pass through the food system sectors within the city. The understanding of the immaterial dimension of the food metabolism, and of the phenomenon of food waste in particular, was enhanced by a qualitative analysis of policy action in Chapter 5. With little coordination between the distinctly organized policy fields of food versus waste, food waste tends to be left in the realm of waste policy with its efficient infrastructure for the destruction of waste but little efficiency in its prevention. Chapter 6 closes the study with another literature review, exploring from a social cultural perspective the reasons and determinants of the generation of food waste. Yet the purpose was not to build the hypothesis of this research, but rather to add input to a broader discussion on how to describe society's relation to food and food waste. Overall, this interdisciplinary study rooted in social, industrial and territorial ecology (Chapter 1) has substance in the form of an analysis that is both quantitative (Chapters 2 to 4) and qualitative (Chapters 5 and 6), of the material and immaterial dimension of the urban food metabolism. The transversal view of the urban food metabolism through a systems approach combined with a sector-wise approach is relevant to enhance our understanding of the food waste phenomenon in cities, as summarized hereafter.

In the conclusions that follow, the first section is dedicated to a summary of the key results of this research as an empirical answer to the initial propositions. A second part draws conclusions from this research with respect to the scientific interdisciplinary field of social ecology, industrial ecology and territorial ecology, and establishes recommendations in terms of the method and data. Avenues for future research and recommendations for policy close this study but not this work as they bridge the gap with a research dynamic that is already underway.

Achievements of this research

Proposition 1: With regard to food, Western cities exemplify the intense, linear, and externalized metabolism that characterizes the relationship between industrial societies and their environment.

The findings of this study confirm a metabolic profile of the food system that is intense, linear and externalized. Several features of the metabolism support this proposition.

As regards intensity, the food metabolism is driven, in variable proportions, by both urban food demand and intense trade and processing activity in Paris Petite Couronne and Île-de-France. Urban consumption in the form of food and drink intake of 1.0 t/cap made up the predominant share (60%) of the input in Paris Petite Couronne, whereas in Île-de-France, it accounted for only a third, leaving the remaining share to export and to processing activities.

The urban food metabolism is furthermore characterized by a share of 19% and 22% of food, excluding drink, that ended up uneaten and turned to food waste in the food supply of the eating population in Paris Petite Couronne and Île-de-France respectively. The perspective of food supply is important as the urban system of both Paris Petite Couronne and Île-de-France has a large throughput of food in the form of import/export activities, with or without processing by local food manufacturing companies. Relating food waste to supply, and not total input, is a way to present food waste from a perspective that is not blurred by the trade and processing activities that serve the demand of other populations, and which we assume contribute marginally to the generation of food waste in the urban system. The focus on food alone, excluding drink, is another way to put the results into a meaningful perspective. Drink waste flows could not be analysed satisfactorily because of scarce access to drink waste data.

Overall, the share of food waste of 19% or 22% in the supply appears low compared to a share calculated for food and drink at national scale or above, for example for France or Europe as a region, where the order of magnitude is nearly 20% of food production wasted. Per capita food waste also appears low, with 95 and 106 kg/cap normalized with the legal population, for Paris Petite Couronne and Île-de-France, respectively, although food loss upstream is missing. Irrespective of the results of other studies, food waste increases the intensity of the metabolism. A share of 19% or 22% would necessarily afford opportunities for a more sufficient and frugal food management. Part of this food waste could be avoided, as it initially was food that, handled differently, could have been saved and used for human consumption. Many initiatives have already been implemented and tested in the prevention of food waste at the various stages of the food system.

The Paris Île-de-France food metabolism is linear. The large majority of the food waste was discharged in a linear way, mostly incinerated or landfilled. Solid food waste (including used cooking oil) that was collected separately and recycled locally totalled only 7% in Île-de-France in 2014, and 9% in Paris Petite Couronne[241]. This amounted to 55 and 36 kilotonnes of food waste, organically managed through anaerobic digestion and composting, and 28 and 23 kilotonnes of cooking oil recycled as fuel, within the boundaries of both urban systems respectively. Infrastructure capacities currently available and planned in the near future are and

[241] The difference in proportions stems from the fact that Paris Petite Couronne generates comparably less food waste than does Île-de-France, as there is almost no agricultural production and consequently no food loss. The quantities collected and recycled were known from Île-de-France data extrapolated to Paris Petite Couronne using employment numbers in the food industry (food waste and used cooking oil were almost exclusively collected by businesses in 2014).

remain insufficient in Île-de-France to treat all of the food waste, if it were collected separately, particularly because most of the food waste is classified as Category 3 animal by-products requiring specific heat treatment for safety reasons. Here we can see certain benefits of a plant-based diet. Food waste not in touch with any animal-based food at any stage does not require the stringent hygiene standards of European regulation 1069-2009 otherwise required for food waste classified as Category 3 animal by-products. The risk of zoonotic pathogen transmission from animals to humans can be excluded by strictly separating plant- and animal-based food at any stage between the generation, collection and treatment of food waste, in food processing plants for example, thus making food waste management easier and less costly. In addition to reduced environmental impacts of agricultural production and to the health benefits of diets rich in plant-based foods (The Eat-Lancet Commission, 2019), the often overlooked management of food waste is another advantage of this type of diet.

To increase bio-waste recycling rates beyond the current situation requires the building of more organic processing units, as well as transfer facilities and facilities to remove the packaging. These are however all highly controversial issues between users and managers insofar as the sites are close to dense urban areas. Limited processing capacities are already resulting in food waste collected in Île-de-France being transported and processed elsewhere, although exact quantities remain unknown. This raises the question, in analogy to supply areas, of the location of the receiving areas for the processing outputs from food waste collected in the urban system. Questions of the destination of food waste and food waste processing products, and of autonomy versus dependency on areas elsewhere for this service, do not appear to be a matter of concern to the general public or to policy makers, unlike questions of the origin and production areas of food. Against the background of a gradual generalization of bio-waste sorting and collection – for which European and national law have already laid the foundations –, the infrastructure of circular systems in Île-de-France designed to close material and nutrient loops through organic treatment is far from being sufficient, and questions are raised on the place of neighbouring areas in future development. Considering the obstacles of high costs and potential hostility by locals to the implementation of a large-scale bio-waste treatment facilities close to Paris, the reduction of food waste could be given a much larger role than it currently has. As shown in the analysis of policy documents (Section 5.2), the policies designed at the various administrative levels related to Paris Île-de-France, from central government to the municipalities and intercommunalities, lack an efficient mix of instruments and coordination between policy sectors and administrative levels for the prevention of food waste. Disregarding the potential of food waste prevention is not trivial: a waste approach to food waste policy involves much bigger infrastructural needs than a food approach to food waste, focussed on prevention, would have.

With regard to externalization, most of the food and drink input is from external sources since local agricultural production is marginal in Paris Petite Couronne. Although local production accounts for 23% of the input in Île-de-France, we have no data on the proportion that serves urban demand and that is exported. Imports are therefore the exclusive or main source of food and drink inputs in both systems. As for exports, they are bigger than food intake and make up 40% and 32% of the input, for Paris Petite Couronne and Île-de-France respectively, thus revealing intense trade activity in both urban systems.

Urban demand and export together account for a large part of the food and drink per capita input of 1.7 t/cap and 2.9 t/cap for Paris Petite Couronne and Île-de-France respectively, in 2014. The difference between the two systems lies in the existence of a material flow in Île-de-France that was not covered by the method developed in this study and appeared as an input-output imbalance in the food metabolism. One possible explanation is that processing activities of food and drink are at the origin of dissipative flows into nature (water) and of by-products not reported in the relevant sections on food and agricultural products in transport statistics. The input-output imbalance was particularly high for sugar, fruit and vegetables, and bread and cereals, therefore suggesting intense processing activity within the urban system.

All in all, the intense, linear and externalized character of the food metabolism of Paris Île-de-France was confirmed. The main difference between the two urban systems studied lies in the degree of externalization of the food input, which was highest for Paris Petite Couronne as almost no food is produced locally, and in the significant input-output imbalance in Île-de-France that suggests large-scale food processing activity. While the hybrid food system–material flow analysis developed in this study has provided novel insights into the food category composition and the sector-wise spatial organization of the food metabolism, it has not yielded easy answers to the question of sustainability. For instance, what are relevant indicators to assess the intensity of the food metabolism and the role that food waste reduction can play therein? Considering the changing water content of food along the stages of the food system, indicators that are independent of water, for example based on energy-content or on the content of food system-relevant substances (N or P), can provide additional insights on the metabolism. They can help to profile output flows, and food waste in particular. Food waste is not a uniform material. Its characteristics, for example avoidable versus unavoidable share, safety level, nutrient and water content, carbon footprint or level of contamination, are relevant for decision-making to optimize food waste management on the scale of a city. Food waste profiles and associated metrics need to be developed with the purpose of providing information on the relevant characteristics. A modelling tool based on the urban metabolism concept and material flow analysis could be of useful guidance in cities' strategies towards a more resource-efficient food system.

Proposition 2: "Opening the black box" of the urban system and analysing inner-urban food flows help to understand the overall food metabolism of a society

This study provided novel insights into the inner-urban food metabolism. Analysed through a sector-wise analysis to "open the black box" of the urban system, food flows between food system sectors could be quantified. Such quantitative information is important to shape food systems in the future. First of all, the analysis revealed some particular features of the consumption sector, the only sector of the inner-urban metabolism for which data were available, with respect to urban food flows. As the results in Section 4.3.3 showed, the contribution, in terms of mass, of out-of-home consumption to total food consumption of the urban system was surprisingly large, with 32% and 30% for Paris Petite Couronne and Île-de-France respectively. The small difference is attributable to the higher share of the additional population, and the non-household population in general, in the total eating population in the case of Paris Petite Couronne, particularly commuters from the Grande Couronne who eat out for lunch at their workplace. Moreover, this higher share explains that the non-household population played a bigger role (26%) in out-of-home consumption in Paris Petite Couronne than in Île-de-France (15%), as Section 4.3.2 showed. Surprisingly, despite its large contribution to total food consumption and the subsequent organization of the urban food system, the food service sector as a support for out-of-home consumption is scarcely characterized. Conversely, the results show that households concentrated most of the total out-of-home food and drink consumption, with 74% and 85% in Paris Petite Couronne and Île-de-France respectively. Obviously, household also concentrated most of the in-home consumption.

For food waste in particular, insights gained from the sector-wise quantification (Chapter 4) are limited. This is particularly disappointing as regards the role of consumption, for which food waste data are largely lacking. There are high expectations from decision makers to have better food waste data for households, identified as the biggest contributing sector but for which it is particularly difficult to measure food waste accurately.

Different methods were used to estimate food waste at consumption stage. While for in-home consumption, an input-output mass balance approach was used based on food and drink purchase and intake data, for out-of-home consumption, food waste was estimated by using coefficients. Because of the different approaches and optional data sources, the results at indivual stages of the food system are difficult to integrate and to compare. For example, total in-home food waste appears as moderate compared to out-of-home food waste, although due to the size of the sector, households altogether should have much higher food waste levels than the food service sector. For Île-de-France, for example, 386 kt food waste were quantified for households (negative purchase – intake balance not considered), whereas the food service sector generated 925 kt or 447 kt, depending on the quantification option. Using the difference between purchase and intake as a proxy for food waste in households initially appeared as a promising solution but was illustrated by negative results. Better quality data than currently available in France are required in the future to feed into the calculation. Overall, it seems that quantified at the level of in-home and out-of-home consumption and added up, total food waste appears higher than estimates obtained from waste statistics, despite limited comparability of results obtained with quantification approaches for the urban system versus individual sectors. Food waste quantified for the urban system was 1,457 kt whereas food waste at consumption stage alone was higher (925 kt or 401 kt for food, 122 kt or -100 kt for drink). Despite these limitations, the results of this study confirm that food waste quantities are highest at the stages close to and including consumption.

The understanding of inner-urban flows within cities' food systems is a useful framework for policy analysis directly or indirectly aimed at food and food waste flows. Information on the contribution of types of population to the food flows per sector is valuable when it comes to shaping a food system. For example, how the urban system's food supply and required upstream resources would be impacted by a given policy intervention can be assessed using such knowledge. Recent laws in France for example the EGALIM Act"[242] encouraged a redirection of the social catering food supply to sustainable products and the reduction of food waste [243].

[242] Law n° 2018-938 of 30 October 2018 for balanced commercial relationships in the agri-food sector and healthy, sustainable food to all; also known as the "EGALim Act"

[243] As explained in Section 5.2.4., the law n° 2018-938 of 30 October 2018 for balanced commercial relationships in the agri-food sector and healthy, sustainable food for all, also known as the "EGALim Act", included for food supply to the social food service sector (excluding canteens of private companies) the obligation to provide at least

Upstream resource use impacts – particularly from agricultural activities – of a potential change towards a larger share of organic, local foods and vegetarian meals in the food service sector can be quantified using the model of this study. Driven by urban demand and/or policy intervention, these quantitative impacts can be integrated into planning tools, such as land use planning or food planning.

Overall, opening the system of inner-urban flows required substantial methodological efforts. Few official data sources provided food flow data per sector or made it possible to perform simple calculations (e.g. extrapolations to the urban systems studied). Periodically produced mass data for food is not available at consumption stage, neither in-home nor out-of-home, nor at any administrative or spatial level, in contrast to agricultural production, for example. The mostly private nature of the sector's organization and little planning and intervention from government at any administrative level whatsoever might be reasons for the dearth of quantitative information.

In this study, data from a wide range of sources were necessary to compile and integrate into the analysis framework. Substitution methods and assumptions to fill data gaps were also explored. For example, an input-out balance approach was used to model food waste at household level, based on household purchase data and individual food and drink intake data used to model household food and drink intake. As a result, food flows from various quantification options for both in-home and out-of-home consumption were compared and discussed. However, more work and further exploration of ways to use the data sources will be required to refine the quantification of inner-urban food flows, including food system sectors which could not be covered in the course this study.

Proposition 3: In an urban system, there is a difference between the resident population and the eating population, which directly affects total urban food demand.

This study estimated the effective urban food consumption of a population present in an urban system. Unlike the legal population, counted regularly by the census, no information is readily available on the magnitude and composition of the eating population.

Surprisingly, despite an additional population of tourists, excursionists and commuters, the total eating population of the urban system of France's capital region was almost equal in size to the

50% quality and sustainable products, of which at least 20% organic food, and for schools, experimentation with the introduction of one vegetarian meal per week.

resident population, with 6.7 million permanent eaters, or PEEQs, a notion developed in this study, versus 6.8 million residents in the case of Paris Petite Couronne. It was even slightly smaller with 11.4 million PEEQs versus 12.0 million residents in the case of Île-de-France. Consequently, urban food consumption seen as food intake of the eating population was also lower: 3% and 6% less for Paris Petite Couronne and Île-de-France respectively. While the additional population of tourists, excursionists and commuters accounted for 11% and 5% of the eating population, its contribution was more than outweighed by the reduced contribution of the residents, due to travelling including commuting and time spent away for personal and professional reasons. Residents accounted for 5.9 million PEEQs, or 88% of the residents' legal population, and for 10.9 million PEEQs, or 90%, in Paris Petite Couronne and Île-de-France respectively. Their tourist activity influenced the eating population as much as the presence of the additional population, in Paris Petite Couronne, and even more, in Île-de-France, leading together to a similar and a lower eating population respectively in both urban systems. The difference between the two systems can be explained by commuters, whose numbers are higher and who commute more frequently to and from PPC than to and from Île de France.

This type of approach that, for urban food consumption, considers the combined effect of time spent away by the resident population and presence of the additional population has yielded significant changes in this study, particularly in the case of Île-de-France, compared to previously used approaches based on the resident population. The latter have most often used food availability or intake data on an annual basis and for residents only. Drawing on the cases of Paris Petite Couronne and Île-de-France, the results of this study suggest that in studies carried out in similarly attractive capital regions in industrialized countries, the urban food consumption calculated from the resident population could be overestimated. Not only is the total food consumption of the eating population a relevant baseline in food metabolism studies, but its structure in terms of in-home and out-of-home consumption directly relates to the types of population comprising the eating population, and to their food practices. Out-of-home consumption plays a bigger role than expected in total urban food consumption. Therefore, not only food waste reduction but also any other intervention promoting more sustainable eating practices out-of-home – for example the inclusion of more plant-based and seasonal food –, is weighted by the size of the out-of-home consumption sector. Consumption-stage food waste reduction interventions, on the efficiency of which some evidence is available, are much easier to conduct in eating-out settings than in peoples' homes (Reynolds et al., 2019; Stöckli et al., 2018). This is important because on average, a meal served out-of-home generates more food waste along the stages of preparation and consumption than a meal served in-home. Therefore, the out-of-home consumption sector warrants particular attention in food waste policy.

Since the user-equivalents approach is familiar in the field of public service planning at city or intercommunal level, the way is paved for wider use adjusted to the eating-population approach. As a useful contribution to an objective quantitative baseline of urban food consumption, beyond existing approaches focusing on residents, it could be useful for city officials and consultants when calculating cities' greenhouse gas footprint or any other environmental indicator, including emissions from food. The approach could also be tested for use in urban metabolism studies of important resources other than food. Energy and water demand for transport and sanitation, for example, is driven by the additional visiting population, and vice-versa, by residents spending time away. While initially rooted in public service planning, the eating-population approach has great utility in the analysis of cities' resource use and environmental emissions as it reflects a picture of urban food consumption that is closer to the reality.

Enhanced understanding of the urban food metabolism beyond the material dimension: cultural, social and political determinants

Our understanding of the social food metabolism can be significantly enhanced when the material dimension, expressed in food and food waste flows, is analysed as "embedded" in a system of cultural, social and political determinants which together shape these flows.

Chapter 6 has looked at a metabolism's social embeddedness, summarizing the cultural and social conditions that shape the material and energy flows generated by society. It has shown that the humanities and social sciences have recently engaged with the wider topic of food waste. We have found that the perspective of a social practice appears for food practices as a promising framework to enhance our understanding of the social food metabolism. Based on the idea that materials and practices are mutually constituted and densely interwoven in people's everyday life (see 6.3), material flows can be analysed in sectors where individuals handle food in various everyday settings, typically households.

In this study, both in-home and out-of-home consumption were found to be the sectors that generated most of the food waste in the Paris Île-de-France food metabolism. Our results show (4.3.1) that roughly half of the food waste generated in-home was food that was purchased to be eaten but was then discarded and thrown away (the other half was inedible parts from food gone to waste). As the first insights from food waste studies on households have revealed the role of an interplay of cultural, social, material and structural determinants in the generation of food waste, at the level of individuals, households and society, we can conclude that the most effective action to reduce food waste is action that simultaneously addresses the determinants of several categories and levels.

This is where the policy perspective, developed in Chapter 5, comes into play. Which determinants in food waste generation in households are addressed? Which are the levels – individual, household or societal – addressed by policy? As high levels of food waste feature amongst the characteristics of unsustainable food systems (see 1.1), the question of strategies and mechanisms to reduce food waste and, more broadly, to achieve food system transformation is key. Besides civil society and business, policy is important for initiating, driving, supporting and controlling transformation processes in food systems. Insights from the policy analysis in Chapter 5 have shown however that with regard to consumers, policy targeting food waste reduction has largely been built so far on the individual level, predominantly through events and awareness-raising campaigns. To effectively address food waste at consumption stage, the biggest food waste flow in the social food metabolism, insights and recommendations from the growing food waste literature of the humanities and the social sciences would provide useful input. Policies considering the multi-level framework in the generation of food waste at consumption stage still need to be designed. It could be a task for researchers to simulate policy impacts on the size of a particular waste flow or on the intense, linear and externalized character of the social food metabolism of Paris Île-de-France, in general. Out-of-home consumption is a relevant field for policy. A large part of food waste is generated in the food service sector. Policy intervention to reduce food waste is easier to implement in the out-of-home setting, for example through information campaigns or behaviourally-driven cues ("nudging") which can be controlled easier in the out-of-home setting than in a household setting. With limited funding, policy may achieve higher cost-effectiveness in food waste reduction policies in the food service sector than in households.

Limits of this research

The main limits of this study relate to the method and data used for the quantification of the food flows.

Adjustments to the method

Adjustments to the Eurostat method, the reference method for the material flow analysis used in this study, have some limitations. These mostly relate to increased difficulties to access data for an accurate quantification of food flows. For example, the delimitation of food within biomass is not an easy task with a clear-cut result but leaves room for interpretation. The inclusion of tap water to drink was done against the recommendation to carry out a separate analysis for water, distinct from material flows. It was however deemed necessary to acquire a comprehensive view of food and drink flows. This decision raises the question of the extent to which the material classification used in statistics (agricultural statistics, transport statistics, etc.) is appropriate to carry out analysis of the food metabolism. The failure to capture processing activities and potential output illustrate the different conceptions of food and food-related material between this study and the classification of statistics.

Availability and access to data

This study suffered from a limited access to data, at the level of Paris Petite Couronne and Île-de-France, required to account for the mass flows of food and drink. Some data were available only at national level.

Access to mass data for food is particularly difficult for food system sectors, for example the retail, food service, and wholesale sectors, which are essentially in the hands of private business. Urban policy and administration have little decision power in the organization of these sectors, except for the public food service sector and municipal contracts. Contrastingly, public data was available from official statistics for agricultural production and for the transport of goods. Several attempts to obtain such data, for example on the food supply of a big retail company for Paris Île-de-France through their logistics department, were unsuccessful.

The lack of mass data on food flows hampered the material flow analysis in this study and left no option other than the use of methods for substitution. Urban food consumption is a good example. To estimate this output flow which is not captured by official data sources, the notion of the eating population and its food intake was developed in this study and quantitatively estimated. Another example is that of food waste. Since there is no unified data source for food waste, the data compiled from several sources (mixed household waste, mixed business waste, food loss in agriculture, etc.) might suffer from incompleteness. Waste statistics in general seem somewhat inadequate to inform on food waste, in the sense of a food system-based definition (see Chapter 2). Since statistics cover only solid waste directed to waste management facilities, food disposed of through the sewer and on-farm losses of food, are totally ignored. Business waste handled through private waste companies might not be completely included either. For a comprehensive estimation of food waste, the statistics must therefore be completed.

Some data sources lack spatialized data at a level that is relevant for the urban system of Paris Île-de-France. Again, waste is an example where some of the data used for this study were drawn from a few rough estimates aggregated to a share (mean % of food waste in mixed household waste) for the region.

Due to the limits of this study, the results should be considered with caution.

Contribution to the scientific field of social, industrial and territorial ecology

Challenging the narrative of urban waste use for circular cities

Insights from this research advise caution when it comes to the narrative of urban waste use for circular cities. This narrative is an appealing tool in business strategies and current environmental policy (see 5.2.3 for the analysis of policy documents). Driven by the Circular Economy's and, more recently, the Bioeconomy's promise of turning waste into a resource and achieving the two objectives of decreasing the ecological burden of waste and increasing resource use efficiency – hence supporting economic growth[244] –, urban waste has begun to be seen no longer as a problem for cities but as a potential means to make them more circular in their material use and ultimately more sustainable. Inspired by the analogy to natural ecosystems and the metabolism metaphor to describe the functioning of ecosystems, a perspective of circularity applied to human-driven ecosystems or social systems found proponents, giving rise to developments of industrial symbiosis and, later, to the circular economy concept (see Chapter 1 on the evolution of urban ecology and industrial ecology). Since Odum's ecosystem theory showed that the metabolism's waste output flow returned to the environment and restored and closed biogeochemical cycles, waste from society's metabolism has also been assigned a function of recycling valuable components back into the environment. During the past decades, this recycling-oriented conception of waste in the scientific discourse in the wider field of industrial ecology has been seen as a solution to the "greening" of business.

General principles of physics are at odds with the idea of complete circularity. Georgescu-Roegen advised about the dissipative nature of material flows along biophysical processes: "In a closed system, available matter continuously and irrevocably dissipates, thus becoming unavailable" (Georgescu-Roegen, 1981: 61). For biomass, circular flows imply a transformation to feed the nutrients into virgin biomass production. Although history has shown that pre- and early industrial societies recovered a large share of food-related waste (not called

[244] One illustration of this narrative can be found in the discourse of the Ellen McArthur Foundation which is developing and promoting circular economy together with business, research and policy. The foundation promotes the idea of urban biocycles: "The aim is to highlight the opportunities to capture value, in the form of the energy, nutrients, and materials embedded in these flows, through the application of circular economy principles" (EMF - Ellen MacArthur Foundation, 2017).

waste at the time) (Barles, 2005), mainly in the form of human and animal waste, there are obstacles to overcome, for example the geographic distance to return nutrients back to agricultural fields, or nutrient losses. Overall, the material balance principle of the social metabolism implies a simple but important rule: “To reduce emissions and waste, one must reduce the input into the system” (Fischer-Kowalski and Erb, 2016).

The detailed analysis of food flows of the urban systems has shown that there are two distinct types of food waste in mixed household waste (the distinction was not possible for food waste flows collected outside of the public service collection scheme). The underlying questions in relation to these types of food waste concern their determinants and the reasons for their existence, and thus alternative strategies to address them compared to the option of circularity.

Part of food waste, termed inedible parts, is directly linked to food intake. It is intrinsically part of the processing and preparation of food (for examples and a discussion of answers to the question of what food is, see Section 2.1.1). Representations of what is considered edible, within a certain margin of physiological possibilities for digestion, are profoundly anchored in humans’ specific food culture, and are variable over time and place. Food cultures also determine that inedible parts are not accepted as food and are difficult to avoid, which qualifies them for recycling as urban waste.

The other part, termed wasted food, is not intrinsically linked to food intake, as it consists of surplus food, meal leftovers and generally surplus from overproduction in the food system. There is no direct relationship between wasted food and food intake, although surplus acts as a buffer to ensure that enough food is available at a given time (at the level of a country, a shop or a household). The question is whether wasted food from surplus is easy to prevent. The cultural anchorage of this waste is debatable. Abundant food supply, at least for those societies which took the path of industrialization, is a relatively new phenomenon for humankind, attributable to high productivity in agriculture enabled by fossil fuels[245]. Jarrige and Roux (2020) show that in the post-war societies of the second half of the 20th century, wasting (*gaspillage* in French) in general, rather than a specific food, became a positively connotated action which generated a feeling of freedom from material constraints. Everyday decisions, at

[245] Social disparity and poverty that limit material use are still a reality in industrial countries. Nevertheless, cultural representations, values and norms change in the sense of a vertical diffusion from the affluent to the needy part of a society, as social theory suggests (Halbwachs, 1912; Simmel, 1957). The argumentation in support of nature-society co-evolution refers to the expansion of a Western-style industrialized food system that changes societies’ relation to food, disregarding social disparity observed within industrial societies in the access to food.

every stage in the food system, to keep or to discard food appear in a new light when there is no longer a threat of insufficient food. Practices around food have changed substantially as societies have become industrialized and the structure of occupations has changed. With women doing paid work out-of-home, food practices have adjusted to time available for domestic work being a scarce resource, such as for cooking fresh meals and going shopping. Today, the economic situation of households in industrial societies, such as France, has improved and the food budget in households has decreased in relative terms (Demoly and Schweitzer, 2017), which in turn can influence food-related behaviour.

Referring to socio-ecological theory developed by the Vienna School of Social Ecology (see 1.2.1), the phenomenon of food waste in industrial societies can be interpreted as an illustration of the principle of co-evolution of society and nature (Weisz and Clark, 2011). Overall, abundance and access to the material dimension has the potential to change the cultural realm and its values, representations and norms, transforming material use in a way which in turn compromises the planet's capacity, in the middle and long run, to maintain the material provision for the global population at the current high level. A change in the norms related to food and food waste may have lowered barriers regarding food wastage in contemporary affluent societies, although people tend to report feeling shameful and blameworthy (Evans, 2012, 2011), which proves that barriers to wasting and food-related values are still strong. Overall, the literature in the humanities and social sciences is growing but still poor on the issues of waste and wasting, and provides only very limited hints to inform the debate, as shown in Chapter 6 on the cultural and social embeddedness of the food metabolism.

Whatever the depth of the cultural anchorage leading to food wastage – itself a matter of debate for the humanities –, we argue that wasted food is different from food waste in its features related to societies' metabolism. The possibility to prevent food wastage, subject to acceptance of social, economic, and ecological costs, places this part of food waste in the unique position to reduce food demand without compromising society's food intake. Hence, resources can be saved and emissions slashed while maintaining human well-being. By contrast, recycling maintains food demand at a high level and fuels the contemporary social-ecological regime, hence saving fewer resources. While there is no biological reason to waste food, there are cultural, social and economic ones, at least, although they are not necessarily easier to change[246]. Nevertheless, the set of multiple reasons offers a margin for industrial societies to explore how to adjust their socio-ecological regime with a view to sufficiency[247].

Drawing on the insights from this study, we suggest a conception of waste in societies' metabolism which considers heterogeneity in the causal relationship between input and waste. Waste as a direct result of the transformation of input is different from waste which is the result of surplus in the system (and is sometimes thrown away right away without being unpacked or prepared). In other words, a conception of heterogeneity does not take waste for granted and does not lead first and foremost to a vision of circularity when it comes to addressing waste. A socio-ecological transformation of societies' metabolism can benefit from this nuanced and heterogeneous conception of waste. Prioritizing absolute reductions of material flows, so-called dematerialization, over circular flows, reuse and recycling – the traditional focus, widespread in industrial ecology thinking), could become possible. As illustrated in this study, heterogeneity in the conception of waste stemming directly from overproduction and surplus, as witnessed in contemporary industrial societies, calls for a sufficiency approach prior to circularity. The fact that waste stems from overproduction and surplus is one important limit to the straightforward application of a circularity approach to transforming the metabolism of industrial societies, and can even be an opportunity to rethink societies' metabolism.

The hybrid food system MFA method proves effective in the analysis of inner-urban food flows

A major outcome of this study is the development of an analysis framework for urban food metabolism studies that combines a food system approach with material flow analysis. This hybrid method appeared necessary to respond to the propositions. A literature review carried out at an early stage of this study suggested the need for an appropriate method to analyse food

[246] Referring to Fischler, he criticizes a position frequently stated in a nutritional health-oriented discourse, that underestimates or even ignores the weight of the cultural and social dimension in food choices, as if humans took decisions purely on the basis of biological requirements.

[247] I use sufficiency here in the sense of material degrowth or dematerialization related to societies' use of material. In the context of this research, sufficiency means consuming less and decreasing demand by eliminating losses and waste while satisfying a society's basic needs. It applies to affluent societies which start from a high level of consumption and can act on it voluntarily. Inevitably, the concept raises questions such as the definition of what basic needs actually are, the extent to which consumption can be decreased at a society level and how this can be reconciled with individual levels of consumption, none of which can be further discussed in the scope of this research. Alcott (2008) relates the sufficiency strategy to consumer behaviour and further distinguishes consumption sufficiency from consumption efficiency, with the latter meaning behaviour that achieves a given level of utility with less input. The author warns that rebound effects through an increase of consumption can be expected in both strategies. In French, we would speak of *sobriété* or *frugalité* which are both common terms in the French debate on the socio-ecological transition.

waste in a city's social food metabolism. The method developed in this study proved effective in connecting data that is otherwise invisible or handled separately, from various sectors in a food system. Using this hybrid method, food flows were analysed with regard to the food system sectors, types of material (food versus drink) and food categories involved.

Two approaches were combined. A top-down approach, rooted in the Eurostat economy-wide MFA method, characterized food flows according to the main input and output flows of the urban system by distinguishing food import and export flows (transport statistics Sitram), local agricultural food production (agricultural statistics Agreste), supply of tap water to drink, and food intake of the eating population (intake survey data INCA 3). A bottom-up approach proceeded sector-wise and gathered a variety of data sources and other information for assumptions where the data were missing. Where the top-down approach ignored the processes between input and output flows, the bottom-up approach filled the gap. Both approaches together yielded an overview of urban and inner-urban food and food waste flows.

Particular adjustments to the Eurostat method were however necessary, which means that the results of this study cannot be directly compared with studies using the unmodified Eurostat approach. The four main adjustments are: i) focus on food not biomass; ii) consideration of livestock products as part of agricultural production of the urban system; iii) inclusion of tap water to drink; and iv) use of intake data as a direct way to calculate urban food consumption. However, the results proved to be hardly sensitive to these changes in the context of the urban systems in this study, for example for considering food not biomass (there is little other biomass than food) and livestock products as part of agricultural production (there is little to no livestock in both systems).

Raw agricultural products, processed food items and food waste were all primarily considered as food and were distinguished only according to food system sectors. This implies that food imports and exports, containing both agricultural products and processed food items (but not food waste which is a sector of its own), were handled regardless of the degree of processing. While information about the distinction between raw and processed food was lost and caution must be taken to obey the mass balance principle, the continuity of food flows across input and output flows became visible with this approach – a promising first step for deeper analysis per food category.

Requirements of improved access to data

While this study has further developed the method, it nevertheless remains dependent on the availability, access and quality of the necessary data at the scale of Paris Petite Couronne and Île-de-France. The study benefited from the particular administrative status of Paris Petite Couronne as a group of *départements*, and of Île-de-France as a region, insofar as this afforded access to most data. This is not the case for cities in general, which hampers the feasibility of urban metabolism studies. Further improvements specifically in relation to the food metabolism of the studied cases would be important to confirm the food flow results of this study, monitor them over time, and deepen the understanding of as yet under-researched sectors through further analysis.

Concerning urban food consumption and the role that the eating population plays, some hypotheses need to be confirmed. While most of the population types and numbers could be retrieved from official databases, mainly from the census, the time that people spend in the area of the urban system studied is much more difficult to ascertain and requires confirmation. This is particularly important for the main types of population which are residents, commuters (in both directions), and tourists, as their mobility patterns (annual time spent in an area) largely determine the eating population. Paris Petite Couronne and even more so Île-de-France, as France's capital region, benefit from a large number of studies on specific topics[248], which are not available for other cities. For the purpose of urban metabolism studies in general, it would be useful to have access to spatialized results (per geographic area, population size, etc.) about mobility patterns per population type. Furthermore, more data is necessary to refine the quantification of the food intake of the eating population. Allocation factors for the distinction between in-home and out-of-home consumption were pivotal for the analysis of inner-urban food flows, but they were available only for the national sample. Their relevance for the specific case of the capital region needs to be confirmed as the high number of restaurants could suggest that the capital region's residents have more meals than the average national resident out-of-home. The sample size used in the most recent INCA 3 study was not large enough to allow for detailed analysis of the food and drink intake results of geographic sub-samples according to socio-demographic parameters. One solution could be to have some general parameters, in particular about out-of-home food consumption, in other surveys concerning health and nutrition using larger samples. A deeper understanding of out-of-home consumption patterns

[248] An example are studies from the Institut Paris Région about travelling activities to and from Île de France (IAU île-de-France, 2014) and about the role of the Rungis market (IAU île-de-France, 2012), as well as studies on topics of less importance for the Paris Île-de-France food metabolism, for example about food production in shared and collective gardens (IAU île-de-France, 2018).

involving the numbers of meals served and meals eaten out-of-home are particularly important as the difference in the out-of-home food and drink intake between the two quantification options was huge. Conversely, the importance of in-home consumption directly impacts the difference between household purchase and intake, considered in this study as a proxy for household food waste.

Concerning food waste, the assumption used to estimate the proportion and composition of food waste in mixed household waste would need to be confirmed. More measurements from a larger sample of public authorities in charge of waste collection, located in Paris Petite Couronne and the Grande Couronne, would be necessary to strengthen the initial assumption for the quantification of household food waste. A standardized approach – ideally developed by the Ademe – to the distinction of wasted food and inedible parts would allow specific patterns of food waste to be identified in relation to urban density, type of housing and so on in Paris Petite Couronne and Île-de-France. Furthermore, business food waste and business waste in general need to be urgently captured by regional monitoring tools. The estimate for business food waste, obtained within the regional plan for waste prevention and management, can be considered only as a temporary solution and needs to be corroborated. Further measurements in the food service sector would help to confirm or adjust food waste coefficients (wasted food and inedible parts) used for the analysis of food flows in out-of-home consumption.

The data from the Household budget survey analysed for the purchase quantities suffered from overall bad quality (frequent "no answer", inconsistencies in the answer for several variables, errors, etc.). While in large studies errors and inconsistencies in answers can always occur and are partly corrected, a particular effort is required at the stage of data collection, in households, to reduce the number of "no answer". It is the responsibility of the data producer, in this case of INSEE, to check the answers given for purchase quantities as rigorously as it usually does for purchase expenses.

For food imports and exports, apart from the limits of the transport statistics discussed in Chapter 3 and pointed out by other authors (Courtonne et al., 2018)[249], the classification of goods appears not to be rigorously followed. The category of food processing by-products, for example, raises the question of their destination as the reported export flow seems to be at odds with estimated quantities in the case of wheat milling. One reason could be that the

[249] Transport of less than 3.5 tons is excluded from the sample for example.

classification is not precise and leaves room for interpretation, leading to the classification of the same product in different divisions and categories. Another reason could be that for reasons of comfort at the data collection stage, the category of miscellaneous goods is used. In both cases, the transport would not be visible to the researcher.

For the processing industry, wholesale trade and logistics, no public mass data for food were available at the level of a region and even less so at that of a *département*. Surveys on input and output mass flows exist for the manufacturing industry at national but not infranational level. Spatialized mass data in these food system sectors would make it possible to close the knowledge gap of inner-urban food flows.

Observed disruptions in the concept of food, from agricultural raw product to waste

In the course of this study, it became increasingly evident that a change has occurred in the concept of food, as seen by society, which might have important impacts on the way society uses food, considers food and discards food. We can see a disruption in the linkages of food with the agricultural production stage, at one point, and with the end of life stage, at another.

Agricultural products are often reduced to standardized raw material that receives further processing and added value in the food processing industry (Colonna et al., 2013). This kind of agricultural production is often linked to the agro-industry and to industrialized food systems where power relations and value sharing are at farmers' expense, and where food items are traded across the world. Vivero Pol speaks of a "progressive commodification of food as a vital resource (…) presented as a social construction (…) which shapes specific food policy options and blocks or discards other policies grounded in different valuations of food" (Vivero Pol, 2017: 9). Strikingly, official statistics reproduce this view. The Sitram data base, for example, distinguishes agricultural products (Division 1) from food and drink (Division 4), as if the two were distinct product groups and not linked albeit often through just one step in-between. It is therefore difficult to obtain an overview of where food is involved. In Western societies, most food is purchased in medium-sized and large shops or supermarkets (INSEE Première, 2014), which developed along with a flourishing food industry from the 1960s on. Fischler highlights a shift that occurred at that time when "food preparation […] moved from the kitchen to the factory, suggesting food items that no longer require domestic work: no more need to eviscerate and pluck a chicken, to mash potatoes in a masher…" (Fischler, 2011: 10). From then on, most of the food processing took place in a dedicated industry and no longer in the workrooms of farms or in household kitchens. Today, trends towards reconnecting producers and consumers, such as community-based agriculture and home delivery of basket schemes, tend to skip the processing and retailing industry complex, and to reassign essential tasks to producers and consumers. Farmers can thus become food producers again. School gardens and school farms serve a similar purpose and teach pupils the origin of food.

Another disruption occurs at the other end of the food system when food is discarded from human consumption. As Chapter 6 shows, food waste, like waste in general, has remained invisible for a long time: invisible to the gaze of social scientists interested in waste, as to those interested in food, and rarely interested in both; invisible to society until a century ago, as food leftovers and refuse were previously reused by preparing leftover meals, feeding urban livestock, and in the specific case of bones, by extracting phosphorous for fertilizer use (Barles, 2007); and invisible to tools for observing society, such as official statistics which still today bury food waste in an undifferentiated concept of undesirable matter, termed waste. Once again, official statistics reproduce a view of food, as a concept, disrupted at a particular point in the food system.

Vivero Pol (2017), in contrast with the conception of food as a commodity, presents an alternative valuation of “food as a commons”, by suggesting six dimensions: “food as an essential life enabler, a natural resource, a human right, a cultural determinant, a tradeable good and a public good” (Vivero Pol, 2017: 7). It seems that this idea of alternative valuation could well align with the need, identified in this study, to engage with a narrative of food that embraces both ends. This could open perspectives for a more sustainable use of food by reducing food waste.

Avenues for research and recommendations for policy

Progressing towards methods for modelling food metabolism

This study has shown that the hybrid method of material flow analysis and the food systems approach works conceptually but requires considerable effort in data collection to carry out a food metabolism study. While early ambitions in this research envisaged a comparative study taking as cases the French and the German or optionally, the Austrian capitals, it soon became clear that the development of the method occupied a much bigger place in the study than initially planned. It was consequently necessary to cancel the comparative part. To be able to test the method of this study in the cases of other cities with diverse profiles, distinct in size, density, socioeconomic status, and embeddedness in city networks, progress in several aspects would be required.

First, quantifying the eating population, and in particular the population of commuters to and from both urban systems analysed in this study, was time-consuming as I used raw census data and analysed them manually, myself, by summing up individuals using Excel sheets. The risk of errors was also large. A promising and much faster approach, discovered in a later stage of this study would be the development of SQL queries. Nevertheless, developing an automated process for capturing the number of commuters to an area would simplify the quantification of the eating population. As the food intake of the eating population of the French capital region is surprisingly several percentages lower than estimates based on the legal population, and because the food flows related to urban consumption directly depend on it, it is important to develop approaches to capture the eating population that are faster, easier to handle and less vulnerable to calculation errors. In this respect, it would be important to identify more control variables, available in official statistics or otherwise accessible, that can be used to cross-check assumptions we used and to which the results were highly sensitive.

The first steps in this direction are already being taken. Drawing on the present work and on similar approaches of members of the research lab, a joint initiative called POPCORN, an acronym for Research network about the POPulation and its food COnsumption in uRbaN areas [250], was developed and accepted for funding in one of INRAE's metaprogrammes, Bioeconomy and Urban Areas, called BETTER. The aim of the metaprogramme is to foster the building of a scientific community within INRAE and beyond, to address questions supporting the necessary transition away from fossil fuel-based society models in urban areas. One of two actions starting in 2021 consists in the development of a web-based tool for the quantification of the eating population and its related food intake. The tool will be designed to enable requests of various public databases, such as census data for the legal population and for commuters, and to include food-related variables such as food intake and consumption patterns (in-home versus out-of-home consumption, purchase channels, etc.). A step further will be the application of the tool to a selection of contrasting case studies, such as tourist ski or seaside resorts, or commuter and dormitory towns, in order to confirm or invalidate the hypothesis that working at the level of the eating population in any food metabolism study is more relevant than working

[250] *Réseau de recherche sur la POPulation et sa COnsommation alimentaire dans les territoires uRbaiNs*

at the level of the legal population. The eating population approach can also be useful to simulate changes in the living patterns and consumption modes of a population. The massive departure of Parisian and Île-de-France residents for the summer holidays, a French characteristic, could be modelled with less time spent away, which would increase urban food consumption within the urban system.

Second, a conceptual effort was necessary to grasp the notion of food, which is more limited than biomass as it excludes feed, wood and other material made from biomass. Limiting food flows to food only reveals the role that food processing plays in the metabolism. By definition, processing output flows different from food are not covered by the implemented method (e.g.by-products, water) and therefore appear as the difference between input and output flows.

Gathering, from various sources, the available data on food waste at the scale of an urban system reveals their weaknesses and invites us to find ways of going beyond them. At the consumption stage, for example, this study was the first in France to analyse the food purchase quantities of the national Household budget survey and to use them to calculate a purchase–intake difference, considered as a rough estimate of food waste. This was done because direct measurement of food waste has rarely been performed for sufficiently large samples of households. It is a rather unpleasant task and one prone to bias and errors, for both household members and study leaders, to sort and measure garbage a couple of times a day. Alternative methods for estimating food waste at the household stage, where most of the food waste is generated, are urgently needed. The approach tested in this study is one alternative based on existing surveys regularly carried out by public institutions. Simple descriptive data analysis was used to calculate the mean purchase quantity per food group but it suffered from multiple obstacles concerning data quality (missing data, multiple units, inconsistencies etc.). Future work should extend existing work by using tools from econometrics, for example for filling data gaps and correcting inconsistencies, and thereby improve the analysis of purchase quantities. The two data sources available in France, the Household budget survey and Kantar Worldpanel, remain interesting for comparison, as did the present study. Both have strengths and weaknesses that can be looked at when put into perspective, for example concerning the role of food items bearing no barcode. Further research opportunities lie in the analysis of food waste according to socio-demographic parameters such as income, education level, household size, urban versus rural area of residence and others assumed to be determinant in the magnitude of food waste at household level.

Extending food metabolism studies to other scales

There were two main reasons for selecting two administrative areas, Paris Petite Couronne and Île-de-France, as case studies: first, access to data, as many public data necessary for this study (imports and exports, agricultural production) are collected at the level of the *départment* as the smallest administrative unit; and second, scientific interest, to extend research to as yet under researched areas of a food metabolism previously characterized through the lens of food supply, supplying areas and the disruption of biogeochemical cycles (see background Chapter 1).

A usual perspective for further research is to apply the method of the present study to cases of other cities with different characteristics in terms of size, socioeconomic status, relationship to other surrounding cities and so on, in order to identify common points and differences compared to the food metabolism results found here.

Beyond these usual developments, further research would be relevant at the level of a unit or area where public or private action is effectively taken, in contrast to purely administrative units. The level of a neighbourhood or a city appears as an example of areas where action is taken, driven for example by local actor networks or local associations, or by opportunities offered by the population's socio-economic characteristics, all potentially impacting an area's foot metabolism. At the level of a neighbourhood there are many albeit small-scale movements and initiatives at work. Taking the example of Paris Île-de-France, food surplus recovery from markets (for example through the associations *Tente des glaneurs* or *Moissons solidaires*), from supermarkets (by start-ups like *Phénix* and *Comerso*), or from the food service sector (the company *Excellents Excédents*), as well as different forms of composting of bio-waste, from neighbourhood composting to emerging on-site composting by a company or centralized collection and management of bio-waste, have come to existence. How does the food metabolism change under the influence of such action at the level of a neighbourhood?

Testing impact from changes on the metabolism

This research started in 2016, at a time when France passed the "Garot Act". It was thus the first country worldwide to legally oblige retailers to connect with food charities, and to prohibit the destruction of retailers' surplus food if it is still fit for consumption. Logically, the reference year for the data collection on the material flow analysis (2014 in the case of this study) lay before the beginning of the research, since public data from the statistics or reports usually become available with some time lag. At the time of finishing this research, it would be interesting to see whether any impact of the Garot Act can be noticed five years later, or of the subsequent laws extending the obligations to other sectors. The year 2020 also witnessed the Covid-19 pandemic affect the global population and trigger major changes in the way people live and eat. For example, despite comparably tight social safety nets in European countries, a peak of people was sliding into a need for food aid. The majority of the food service sector was closed for some time or limited to take away offers, consequently shifting large amounts of the population's food supply to the retail sector. Carrying out MFA across several years, including 2020, would be an interesting follow up to see whether and how small and big changes in the way societies organize their food system are reflected in the food metabolism. Yet a prerequisite for such work would be the availability of periodically collected mass data for food flows[251] and detailed information about effective mobility and consumption modes, for example the extension of new work patterns and home office work, as well as reduced traveling for professional and private reasons. Future developments in the modelling of the eating population, already planned and funded within the POPCORN project, will be designed to include these changes and will thus go hand in hand with future work on the Paris Île-de-France food metabolism.

Food waste policies

This research has shed light on a multi-layer system of administrative competencies and responsibilities addressing food waste reduction. Located simultaneously in both food policy and waste policy, coordination between the two is lacking. While opening this multi-layer system by analysing the nature and destination of the various enablers, according to a policy analysis framework from Lascoumes and Galès (2007), a need came up for a more general understanding of the evolution of the policy framework related to the food waste target, in the example of the French situation. France has been internationally known for running a law-driven food waste reduction policy which made the redistribution of surplus food the main pillar, widely anchored in multi-stakeholder negotiation practices. However, there is little evidence that the current policy design does indeed have the potential to effectively reduce food waste. Avenues for research could lie in the exploration of policy makers' representations of food waste and the way these representations drive policy design.

[251] It cannot be excluded that data collection for surveys was disturbed in 2020 when the country (France) was locked down twice for periods of several weeks.

The "social production of food waste" (Audet and Brisebois, 2019) is far from being limited. The reason is that structural determinants of food waste are not being addressed at the source. The food system is designed to over-produce, disregarding the destination of food and whether food becomes eaten or thrown away – which in a situation of oversupply leads to similar results. Food then no longer fulfils peoples' physiological needs (it may nevertheless fulfill psychological or social needs, like eating together) and can be seen as wasted food.

Policy outlook

This study provides a useful extension of previous work on the Paris Île-de-France food metabolism to policy makers in the capital of Paris and the close administrative units, such as Île-de-France. Local policy makers usually refer to metabolism studies to build policy projects. This study's focus on food waste flows is a valuable contribution to observation tools at the regional waste agency Ordif and to studies commissioned by the regional council, in particular those which serve the regional waste prevention and management plan (PRPGD). Despite the fact that results from the PRPGD informed this work, the PRPGD can be read in light of the challenges of dematerialization and reduced resource and material use that motivate policy action at local and regional level. Reading food waste flows from the perspective of the complete food metabolism helps to shift the focus to the part of the metabolism prior to the generation of waste, where preventive action can be taken.

Although further work is required to fill the knowledge gaps in food flows, particularly inner-urban flows, this study's analysis framework can be used to simulate scenarios of policies designed to prevent and to recycle food waste, in the respective sectors of the food system. Particular interest of this work lies in the possibility to see how policies supporting prevention and food waste recycling can interact and impact the food metabolism as a whole. Concerns to enhance the efficiency of such policies with respect to reduced intensity of food use are informed by the policy analysis carried out in the course of this study (see Chapter 5). Accepting uncertain efficiency in the interests of promoting change to a less intense and more circular food metabolism – given the illegible and poorly coordinated policy framework for food waste reduction at the level of municipalities, intercommunalities, *département* and the region –, can help policy makers to rethink the way food waste policies are currently designed.

The various reduction and recycling strategies currently adopted in Paris Île-de-France still seem to be in their infancy and to concern small changes in the overall organization of the food metabolism, although a thorough monitoring would be necessary to assess them over time. It seems that more profound changes are needed, despite flourishing local NGOs and citizen engagement around “zero waste” issues. The question of how to address the “social production of food waste” (Audet & Brisebois 2019) from a policy perspective is still unanswered. When everything seems to reflect affluence and abundant food supply, how can endeavours to promote sufficiency (as opposed to abundance) be successful? Issues of overproduction and oversupply are hardly addressed from a policy perspective. Such policies would require changes in the value system and social norms related to food, and in the concept of waste, and related changes in food practices and lifestyle. This study can stimulate the discussion about more integrated food policies.

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Glossary

Ademe	French agency for ecological transition
Eurostat	Statistical office of the European Union
FAO	Food and Agriculture Organization of the United Nations
DRIAAF	Regional Ministry of Food and Agriculture Île-de-France
IAU îdF	Urban planning institute Ile-de-France (now Institut Paris Région)
INSEE	National Institute of Statistics and Economic Studies
ISIE	International Society for Industrial Ecology
MFA	Material Flow Analysis
N	Nitrogen
ORDIF	Paris Île-de-France Waste Observatory
P	Phosphorous
PRPGD	Regional plan for waste prevention and management
UN	United Nations
UNEP	United Nations Environment Programme
WHO	World Health Organization

Appendices

Appendix to Introduction

A0.1. Interviews to support data collection

Table A0.1. Interviews to support data collection

Name	Responsability	Institution	Date	Interview type	Data
Barrault, Blandine	Project manager waste treatment	ORDIF Institut Paris Région	18 November 2019	By email	Food waste treatment, public service
Baros, Catherine	Head of research department consumer and food service	CTIFL, organization for applied research in the fruits and vegetable sector	29 August 2017	By email	Waste statistics
De Biasi, Laure	Project manager	Institut Paris Region	27 April 2018	Face-to-face	Food metabolism
Bize, Sandrine	Head of departement hygiene, safety, quality and the environment	General Confederation of Food Retailers (CGAD)	31 August 2017	By telephone	Food waste at independant food business
Demoly, Elvire	Head of the INSEE household budget survey	INSEE - DSDS	17 April 2019 10 September 2019	By email	Household purchase data
Ducottet, Séverine	Project manager Biomass and energy	Conseil Régional Île-de-France	27 April 2018	By telephone	Biomass use in Île-de-France
Farlotti, Nicole	Director	Banque alimentaire Paris Île-de-France	3 October 2017	Face-to-face	Donation
Flagueil, Julien	Project manager Food	Officer of the city	25 April 2018	By email	Waste statistics

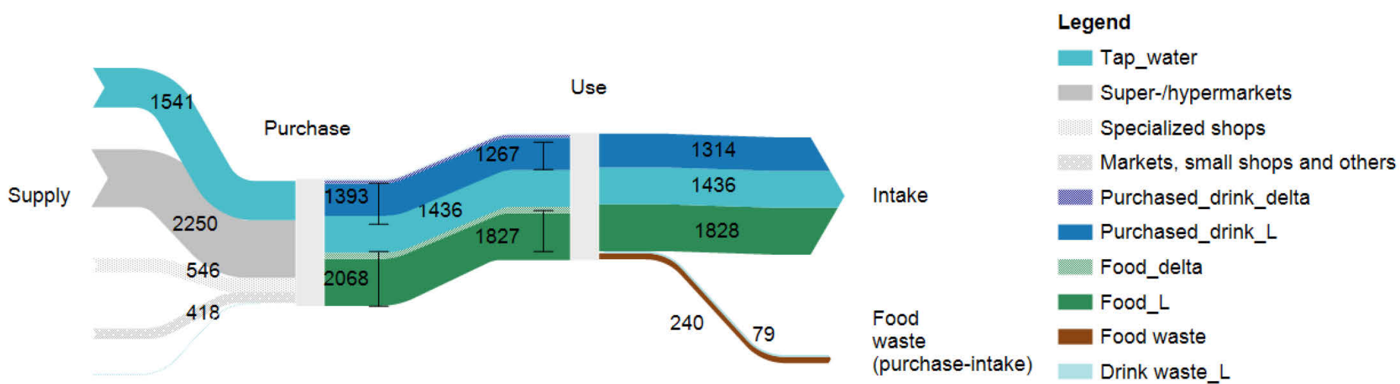
	waste and Reuse	government of Paris			
Guinot, Magali	Head of Waste department	Conseil Régional Île-de-France	31 August 2019	By email	Waste statistics, regional waste plan
Hebel, Pascale	Head of consumer studies department	CREDOC research institute	8 September 2016	Face-to-face	Consumer food waste, consumer consumption data
Hebert, Christophe	President of association	Agores, national association of directors of social food service	18 September 2017	By telephone	Social food service
Lagarigue Julien, Marcinkowska Grazyna,	Consumer studies department	FranceAgriMer	25 August 2019	By telephone	Aggregated household purchase data of the Kantar household panel
Mauvais, François	Head of the food department, Resytal data base	DRIAAF, regional Ministry of Food and Agriculture, Île-de-France	16 December 2019	By email	Meals served in the social food service sector
Roussel, Sébastien	Commercial manager, waste recycling and valorization,	Veolia	21 November 2017.	By telephone	Food waste collection and treatment, private service
Sauques, Valentin	Project manager mixed household waste, observatory of the waste economy	ORDIF Institut Paris Région	7 October 2020	By telephone	Financial aspects of waste management
Tison, Anne	Founder and director	Excellents Excédents	9 May 2017	Face-to-face	Surplus food collection from the food service sector for donation

Thibaud, Alex	Project manager waste collection	ORDIF Institut Paris Région	12 July 2019	By telephone	Food waste collection, public service

A0.2. Preliminary guidelines for reading the food flow diagrams

All material flow figures in this study were elaborated as Sankey diagrams with the software e!Sankey. Diagrams must be read from left to right following the life cycle stages of food. Food flows are shown as arrows between grey nodes. Nodes represent key food system activities analysed in this study, such as food purchases and use at the consumption stage or input and output to and from the urban system. Food flows are shown in green, drink flows in blue, and food waste in brown. With regard to food, no stock changes are considered in this study as the convention of material lifetime exceeding one year is supposed to be met only in rare cases in an urban system.

Figure. Food and drink flows related to in-home consumption, eating population, Paris Petite Couronne, 2014, kilotons



The Sankey diagrams of the urban system food metabolism follow the same scale for Paris Petite Couronne and Île-de-France, so that the difference in the size of material flows in the two systems can be compared. For the reader's comfort, the scale changes in diagrams where the size of flows varies widely, for example in diagrams on the households' food metabolism.

At consumption stage in Chapter 4, different options of data sources were used for the quantification resulting in high and low estimations. Figures should be read as follows (see example). Labels ending with "_L" show the flows with the lowest (_L) estimation. Labels ending with "_delta" show the remaining flow to add to obtain the flow with the highest value.

The values of the highest and the lowest estimation are shown by lines in the form of a "dumbbell". Optional flows are represented as flows in two different shades. Flows with the lowest value are shown in bold colors, while the remaining flow to add to obtain the flow with the highest value is represented in the same color but in a much lighter shade.

Flows of negligeable size were omitted in the food flow diagrams, but mentioned in a note below the figure.

Appendix to Chapter 3

Table A3.1 shows the complete Divisions 01 and 04 of the standard goods nomenclature for transport statistics. Both divisions include transport data for food. Whereas Division 01 refers to food in its form as unprocessed agricultural products, Division 04 refers to food after simple or more complex processing steps in food manufacturing. Other divisions in the nomenclature do not include food (e.g. Division 07, coke and refined petroleum products) or do not allow food to be identified (e.g. Division 14 assigned to secondary raw materials; municipal waste and other waste). The first column shows the categories retained for this study, identified by X.

Table A3.1. Extraction of food from the standard goods nomenclature for transport statistics (NST 2007)

Retained for this study	Code	Category name
	01	Products of agriculture, hunting. and forestry; fish and other fishing products
	01.1	Cereals
X	1.11	Wheat. spelt. triticale
X	1.12	Barley
X	1.13	Rye
X	1.14	Oat
X	1.15	Corn
X	1.16	Rice
X	1.17	Sorgho. millet and other cereals
	01.2	Potatoes
X	01.2	Potatoes
	01.3	Sugar beet
X	01.3	Sugar beet
	01.4	Other fresh fruit and vegetables
X	1.41	Sugar cane
X	1.42	Fresh or frozen citrus fruits
X	1.43	Fresh or frozen banana
X	1.44	Fresh or frozen apples
X	1.45	Fresh corn
x	1.46	Chilipepper and green pepper (only Capsicum)
x	1.47	Dried dates and figs
x	1.48	Sweet potatoe - Manioc – Other roots and tubers containing starch or inuline
x	1.49	Fruits and oil seeds (other than peanut). nuts. fresh almond
x	01.4A	Other fruit and nuts. fresh or frozen – other fresh or frozen vegetables
	01.5	Products of forestry and logging
	01.6	Live plants and flowers
	01.7	Other substances of vegetable origin
x	1.71	Material of vegetable origin – dried chili pepper and pepper (Capsicum spp.)
	1.72	Coton. harvested or bulk

	1.73	Flax. jute. hemp and raw textile plants
	1.74	Raw natural rubber
x	1.75	Coffee. cacao. tea. maté. unprocessed spices
	1.76	Raw tobacco
x	1.77	Hop
	1.78	Straw. hay. cereal bale – fodder plants
x	1.79	Seeds and oil fruits
	01.7A	Other substances of vegetable origine n.c.a.
	1.8	Live animals
	1.81	Live chicks
	1.82	Other live animals
	1.9	Raw milk from bovine cattle. sheep and goats
x	1.9	Raw milk from bovine cattle. sheep and goats
	01.A	Other raw materials of animal origin
	01.A1	Unwashed wool and sheep and goat hair
	01.A2	Silkworm cocons
	01.A3	Furs
x	01.A4	Natural honey
x	01.A5	Edible products of animal origin unlisted elsewhere
x	01.A6	Snail other than sea snail
x	01.A7	Poultry eggs. in eggshell. fresh
	01.A8	Vegetable wax. insect wax and spermaceti
	01.A9	Steer and buffalo sperm
	01.B	Fish and other fishing products
	01.B1	Corals and similar products. seashells – pearls – natural sponges – algae
x	01.B2	Fish. shellfish. seashells. fresh or frozen unprepared
x	01.B3	Living products from fishing and aquaculture
	01.B4	Marine mammals: cetacean and sirenians
	4	Food products, beverages and tobacco
	04.1	Meat. raw hides and skins and meat products
	4.11	Greasy wool from pulling including washed wool (excluding shorn wool)
	4.12	Raw hides
	4.13	Other inedible raw products of animal origin (excluding sea products)
x	4.14	Meat and edible offal. fresh. refrigerated or frozen
x	4.15	Lard. pig and poultry fat
x	4.16	Dried. salt-treated. smoked. processed or canned meat
	4.17	Meat meal and pellets. unfit for human consumption
	4.18	Beef. sheep or goat fat
	4.19	Feather and downs
	04.2	Fish and fish products. processed and preserved
x	4.21	Fish. shellfish. seashells. fresh or frozen – salted cod
x	4.22	Prepared and canned fish. shellfish. molluscs
	4.23	Fish and shellfish meal. unfit for human consumption

x	4.24	Smoked. dried. salted fish (except for salted cod) and edible meal
	4.25	Other inedible by-products made from fish. shellfish. molluscs
	4.3	Fruit and vegetables. processed and preserved
x	4.31	Products made from unprepared corn
x	4.32	Dehydrated potato. cut or uncut. without any other preparation
x	4.33	Other cans and preparations made from potato
x	4.34	Prepared chilipepper. canned or frozen
x	4.35	Food preparations made from corn. peanut. hearts of palm. yam and sweet potato
x	4.36	Dried vegetables and vegetable preparations – potato meal and flakes
	4.37	Industrial vegetable waste and by-products for animal feed
x	4.38	Products. preparations and cans made from fruit
x	4.39	Fresh or frozen vegetables and potato. or prepared for temporary conservation
	4.4	Animal and vegetable oils and fats
	4.41	Cotton linters
x	4.42	Margarine and similar edible fats
	4.43	Press cake. residues of oil extraction
x	4.44	Meal and powder of oil seeds or fruits. except for mustard
x	4.45	Oil. animal or vegetable fat (other than 0418 et 0415). wax. waste
x	4.46	Fat used for mould release
	4.47	Hydrogenated. esterified oil. but not processed otherwise (castor oil)
x	4.48	Margarine and food mixture including between 10 and 15% of fat
	4.5	Dairy products and ice cream
x	4.51	Milk and cream including more than 6% fat. not condensed. unsweetened
x	4.52	Butter. cheese. other dairy products
x	4.53	Ice cream even containing cocoa
x	4.54	Lactose and lactose syrup
x	4.55	Butter and spread made from milk – Yoghourt and fermented or acidified dairy products
x	4.56	Casein and casein derived – casein glues
	4.6	Grain mill products. starches. starch products and prepared animal feeds
x	4.61	Rice. husked – semi-milled or milled or broken rice
x	4.62	Flour. semolina. groats
x	4.63	Starch. gluten
x	4.64	Lard. unrendered pig and poultry fat – corn oil and his fractions
x	4.65	Glucose and syrup; inverted sugar; fructose and maltose other than pure
x	4.66	Breakfast cereal and other cereal based products
x	4.67	Plant meal – tapioca and starch-based substitutes, such as grain flakes
	4.68	Bran and other milling residues animal feed – lucerne meal
x	4.69	Pure fructose and maltose - dextrin and other modified starch
	4.7	Beverages
x	4.71	Wine

x	4.72	Beer
x	4.73	Rum – Mixtures and distilled fermented alcoholic beverages (cider. *poiré*. *hydromel*)
x	4.74	Mineral water and sparkling water, unsweetened, unflavoured
x	4.75	Other non-alcoholic beverages
x	4.76	Malt
x	4.77	Grape must
	4.78	Wine lees, tartaric acid – Brewery and distillation residues
	4.8	Other food products n.e.c. and tobacco products (except in parcel service or grouped)
x	4.81	Cane sugar, beet sugar, maple sugar – pure sucrose - molasses – sweets without cacao
x	4.82	Coffee, cacao, chocolate, tea, mate, spices, prepared, ground or pulverized chili pepper
	4.83	Cigars, cigarettes and other manufactured tobacco products - Tobacco waste
x	4.84	Eggs without eggshell and egg yolk, fresh, cooked and canned
x	4.85	Different food preparations (pasta, couscous, vinegar, extract, essences, etc.)
x	4.86	Raw or refined salt for human consumption
	4.87	Juices and plant extracts, peptides, mucilages and thickener
	4.88	Essential oils, ovalbumin, beetroot pulp, oleoresin of vanilla, cacao waste
x	4.89	Bakery and pastry products, pasta, malt extract
	4.9	Various food products and tobacco products in parcel service or grouped
	4.9	Various food products and tobacco products in parcel service or grouped

Table A3.2 Transversal nomenclature (to transport statistics, household purchase and food intake surveys)

Transversal nomenclature	Standard goods nomenclature for transport statistics (NST)		Household purchase panel nomenclature KANTAR Worldpanel		Household purchase panel nomenclature COICOP, INSEE		Food intake survey INCA3, Anses	
Food category	**Food category**	**Group code (three or four-digit level)**	**Food category**	**Group code**	**Food category**	**Group code (five-digit level)**	**Food category**	**Group code**
Bread and cereals	Cereals	01.1	Bread, rusk, pastry, patisserie, cake	1	Rice and rice-based products	01111	White bread and bakery products	1
	Rice. husked – semi-milled or milled or broken rice,	04.61	Semolina, cereal preparation, pasta-based meals	1	Bread and other bakery and pastry products including biscuits and cakes	01112	Wholemeal or partly wholemeal bread and bakery products	2
	Flour, semolina, groats	04.62	Rice, pasta, cereal flour, cereal grains	1	Pasta and pasta-based meals	01113	Breakfast cereals	3
	Starch, gluten	04.63			Other cereal and grain mill products including flour, semolina, breakfast cereal, couscous, taboulé	01115	White pasta, rice, wheat and other refined cereal grains	4
	Breakfast cereal and other grain mill products	04.66					Wholegrain or partly wholegrain pasta, rice, wheat and other whole cereal grains	5

	Bakery and pastry products, pasta, malt extract	04.89					Pastry, patisserie, cake and sweetened biscuits	6
Milk and dairy products, soy-based products	Raw milk from bovine cattle. sheep and goats	01.90	Condensed milk	8	Whole milk	01141	Milk	7
	Milk and cream including more than 6% fat. not condensed. unsweetened	04.51	Soy-based products (steak, yoghurt, milk)	8	Semi-skimmed and skimmed milk	01142	Yoghurt and curd	8
	Butter. cheese. other dairy products	04.52	Fresh products of very short shelf life (*ultra frais*) including fresh dessert	10	Condensed milk	01143	Cheese	9
	Butter and spread made from milk – Yoghourt and fermented or acidified dairy products	04.55	Cream	10	Yoghurt, curd and *petits suisse*, including soy-based products	01144	Dessert, cream	10
			Cheese	10	Cheese and curdled milk	01145	Soy-based and other non-animal milk products	42
			Milk (liquid)	10	Other dairy products (milk-based dessert, cream, flavored milk)	01146		
Oil and fat	Lard. pig and poultry fat	04.15	Animal fat other than butter	2	Butter	01151	Animal fats and oil (including cream)	12

	Margarine and similar edible fats	04.42	Edible oil, *Végétaline*	2	Margarine, diet margarine and other vegetables fats	01152	Vegetable fats and oil	13
	Oil, animal or vegetable fat (other than 04.18 et 04.15), wax, waste	04.45	Margarine, low-fat fat product	10	Olive oil	01153		
	Fat used for mould release	04.46	Butter	10	Groundnut, sunflower-seed, corn and rapeseed oil	01154		
	Margarine and food mixture including between 10 and 15% of fat	04.48			Pig fat and other animal fats	01155		
	Lard, unrendered pig and poultry fat – corn oil and his fractions	04.64						
Eggs	Poultry eggs, in eggshell, fresh	01.A7	Eggs	9	Eggs	01147	Eggs and egg-based meals	14
	Eggs without eggshell and egg yolk, fresh, cooked and canned	04.84						
Meat, poultry and processed meat products	Meat and edible offal, fresh, refrigerated or frozen	04.14	Meat-based ready-to-eat meal	8	Fresh or frozen meat from bovine animals	01121	Meat (excluding poultry)	15

	Dried, salt-treated, smoked, processed or canned meat	04.16	Fresh meat including fresh offal	11	Fresh or frozen meat from pigs	01122	Poultry	16
			Frozen meat and poultry	11	Fresh or frozen meat from sheep or goat	01123	Processed meat	17
			Fresh poultry and rabbit	11	Fresh or frozen poultry	01124	Offal	20
			Ham and other processed meat	11	Dried, salted and smoked meat, processed meat (*charcuterie*) and fresh or frozen offal (ham, sausages, pâté, offal, etc.)	01125	Meat-based meals	36
					Canned meat, meat processing product, meat-based ready-to-eat meat	01126		
					Other fresh or frozen edible meat (horse, rabbit or game) including live animals	01127		
Fish and fish products	Fish, shellfish, seashells, fresh or frozen unprepared	01.B2	Fish-based ready-to-eat meal	8	Fresh fish	01130	Fish	18
	Living products from fishing and aquaculture	01.B3	Fish and fish products	12	Frozen fish (excluding breaded or prepared fish)	01131	Shellfish and molluscs	19
	Snail other than sea snail	01.A6			Fresh or frozen seafood (including	01132	Fish-based meals	37

					cooked, but not prepared)			
	Fish, shellfish, seashells, fresh or frozen – salted cod	04.21			Salted, smoked, dried including frozen fish and seafood	01133		
	Prepared and canned fish, shellfish, molluscs	04.22			Canned fish and seafood and fish and sea-food based meals	01134		
	Smoked, dried, salted fish (except for salted cod) and edible meal	04.24						
Fruit, vegetables and potatoes	Potatoes	01.20	Fresh, pre-cooked or frozen potatoes, potato flakes, chips, potato-based ready-to-eat meal	7	Fresh citrus fruits	01161	Vegetables	21
	Fresh or frozen citrus fruits	01.42	Fresh vegetables	13	Fresh bananas	01162	Vegetable-based meals	38
	Fresh or frozen banana	01.43	Processed vegetables	13	Apples	01163	Pulses	22
	Fresh or frozen apples	01.44	Fresh fruits	13	Pears	01164	Potatoes and other tubers	23
	Fresh corn	01.45			Stone fruits (peaches, cherries, plums, avocado, etc.)	01165	Fresh and dried fruits	24

	Chilipepper and green pepper (only Capsicum)	01.46			Fresh berries (grapes, strawberries, currants, etc.)	01166		
	Dried dates and figs	01.47			Other fruits, fresh tropical fruits	01167		
	Sweet potato - Manioc – Other roots and tubers containing starch or inuline	01.48			Dried fruits	01168		
	Products made from unprepared corn	04.31			Fresh leafy and stem vegetables (chicory, lettuce, celery, spinach, etc.), fresh herbs	01171		
	Dehydrated potato. cut or uncut. without any other preparation	04.32			Fresh cabbage	01172		
	Other cans and preparations made from potato	04.33			Fresh fruit-bearing vegetables (tomato, green beans, soya beans, peas, zucchini etc.)	01173		
	Prepared chili pepper, canned or frozen	04.34			Fresh root vegetables (carrots, artichoke, leek, onions, etc.) and fresh mushrooms	01174		
	Food preparations made from corn, peanut, hearts of	04.35			Pulses	01175		

	palm, yam and sweet potato							
	Dried vegetables and vegetable preparations – potato meal and flakes	04.36			Frozen unprepared vegetables	01176		
	Fresh or frozen vegetables and potato or prepared for temporary conservation	04.39			Canned vegetables or vegetable-based meals (without potato)	01177		
	Other fruit and nuts, fresh or frozen – other fresh or frozen vegetables	01.4A			Fresh and frozen prepared vegetables or vegetable-based meals (without potato)	01178		
					Potato, other tubers, potato- or tuber-based products (chips)	01179		
Sugar-based products and dessert	Sugar beet	01.30	Fruit compote, fruit in syrup	3	Fruits in syrup and frozen fruits	01169	Compotes and fruits in syrup	25
	Sugar cane	01.41	Dried fruit and seeds	3			Nuts, oil seeds and fruits	26
	Fruits and oil seeds (other than peanut). nuts. fresh almond	01.49	Chocolate, sweets, dessert preparation, other sweet products	3	Sugar including sweetener	01181	Confectionary and chocolate	27
	Seeds and oil fruits	01.79	Sugar, sweetener, jam,	3	Jam, marmalade, compote, jelly, purée	01182	Sugar and sugaring products	28

			fruit paste and candied fruit, honey		and fruit paste, honey			
	Other fruit and nuts. fresh or frozen – other fresh or frozen vegetables	01.A4			Chocolate and chocolate-based confectionary	01183		
	Products. preparations and cans made from fruit	04.38			Sweets, candy and other confectionary	01184		
	Meal and powder of oil seeds or fruits. except for mustard	04.44			Other sugar-based products (spread, candied fruits, etc.)	01186		
	Cane sugar, beet sugar, maple sugar – pure sucrose - molasses – sweets without cacao	04.81						
Drink	Coffee. cacao. tea. maté. unprocessed spices	01.75	Coffee, coffee substitute, tea, cacao, brewed drink and herbal tea	4	Coffee	01211	Bottled water	29
	Wine	04.71	Bottled water	5	Tea and plant products for infusion	01212	Tap water	30
	Beer	04.72	Sparkling and non-sparkling soft drinks	5	cocoa and chocolate-based drinks	01213	Non-alcoholic soft drinks	31

	Rum – Mixtures and distilled fermented alcoholic beverages (cider. *poiré*. *hydromel*)	04.73	Fruit juice, vegetable juice, syrup	5	Mineral water	01221	Fruits and vegetable juices	32
	Mineral water and sparkling water, unsweetened, unflavoured	04.74	Alcoholic drinks	6	Soft drinks	01222	Alcoholic drinks	33
	Other non-alcoholic beverages	04.75			Fruit and vegetable juice, syrup, flavored drinks	01223	Hot drinks	34
	Malt	04.76			Vegetable juice	01224		
	Grape must	04.77			Spirits and liquors	02111		
	Coffee, cacao, chocolate, tea, mate, spices, prepared, ground or pulverized chili pepper	04.82			Wine and cider	02121		
					Wine-based aperitifs, Champagne and other sparkling wines and other	02122		
					Beer and beer-based drinks	02131		
Other products	Material of vegetable origin – dried chili pepper	01.71	Pizza, quiche and savory custard pie, packed	1	Preparations such as ready-to-use dough, cake, tart, custard pie, quiche, pizza	01114	Ice, ice cream, sorbets	11

	and pepper (Capsicum spp.)		sandwich, ready-to-use pie crust					
	Hop	01.77	Ice, ice cream, sorbets	3	Ice cream, sorbet, iced dessert	01185	Soup and stock	35
	Edible products of animal origin unlisted elsewhere	01.A5	Soup and stock (dry-frozen, ready-to-eat, etc.)	8	Sauces, seasoning and cooking aids	01191	Meals based on potato, cereals or pulses	39
	Ice cream even containing cocoa	04.53	Jarred baby food	8	Salt, pepper and dried spices	01192	Sandwich, pizza, tarts, patisserie and savory biscuits	40
	Lactose and lactose syrup	04.54	Meal replacement	8	Yeast, dessert preparations, soup	01193	Seasoning, herbs, spices and sauces	41
	Casein and casein derived – casein glues	04.56	Powdered milk (including instant formula)	8	Other food products (baby food, diet products)	01194	Baby food meals and desserts	43
	Glucose and syrup; inverted sugar; fructose and maltose other than pure	04.65	Salty appetizer products	8			Infant formula and drinks	44
	Plant meal – tapioca and starch-based substitutes, as flakes grain	04.67						
	Pure fructose and maltose - dextrin and other modified starch	04.69						
	Different food preparations	04.85						

	(pasta, couscous, vinegar, extract, essences.…)							
	Raw or refined salt for human consumption	04.86						

Table A3.3. Legal and eating population, Paris Petite Couronne and Île-de-France, 2014

	Paris Petite Couronne			Ile de France		
	legal population (number of inhabitants)	Eating pop. (number of PEEQs[1]) and share of eating population (in %)	Ratio eating to legal populat-ion (in %)	legal population (number of inhabitants)	Eating pop. (number of PEEQs[1]) and share of eating population (in %)	Ratio eating to legal populat-ion (in %)
Resident population	*6,754,282*	*5,977,821 (91)*	*88*	*12,027,565*	*10,845,342 (96)*	*90*
living in a household	6,624,460	5,852,937 (89)	88	11,792,157	10,618,728 (94)	90
0-9 y	860,003	767,170	89	1,623,950	1,448,652	89
10-19 y	762,161	679,889	89	1,477,089	1,317,644	89
20 y and older	5,002,296	4,462,322	89	8,805,973	7,855,410	89
Commuters from PPC to GC [2]	191,293	52,672	28			
Commuters to outside of Ile de France[2]	98,350	3,772	4	77,646	2,978	4
living outside of a household	129,822	124,884 (2)	96	235,408	226,614 (2)	96
In retirement homes	36,925	36,925	100	65,753	65,753	100
In prisons	1,393	1,393	100	12,660	12,660	100
In student halls of residence	42,286	37,768	89	75,300	67,254	89
In young workers' hostels	3,931	3,511	89	7,000	6,252	89
Homeless adults	16,173	16,173	100	28,800	28,800	100
Homeless children	3,510	3,510	100	6,250	6,250	100
Remainder	25,605	25,605	100	39,645	39,645	100

additional population		*572,787 (9)*			*493,392 (4)*	
Tourists[1]						
-18 y +	121,860,000	333,863		153,720,000	421,151	
-0-17 y	13,540,000	37,096		17,080,000	46,795	
Commuters from *Grande Couronne*	643,082	177,068	28			
Commuters from outside of *Ile de France*	408,173	15,656	4	364,007	13,962	4
Excursionists[1]	6,645,743	9,104	*<1*	8,383,256	11,484	*<1*
total population		***6,550,608 (100)***			***11,338,734 (101)***	

[1] For tourists and excursionists, numbers are provided in number of overnight stays and in trips respectively, and not in terms of population.
[2] Commuters leaving the urban system are part of the resident household population and are subtracted from it.
source: INSEE, occupational mobility, 2014, except for the number of commuters to and from PPC, which is from 2015; author's calculations (see text in chapter 3)

Table A3.4. Food intake of the eating population, Paris Petite Couronne and Île-de-France, 2014, t/y

	Paris Petite Couronne		**Ile de France**	
	food intake (t/y)	share of total food intake (in %)	food intake (t/y)	share of total food intake (in %)
resident population	*6,133,502*	*91*	*11,074,355*	*96*
living in a household	6,001,683	89	10,835,113	94
0-9 y	473,509		894,130	
10-19 y	567,045		1,098,948	
20 y and older	5,024,686		8,845,389	
Commuters from PPC to GC [2]	59,309			
Commuters to outside of Ile de France [2]	4,248		3,354	
living outside of a household	133,819	2	239,242	2
In retirement homes	393,354		70,080	
In prisons	1,484		13,493	
In student halls of residence	40,253		71,680	

In young workers' hostels	3,742		6,663	
Homeless adults	17,237		30,695	
Homeless children	2,458		4,378	
Remainder	27,290		42,254	
additional population	*596,922*	*9*	*508,759*	*4*
Tourists 18 y and older [1]	355,831		448,862	
Tourists 0-17 y [1]	25,983		32,777	
Commuters from *Grande Couronne*	188,719			
Commuters from outside of *Ile de France*	16,686		14,881	
Excursionists [1]	9,703		12,240	
eating population	*6,730,424*	*100*	*11,583,114*	*100*

Source: author's calculations (see text in chapter 3)

Table A3.5. Food material balance, Paris Petite Couronne, 2014

	Total food and drink	Food	Tap water to drink	Drink excl tap water
	Quantities (tonnes)			
INPUT FLOWS				
Food and drink imports	9,056,662	7,384,912		1,671,750
Agricultural production - crops. dairy and eggs	29,055	29,055		
Tap water to drink	2,111,110		2,111,110	
Total input flows	**11,196,827**	**7,413,967**	**2,111,110**	**1,671,750**
OUTPUT FLOWS				
Food and drink intake incl tap water	6,730,424	2,677,256	2,111,969	1,927,676
Food and drink exports	4,089,254	3,689,035		400,219
Food waste	718,322	641,306		104,016
- food loss in agriculture	1,030	1,030		
- food waste in mixed household waste (OMr)	401,677	401,677*		
- food waste in mixed business waste	152,750	152,750		
- food waste to the sewer	104,016			104,016
- separately collected bio-waste	36,007	36,007		
- used frying oil	22,842	22,842		
Total output flows	**11,538,001**	**6,980,597**	**2,111,110**	**2,431,911**
INPUT-OUTPUT	**-341,174**	**433,370**	**0**	**-760,161**

Source: author's calculations (see text in chapter 3)

Table A3.6. Food material balance, Ile de France, 2014, tonnes

	Total food and drink	Food	Tap water to drink	Drink excl tap water
	Quantities (tonnes)			
INPUT FLOWS				
Food and drink imports	23,412,278	20,088,444		3,323,833
Agricultural production	7,928,954	7,928,954		
- edible parts from meat livestock	8,133			
- inedible parts from meat livestock	5,335			
- crops. dairy and eggs	7,915,485			
Tap water to drink	3,609,254		3,609,254	
Cereals used as animal feed in the urban system	-16,998	-16,998		
Total input flows	**34,933,487**	**28,000,400**	**3,609,254**	**3,323,833**
OUTPUT FLOWS				
Food and drink intake incl tap water	11,583,114	4,628,165	3,609,254	3,331,099
Food and drink exports	11,333,374	10,178,883		1,154,491
Food waste	1,457,336	1,272,111		185,225
- food loss in agriculture	161,428	161,428		
- food waste in mixed household waste (OMr)	792,087	792,087		
- food waste in mixed business waste	235,000	235,000		
- food waste to the sewer	185,225			185,225
- separately collected bio-waste	55,396	55,396		
- used frying oil	28,200	28,200		
Cereals used as animal feed in the urban system	-16,998	-16,998		
Total output flows	**24,356,826**	**16,079,158**	**3,609,254**	**4,670,815**
INPUT-OUTPUT	**10,576,661**	**11,921,242**		**-1,346,982**

Source: author's calculations (see text in Chapter 3)

Table A3.7. Food and drink per category, in agriculture, import incl tap water to drink, intake of the eating population and export, Paris Petite Couronne, 2014, tonnes

	Agriculture	Import incl tap water to drink	Intake eating population	Exports		Product category imbalance
bread and cereals	9,167	867,375	588,703	345,766		-57,928
Fruits, vegetables, potatoes	6,714	3,748,167	797,701	1,790,662		1,166,519
Milk and dairy	0	294,992	523,142	454,462		-682,612
Fish, seafood, eggs, meat	0	699,971	372,883	248,477		78,611
fat and oil	868	148,221	31,936	41,984		75,169
Sugar, sweets, ice cream	12,305	418,091	114,405	254,077		61,914
drink excl milk	0	1,671,710	3,802,689	396,166		-416,035
Other food	0	1,208,135	512,167	557,660		138,307
TOTAL	29,054	9,056,662	6,743,627[1]	4,089,254		302,031[2]

[1] When food and drink categories are summed up the total intake is slightly different (6,743,627 tonnes) than when calculated as a total (6,730,424 tonnes).

[2] The total material imbalance (- 341,174 t) considers food waste (718,322 t) which is not associated to food categories and partly explains the difference with the total imbalance added up from product categories (302,031 t). Another 75,117 t contributing to the difference cannot be explained.

Table A3.8. Food and drink per category, in agriculture, import, intake of the eating population and export, Ile de France, 2014, tonnes

	Agriculture	Import incl. tap water to drink	Intake of eating population	Exports		Product category imbalance
Bread and cereals	3,202,131	5,299,640	1,019,432	2,801,859		4,463,737
Fruits, vegetables, potatoes	402,742	5,742,413	1,373,192	3,396,482		1,375,837
Milk and dairy	48,694	812,314	912,032	447,144		-497,948
Fish, seafood, eggs, meat	25,541	1,010,121	641,306	279,082		115,454
Fat and oil	333,366	239,485	54,482	60,825		457,563
Sugar, sweets, ice cream	3,916,480	4,620,214	198,212	1,644,252		6,694,286

drink excl milk	--	3,276,046	6,521,181	1,134,662		-769,774
Other food	--	2,412,046	883,170	1,569,069		-39,932
TOTAL	**7,928,954**	**23,412,278**	**11,603,007**[1]	**11,333,374**		**11,999,222**[2]

[1] When food and drink categories are summed up the total intake is slightly different (11,603,007 tonnes) than when calculated as a total (11,583,114 tonnes).
[2] The total material imbalance (10,576,661 t) considers food waste (1,457,336 t) which is not associated to food categories and explains the difference, up to 2,087 t, with the total imbalance added up from product categories (11,999,222 t).

Table A3.9. Simulation of biomass flows, Paris Petite Couronne, Ile de France, 2014, tonnes and t/cap/y

	Paris Petite Couronne			Ile de France		
	total quantity	quantity normalized using		total quantity	quantity normalized using	
		legal pop [1]	eating pop [2]		legal pop[3]	eating pop [4]
	tonnes	t/cap/y	t/cap/y	tonnes	t/cap/y	t/cap/y
Input flows	11,763,394	1.7	1.8	36,931,026	3.1	3.3
Import	9,623,229	1.4	1.4	24,969,197	2.1	2.2
Agricultural production	29,055	0.0	0.0	8,352,575	0.7	0.7
Tap water to drink	2,111,110	0.3	0.3	3,609,254	0.3	0.3
Output flows	11,898,093	1.8	1.8	25,138,073	2.1	2.2
Food intake	6,730,424	1.0	1.0	11,583,114	1.0	1.0
Export	4,449,347	0.7	0.7	12,097,623	1.0	1.1
Food waste	718,322	0.1	0.1	1,457,336	0.1	0.1
Input – output	-134,700	0.0	0.0	11,792,953	1.0	1.0

[1] 6,754,282 inhabitants
[2] 6,695,992 PEEQs
[3] 12,027,565 inhabitants
[4] 11,361,202 PEEQs

Appendix to Chapter 4

A4. Household purchase quantities for food and drink from the INSEE Household budget survey

A4.1 Introduction

This document presents step-by-step how the raw data of the Household Budget Survey were analysed for the mass quantities of food and drink purchased by Île-de-France households. The relevant file for this study, named CARNETS, the French word for diaries, contains information about all purchases reported by household members in a diary over the course of one week. Using the software RStudio Version 1.1.463, the mean purchase quantity of food and drink per household for one week was computed from the data of the Île-de-France household sample.

Initially structured according to the Classification of Individual Consumption by Purpose (COICOP), the sixty-one food and drink product categories were restructured to follow the transversal nomenclature developed in this study for the food flow analysis across several sectors and their specific data sources and nomenclatures (see Appendix to Chapter 3). A second data set named MENAGES containing socio-demographic information at the household level allowed us to check the representativeness of the household sample in terms of socio-economic profile.

For the purposes of this study, a secondary data set based on CARNETS, named francbis, was extracted by filtering purchases of food and drink items exclusively by households of the urban unit of Paris, used as a proxy for Île-de-France. All further steps of data analysis were performed using francbis.

A4.2 Characterizing data frame CARNETS, preparing data frame francbis

Uploading the data frame CARNETS.dta

```
library(foreign)
CARNETS<-read.dta("CARNETS.dta")
library(plyr)
library(dplyr)

##
## Attachement du package : 'dplyr'

## Les objets suivants sont masqués depuis 'package:plyr':
##
##     arrange, count, desc, failwith, id, mutate, rename, summarise,
##     summarize

## Les objets suivants sont masqués depuis 'package:stats':
##
##     filter, lag
```

```
## Les objets suivants sont masqués depuis 'package:base':
##
##     intersect, setdiff, setequal, union
```

```
str(CARNETS)
```

```
## 'data.frame':    712652 obs. of  10 variables:
##  $ ident_men: chr  "00001" "00001" "00001" "00001" ...
##  $ noi      : chr  "01" "01" "01" "01" ...
##  $ numligne : chr  "001" "002" "003" "004" ...
##  $ montant  : num  1 0.99 5.4 1 2.5 2.5 2 2 0.88 0.6 ...
##  $ code_mag : chr  "1112" "1112" "2352" "2352" ...
##  $ unite    : chr  "L" "" "" ""  ...
##  $ quantite : num  0.33 NA 1 1 2 2 1 1 0.35 0.2 ...
##  $ dist     : num  0 0 0 0 0 0 0 0 0 0 ...
##  $ tuu      : num  7 7 7 7 7 7 7 7 7 7 ...
##  $ nomen5   : chr  "01221" "01183" "02211" "02213" ...
##  - attr(*, "datalabel")= chr ""
##  - attr(*, "time.stamp")= chr ""
##  - attr(*, "formats")= chr [1:10] "%6s" "%2s" "%4s" "%12.0g" ...
##  - attr(*, "types")= int [1:10] 6 2 4 255 4 10 255 255 255 6
##  - attr(*, "val.labels")= chr [1:10] "" "" "" "" ...
##  - attr(*, "var.labels")= chr [1:10] "Identifiant de diffusion du ménag
e" "Numéro d'ordre de l'individu dans le ménage" "Numéro d'ordre de la lig
ne dans le carnet" "Montant de la dépense" ...
##  - attr(*, "version")= int -7
```

CARNETS is built on the ten variables[252] household identification number (IDENT_MEN), number of a person (NOI), distance between the municipalities of the store and the household residence (DIST), store code (CODE_MAG), product code (NOMEN5), purchase unit (UNITE), purchase quantity (QUANTITE), purchase expense (MONTANT), line number (NUMLIGNE) and size of urban unit (TUU). CARNETS is 712,652 lines long, with each line referring to one purchased item characterized by the values of the ten variables. The dataset contains purchase data from 15,469 households. The relevant information concerning the purchase quantity of an item is available in the three variables product code (NOMEN5), purchase unit (UNITE), and purchase quantity (QUANTITE). The variable purchase expense (MONTANT), expressed in euros, was additionally used to fill data gaps. The purchase unit is optional mass, volume or unit.

Building data frame franc filtered on Île-de-France households

The filter was set on the variable TUU (*taille de l'unité urbaine*) code 8 that stands for the urban unit of Paris (agglomeration de Paris). With a population of 10.7 million inhabitants, according to INSEE, in 2016, the urban unit of Paris is close to the Île-de-France region (12.1 million inhabitants the same year).

```
franc<-CARNETS %>% filter(tuu==8)
```

Franc is 73,837 observations long. 1,732 households from the urban unit of Paris have filled in the purchase diaries coded in CARNETS.

[252] Variable names are written in capital lettres.

Building data frame francbis filtered on food and drink purchases

To obtain francbis, a filter is set on NOMEN5 for food (01111 to 01224) and drink (02111 to 02131). Before, variable NOMEN5 must be converted into a numeric variable.

```
franc<-franc %>% mutate(nomen5=as.numeric(nomen5))
francbis <-franc %>% filter(nomen5 %in% c(01111:01224,02111:02131))
length(unique(francbis$ident_men))

## [1] 1549
```

Francbis is 55,387 observations long, that is, 7.8 % of the observations in CARNETS. 1,549 households, that is 10 % of the household sample in CARNETS, have reported food and drink purchases.

Identifying missing values in variables used for analysing mean purchase quantities Variable UNITE:

```
summary(francbis$unite)

##    Length     Class      Mode
##     55387 character character
```

UNITE is a character variable and must be changed to factor. Once converted to factor, summary () provides the number of observations per level (KG, L or U).

```
francbis<-francbis %>% mutate(unite=as.factor(unite))
summary(francbis$unite)

##          KG     L     U
## 19800 19541  5270 10776
```

19,800 observations have empty fields (missing values) in UNITE, which means that no purchase unit was reported. To continue the analysis, we replace empty fields by NA using mutate/replace ().

```
francbis<-francbis %>% mutate (unite=as.factor(unite)) %>% mutate(unite =
replace(unite, unite == '', NA))
```

Variable QUANTITE:

```
summary(francbis$quantite,na.rm=TRUE)

##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's
##   0.011   0.450   1.000   1.629   1.000 650.000   11601

sum(is.na(francbis$quantite))

## [1] 11601
```

11,601 observations out of 55,387 are coded no answer (NA).

Variable MONTANT:

```
summary(francbis$montant,na.rm=TRUE)
```

```
##     Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## -45.060   1.020   1.800   2.581   2.930 239.000
```

The dataset contained no missing values, but negative values in purchase expenses MONTANT

```
range(francbis$montant)

## [1] -45.06 239.00

francbis%>%count(montant<0)

##   montant < 0     n
## 1       FALSE 50801
## 2        TRUE  4586
```

4,586 of a total of 55,387 observations had a negative value, that is, 8 % of the dataset francbis.

```
nbobserv_3<-subset(francbis,montant<0)%>% count(nomen5) #montant negatif p
ar nomen5
nbobserv_3<-subset(francbis,montant<0)%>%group_by(nomen5,quantite)
```

Negative values were found in any product NOMEN5. Negative purchase amounts are price reductions, vouchers, etc. related to the purchase expense but do not impact the purchase quantity. These observations can be removed without losing information about purchase quantities.

Multiple units (mass, volume, unit) per purchased food product Respondents reported the purchase of a given product in one of the three different units – mass, volume or unit –, or left the field empty.

```
nbobserv_2<-francbis %>% group_by(nomen5,unite) %>% filter(montant>0) %>%
summarise(nb=n()) %>% arrange(nomen5)

## `summarise()` has grouped output by 'nomen5'. You can override using th
e `.groups` argument.
```

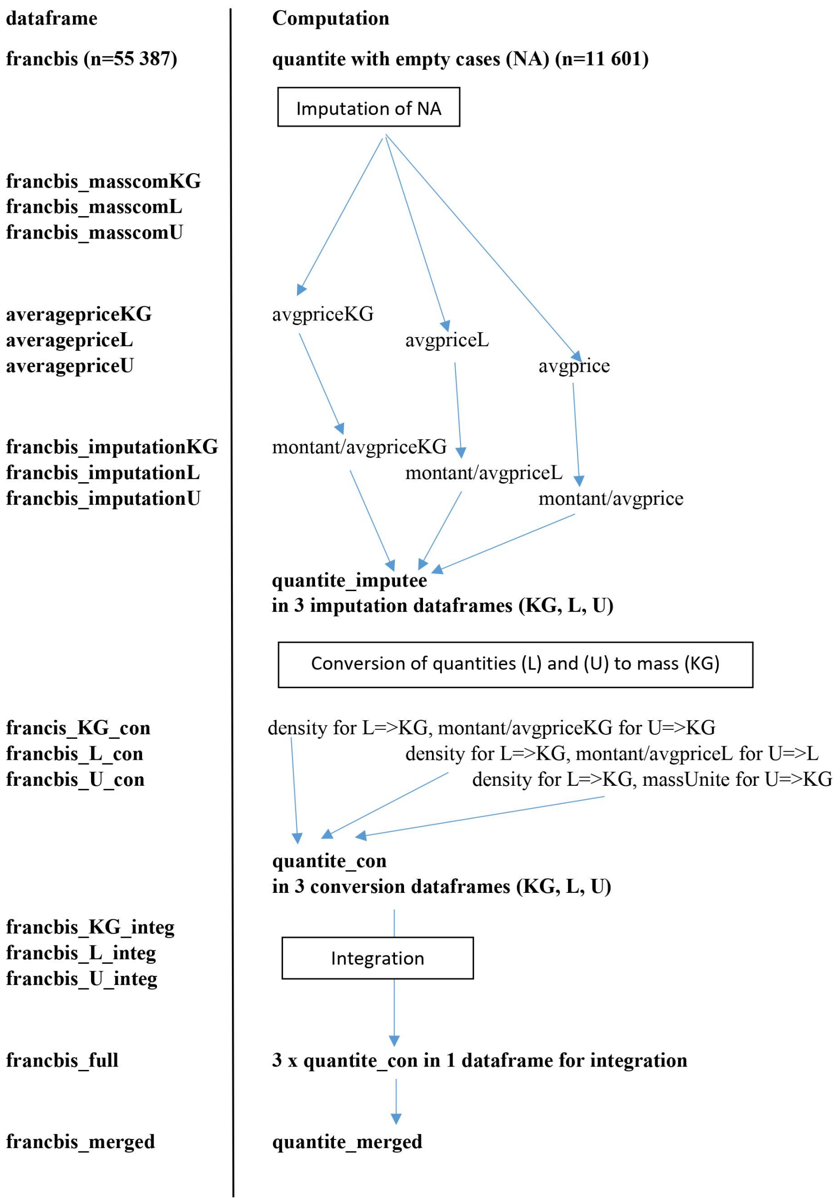
Table A4.2 shows the number of observations per purchased product nomen5 and unit. For most of the sixty-one product categories, the observations covered at least two units and no answer given. Purchases reported in volume or unit need to be converted to mass, in order to sum up the purchase quantities.

Errors Errors may have occurred at data collection stage, and are hard to identify, when quantity or unit were reported. Frequent errors are for example reporting of number of egg boxes and yogurt packs instead of number of eggs and yogurts as requested. Errors may have occurred in unit choice (litres of bread etc.). Most of these errors were left undiscovered and unchanged. In the cases of eggs and yogurt, the error seemed obvious since these items are usually not sold per unit. Purchases of eggs and yogurt reported as one unit were removed from further data analysis (see next step). This concerned 14 out of 322 and 235 out of 459 purchases reported in UNITE.

A4.3 Main principles of data analysis

Solutions were required to cope with the problem of missing values in QUANTITE and UNITE and of multiple units per purchased food product to be converted to mass (see flowchart Figure A4.1):

Figure A4.1. Flowchart of computation steps



- **Imputing missing values NA**: To fill in empty fields ("impute") with purchase quantity, I divided purchase expenses (MONTANT) through average prices per KG, per L and per U calculated from purchases predominantly reported in mass (KG), in volume (L) and in units (U) respectively. This implies that purchases were distributed into three imputation data frames and that a new variable, QUANTITE_IMPUTEE, was built in each of the three data frames for imputation.
- **Converting quantities reported as volume and unit into quantities in mass**: The values were converted in the three data frames separately.
- L => KG: use of densities as conversion factors.
- U => KG: different ways of proceeding in the three data frames.
- Data frame francbis_KG_con: use of montant/avgpriceKG to calculate quantity (KG) disregarding the initial quantity (U)
- Data frame francbis_L_con: use of montant/avgpriceL to calculate quantity (L) and convert as described above
- Data frame francbis_U_con: conversion of unit to mass assuming, in the two relevant cases of eggs and yogurt, a conversion factor of standardized unit (average mass of egg and yogurt).

A new variable QUANTITE_CON was built in each of the three data frames used for conversion.

- **Integrating the three data frames into one single data frame**: The three data frames were merged to obtain a single variable of purchase quantities reported in kg, QUANTITE_MERGED.

QUANTITE_MERGED allowed me to compute the total quantity of food and drink, per product, purchased by households of the Paris urban unit over one week.

A4.4 Coding

A4.4.1 Preparing data frames for computing average prices per KG, L and U

First, the products NOMEN5 must be assigned to the data frames francbis_masscomKG, francbis_masscomL and francbis_masscomU. The distribution of units and their share of total purchases are used to justify attribution of products nomen5 to the data frames francbis_masscomKG, francbis_masscomL et francbis_masscomU...L. A proportion below 5% of unit used was considered an error and observations computed as having no unit.

```
for (i in (1:nrow(nbobserv_2)))
{nbobserv_2$prop[i]<-nbobserv_2$nb[i]/sum(nbobserv_2$nb[nbobserv_2$nomen5=
=nbobserv_2$nomen5[i]])}

## Warning: Unknown or uninitialised column: `prop`.

nbobserv_2<-subset(nbobserv_2,prop>0.05)
```

Data frame for computing average price per KG To compute average price per mass unit per food product, observations (purchases) were eligible if 2 conditions were fulfilled: i) reported in mass (kg) (n=19541), and ii) quantity reported per food product (no NA). For coding, francbis was filtered for observations having kg as the unit and fields in quantity that are filled in (no NA). A new data frame francbis_masscomKG (for mass complete) was built for purchases predominantly reported in mass unit KG.

For francbis_masscomKG, the following code was built on the following arguments: Based on the data frame francbis; only observations in mass unit (KG); product categories which are predominantly (nb of observations) reported in volume (L) or unit (U) were removed (see Table A42). Product categories reported in KG and with no unit reported (NA) were kept. However, there were exceptions: 01185 ice cream (predominantly NA) was grouped with francbis_masscomL; 01144 yogurt (predominantly NA) was grouped with francbis_masscomU; 01167 other fruit, fresh tropical fruit (predominantly U) was grouped with francbis_masscomKG; 01171 greens, salad, fresh herbs (predominantly U) were grouped with francbis_masscomKG. Observations with QUANTITE equal NA were removed. Only observations where expenses MONTANT have positive values were kept.

```
francbis_masscomKG<- francbis %>% filter (unite=="KG") %>% filter(!nomen5
%in% c(01141,01142,01153,01154,01185,01193,01221:01224,02111:02131,01147,0
1144)) %>% filter(!is.na(quantite)) %>% filter(montant>0)
```

Data frames for computing average price per L and average price per U

The same procedure was applied for data frames francbis_masscomL and francbis_masscomU.

```
francbis_masscomL<- francbis %>% filter (unite=="L")  %>%
  filter(nomen5 %in% c(01141,01142,01153,01154,01185,01193,01221:01224,021
11:02131)) %>%
  filter(!is.na(quantite)) %>% filter(montant>0)%>%arrange(nomen5)

francbis_masscomU<- francbis %>% filter (unite=="U")  %>%
  filter(nomen5 %in% c(01144,01147)) %>%
  filter(!is.na(quantite)) %>% filter(quantite>1) %>% filter(montant>0)%>%
arrange(nomen5)
```

Francbis_masscomU contained two food items which usually are purchased in a pack of 6 (eggs) or 4, 12 or 16 (yogurts). It seems that some respondents reported the number of packs instead of the number of eggs and yogurts respectively, as requested. Purchase of one single egg or yogurt is certainly possible but very rare. For yogurt, 459 purchases were reported in U, and 235 of them had quantity reported of 1.

```
yogurt<-francbis%>%filter(unite=="U")%>%filter(nomen5%in%c(01144))%>%filte
r(quantite==1)%>%count(quantite==1)
View(yogurt)
```

For eggs, 322 purchases were reported in U, and 14 of them had a reported quantity of 1.

```
eggs<-francbis%>%filter(unite=="U")%>%filter(nomen5%in%c(01147))%>%filter(
quantite==1)%>%count(quantite==1)
View(eggs)
```

For both eggs and yogurt, I decided to remove purchases having a reported quantity of 1. Whereas the removal of 14 out of 322 purchases of eggs has little impact, the number of purchases of yogurt concerned is quite high, with 235 out of 459 having a reported purchase of yogurt in unit. This loss of data was compensated for later when the annual food and drink purchases of Île-de-France households were extrapolated (see Chapter 4.2.2).

A4.4.2 Computing average prices

Following the preparation of data frames, average price per KG, L and U was computed for purchases predominantly reported in the three units KG, L and U, respectively, based on results in Table A4.2. For example, average price of olive oil was computed per litre, but not per unit of olive oil, although some respondents may report quantities in U (e.g. bottles). Whether it is an error or not, those respondents are fewer compared to those having reported the purchase in L. To test consistencies between average prices of other units, I calculated average price per KG for all products (see Tables A4.3, A4.4 and A4.5).

Average price per mass unit (KG) - for KG selected products

```
averagepriceKG<-francbis_masscomKG %>%
  group_by(nomen5) %>%
  summarise(summontant=sum(montant),
            sumquantite=sum(quantite),
            unite="KG",
            avgpriceKG=summontant/sumquantite)
```

Average price per volume (L) - for L selected products

```
averagepriceL<-francbis_masscomL %>%
  group_by(nomen5) %>%
  summarise(summontant=sum(montant),
            sumquantite=sum(quantite),
            unite="L",
            avgpriceL=summontant/sumquantite)
```

Average price per unit (U) - for U selected products

```
averagepriceU<-francbis_masscomU %>%
  group_by(nomen5) %>%
  summarise(summontant=sum(montant),
            sumquantite=sum(quantite),
            unite="U",
            avgpriceU=summontant/sumquantite)
```

A4.4.3 Imputing missing quantities (NA)

Imputing missing quantities in KG by averagepriceKG

Data frame francbis_KG_imputation was built for imputing missing quantities. The data frame was based on francbis and contained purchases in all units (KG, L, U, NA), NA or >0 in purchase quantity (therefore different from francbis_masscomKG), and food categories having kg as dominant unit (Table A4.2) and selected for the calculation of averagepriceKG.

```
francbis_KG_imputation<- francbis %>% select(nomen5,unite,quantite,montant
) %>%   filter(!nomen5 %in% c(01141,01142,01153,01154,01185,01193,01221:01
224,02111:02131,01147,01144))  %>%   filter(montant>0)
```

Variable averagepriceKG was converted into a data frame and avgpriceKG selected as a column together with product NOMEN5.

```
averagepriceKG<-as.data.frame(averagepriceKG)
averagepriceKG <-averagepriceKG %>% select(nomen5,avgpriceKG)
```

Both variables are needed to integrate averagepriceKG in the imputation data frame francbis_KG_imputation. After inclusion of both variables, both data frames were merged through Left_join(). This means that the left data frame is kept unmatched, and is filled in by new columns at the right side. I calculated average price per KG for all products.

```
francbis_KG_imputation <-francbis_KG_imputation %>% left_join(averageprice
KG,by="nomen5") %>% mutate(unite=as.factor(unite))
```

For imputation, according to the following rules: If UNITE=KG and QUANTITE>0, keep quantity. If UNITE=KG and QUANTITE=NA, we impute quantity by montant/averagepriceKG. If UNITE=NA, we impute quantity by montant/averagepriceKG (quantity without unit does not provide sufficient information). If UNITE=L or U and QUANTITE>0, we keep initial quantity and convert later L => KG and U=>KG

For coding:

If UNITE = NA OR if QUANTITE=NA, then the variable QUANTITE_IMPUTEE will be computed (quantite_imputee = montant/avgpriceKG). If not, the quantity initially reported will be used (Nested Ifelse statement in R). That means, if quantities are reported in U or in L, the initial quantity remains unchanged.

```
francbis_KG_imputation<-francbis_KG_imputation %>%   mutate(quantite_imput
ee= ifelse(is.na(unite), montant/avgpriceKG,ifelse(is.na(quantite),montant
/avgpriceKG,quantite)))
```

Imputing missing quantities in L in respective imputation data frame

A data frame for imputation of missing quantities in L is built (selected products reported in L).

```
francbis_L_imputation<- francbis %>%
 select(nomen5,unite,quantite,montant) %>%
 filter(nomen5 %in% c(01141,01142,01153,01154,01185,01193,01221:01224,0211
1:02131)) %>% filter(montant>0)
```

If UNITE=L and QUANTITE=NA, quantity is imputed by avgprice and converted later L => KG.

```
averagepriceL<-as.data.frame(averagepriceL)
averagepriceL<-averagepriceL%>%select(nomen5,avgpriceL)

francbis_L_imputation<-francbis_L_imputation%>%left_join(averagepriceL,by=
"nomen5")%>%mutate(unite=as.factor(unite))

francbis_L_imputation<-francbis_L_imputation%>%mutate(quantite_imputee=ife
lse(is.na(unite),montant/avgpriceL,ifelse(is.na(quantite),montant/avgprice
L,quantite)))
```

Imputing missing quantities in U in respective imputation data frame

A data frame for imputation of missing quantities in U is built (selected products reported in U - eggs and yogurt)

```
francbis_U_imputation<-francbis%>%select(nomen5,unite,quantite,montant)%>%
filter(nomen5 %in%c(01144,01147))%>%filter(montant>0)
```

If UNITE=U and QUANTITE=NA, quantity is imputed by avprice_U.

```
averagepriceU<-as.data.frame(averagepriceU)
averagepriceU<-averagepriceU%>%select(nomen5,avgpriceU)

francbis_U_imputation<-francbis_U_imputation %>% left_join (averagepriceU,
by="nomen5")%>%mutate(unite=as.factor(unite))

francbis_U_imputation<-francbis_U_imputation %>% mutate(quantite_imputee=i
felse(is.na(unite),montant/avgpriceU,ifelse(is.na(quantite),montant/avgpri
ceU,quantite)))
```

A4.4.4 Converting quantities reported in L and U units into KG

In each of the three imputation data frames, quantities recorded in L and in U were converted to quantities recorded in KG.

Converting quantities in L into KG

L was converted to KG by using density per product. Density values for all food and drink are available from the FAO (FAO, 2015). I prepared a data frame for density including the variables NOMEN5 and density for those products reported in L and imported it for conversion (using left_join () by nomen5). Mutate(as factor ()) seems important for further use of ifelse (), similar to what was done for imputation.

```
densites<-read.csv2("densites.csv")
str(densites)

## 'data.frame':    41 obs. of  2 variables:
##  $ nomen5 : int  NA 1112 1114 1132 1134 1141 1142 1143 1144 1145 ...
##  $ densite: num  NA 0.29 0.59 0.58 0.77 1.03 1.03 1.07 1.06 0.58 ...

francbis_L_con<-francbis_L_imputation%>%left_join(densites,by="nomen5")%>%
mutate(unite=as.factor(unite))
```

Converting quantities in U into KG

I first explored whether we can obtain quantities in kg from quantities in U through MONTANT and averagepriceKG, disregarding the initial quantity recorded in unit U. Tables A4.3, A4.4 and A4.5 provide the complete list of average prices per KG, U and L. For several products, average prices per KG seemed implausible when compared with average prices per L combined with density. Implausibility was found mostly for liquids, as synthesized in Table A4.1: Average prices per KG seem implausible in the case of selected drinks. One reason may be the few observations of purchase quantities reported in KG used to calculate average price. Reporting errors may be another reason. The average price per L for the same product seems more plausible, and in these cases, is based on more observations. No average prices per KG were available, because of zero purchases reported in KG, for the products: 01141 (whole milk), 01153 (olive oil), 01154 (sunflower and other oil), 01221 (mineral water), 01222 (sparkling water), 02111 (spirits and liqueur), 02121 (wine and cider). One case, ice cream 01158, had an average price per KG of 5.86 € and an average price per L of 3.65 €. I used density to convert prices and test the plausibility of the results. Using a density of 0.61 KG/L for ice cream, the average price per KG calculated from the average price per L is 5.98€/KG which is very close to the value obtained from reported purchases in KG.

All these products referred to the imputation framework L, which means that their purchases were most often recorded in L. This explains that average price per L is relatively more plausible than average prices per KG or U. I argue that for these cases, it is best to use average price per L, divide purchase expenses MONTANT and obtain purchase quantities in L, and only then, convert L to KG.

For the products 01144 (yogurt) and 01147 (eggs), predominantly reported in U and having mostly standardized units (yogurt U=0,125 KG), and (eggs U=0,06 KG), I calculated quantity in KG through quantity in U multiplied by mass per unit. Eggs from Gallus gallus hens, the dominant species for the egg market in France, show little variability in egg size and mass. Four different sizes are marketed, ranging from S (less than 53 grams) to XL (more than 73 grams). A mean mass of 60 grams per egg is commonly used. For yogurt, one serving usually is 125 grams and comes in a glass jar or plastic cup, although bigger servings (such as cups of 500 grams) exist on the market. One serving is rarely sold alone; it is usually found in packs of 4, 8 or 16.

A4.4.5 Converting quantities (L) and (U) in the three data frames "KG", "L" and "U"

Data frame L Drawing on data frame francbis_L_con, I added a code to compute, for purchases reported in U, the quantity in L by using montant/avgpriceL. The resulting variable QUANTITE_IMPUTEE_UL allowed me to keep track of the conversion from U to L (and later to KG through density) and to distinguish between initial columns QUANTITE and newly created columns QUANTITE_IMPUTEE and QUANTITE_IMPUTEE_UL. Conversion of QUANTITE_IMPUTEE from NA failed, which is why I coded to replace NA by L and created another variable, UNITE_NAL.

```
library(forcats)
francbis_L_con<-francbis_L_con%>%mutate(unite_NAL=fct_explicit_na(unite,na
_level="L"))
francbis_L_con<-francbis_L_con%>%mutate(unite_NAL=fct_explicit_na(unite,na
_level="L"))%>%  mutate(quantite_imputee_UL=ifelse(unite_NAL=="U",montant/
avgpriceL,quantite_imputee))%>% mutate(quantite_con=ifelse(unite_NAL=="L",
quantite_imputee_UL*densite,ifelse(unite_NAL=="U",quantite_imputee_UL*dens
ite,quantite_imputee)))
```

Data frame KG

```
francbis_KG_con<-francbis_KG_imputation%>% left_join(densites,by="nomen5")
%>% mutate(unite=as.factor(unite))
```

Again, I replaced NA by KG, otherwise QUANTITE_IMPUTEE did not follow to QUANTITE_CON. I converted L to KG by density and U to KG by montant/avgpriceKG.

```
francbis_KG_con<-francbis_KG_con%>% mutate(unite=replace(unite,is.na(unite
),"KG"))%>% mutate(quantite_con=ifelse(unite=="L",quantite_imputee*densite
,ifelse(unite=="U",montant/avgpriceKG,quantite_imputee)))%>%arrange(nomen5
)
```

Data frame U Information about mass per unit was gathered in a data frame masseUnite and integrated into the imputation data frame.

```
masseUnite<-read.csv2("masseUnite.csv")
francbis_U_con<-francbis_U_imputation%>%left_join(densites,by="nomen5")%>%
left_join(masseUnite,by="nomen5")%>%mutate(unite=as.factor(unite))
francbis_U_con<-francbis_U_con%>%mutate(unite_NAU=fct_explicit_na(unite,na
_level="U"))%>% mutate(quantite_con=ifelse(unite_NAU=="U",quantite_imputee
*masseUnite,ifelse(unite_NAU=="L",quantite_imputee*densite,quantite_impute
e)))
```

A4.4.6 Integrating three imputation data frames into one single frame

Before integrating imputation data frames into one single data frame, intermediary data frames francbis_KG_integ, francbis_L_integ and francbis_U_integ were built.

```
francbis_KG_integ<-francbis_KG_con%>%select(nomen5,quantite_con)
francbis_L_integ<-francbis_L_con%>%select(nomen5,quantite_con)
francbis_U_integ<-francbis_U_con%>%select(nomen5,quantite_con)
```

They were integrated into data frame francbis_full.

```
francbis_full<-francbis_KG_integ%>%full_join(francbis_L_integ,by="nomen5")
%>%full_join(francbis_U_integ,by="nomen5")%>%arrange(nomen5)
francbis_full<-as.data.frame(francbis_full)
```

To merge the quantities of data frame specific variables QUANTITE_CON, QUANTITE_CON.X et QUANTITE_CON.Y in one single variable QUANTITE_MERGED, I used function coalesce() from the package tidyr.

```
library(tidyr)
francbis_merged<-francbis_full%>%mutate(quantite_merged=coalesce(quantite_
con,quantite_con.x,quantite_con.y))
francbis_merged<-as.data.frame(francbis_merged)
```

The different computation steps resulted in the newly created variable entitled QUANTITE_MERGED which contains the purchase quantities in KG for all purchases retained for analysis in the data frame francbis. The initial data frame francbis contained 55,387 observations, but was reduced by negative purchase expenses (n=4,586), and misreported egg (n=14) and yogurt (n=235) purchases. 50,552 observations in francbis were retained for further analysis of purchase quantities. The values in quantity_merged can be either: i) initial quantity (KG); ii) imputed quantity (KG, L or U); or iii) converted quantity (KG) from initial or imputed quantity (L) or (U). Using variable QUANTITE_MERGED, I computed the total quantity of food and drink per product purchased by households of the Paris urban unit over one week, as required for the analysis of household food and drink purchases within the broader work of the urban system food flows.

A4.4.7 Summing up total purchase quantity of food and drink

Drawing on variable QUANTITE_MERGED, total quantities could now be summed up: Total number of observations in the data frame

```
total_quantite<-francbis_merged%>%summarise(sumquantite=sum(quantite_merge
d))
```

Results are exported into a csv.file.

```
write.csv(total_quantite,file="total_quantite.csv")
```

- A selection of products according to the broad categories food(without milk 01141,01142) and drink (or beverage) using group_by

```
food_quantite2<-francbis_merged%>%group_by(nomen5%in%c(01111:01134,01143:0
1194))%>%  summarise(sumquantite=sum(quantite_merged))

beverage_quantite2<-francbis_merged%>% group_by(nomen5%in%c(01141:01142,01
211:01224,02111:02131))%>%  summarise(sumquantite=sum(quantite_merged))
```

- Food groups as defined below

```
library(plyr)

foodgroups<-francbis_merged %>%
  mutate(groupfood=mapvalues(nomen5,from=c(01111:01113,01115),to=rep("Brea
d and cereals",length(c(01111:01113,01115)))))%>%
  mutate(groupfood=mapvalues(groupfood,from=c(01121:01127),to=rep("Meat,po
ultry and charcuterie",length(c(01121:01127))))) %>%
  mutate(groupfood=mapvalues(groupfood,from=c(01130:01134),to=rep("Fish, f
ish products and seafood",length(c(01130:01134))))) %>%
  mutate(groupfood=mapvalues(groupfood,from=c(01141:01146),to=rep("Milk an
d dairy products",length(c(01141:01146)))))%>%
  mutate(groupfood=mapvalues(groupfood,from=c(01147),to=rep("Eggs",length(
c(01147)))))%>%
  mutate(groupfood=mapvalues(groupfood,from=c(01151:01155),to=rep("Oil and
 fat",length(c(01151:01155)))))%>%
  mutate(groupfood=mapvalues(groupfood,from=c(01161:01168,01171:01179),to=
rep("Fruits, vegetables and potatoes",length(c(01161:01168,01171:01179))))
)%>%
  mutate(groupfood=mapvalues(groupfood,from=c(01169,01181:01184,01186),to=
rep("Sugar and sugar-based products, and dessert",length(c(01169,01181:011
84,01186)))))%>%
  mutate(groupfood=mapvalues(groupfood,from=c(01185),to=rep("Icecream",len
gth(c(01185)))))%>%
  mutate(groupfood=mapvalues(groupfood,from=c(01114,01191:01194),to=rep("O
ther food",length(c(01114,01191:01194)))))%>%
  mutate(groupfood=mapvalues(groupfood,from=c(01211:01224,02111:02131),to=
rep("Beverages without milk",length(c(01211:01224,02111:02131)))))%>%
  mutate(groupfood=mapvalues(groupfood,from=c(01141:01142,01211:01224,0211
1:02131),to=rep("Beverages inc milk",length(c(01141:01142,01211:01224,0211
1:02131)))))%>%
  mutate(groupfood=mapvalues(groupfood,from=c(01111:01134,01143:01194),to=
rep("Food without milk",length(c(01111:01134,01143:01194)))))
```

```
## The following `from` values were not present in `x`: 1214, 1215, 1216,
1217, 1218, 1219, 1220, 2112, 2113, 2114, 2115, 2116, 2117, 2118, 2119, 21
20, 2123, 2124, 2125, 2126, 2127, 2128, 2129, 2130

## The following `from` values were not present in `x`: 1141, 1142, 1211,
1212, 1213, 1214, 1215, 1216, 1217, 1218, 1219, 1220, 1221, 1222, 1223, 12
24, 2111, 2112, 2113, 2114, 2115, 2116, 2117, 2118, 2119, 2120, 2121, 2122
, 2123, 2124, 2125, 2126, 2127, 2128, 2129, 2130, 2131

## The following `from` values were not present in `x`: 1111, 1112, 1113,
1114, 1115, 1116, 1117, 1118, 1119, 1120, 1121, 1122, 1123, 1124, 1125, 11
26, 1127, 1128, 1129, 1130, 1131, 1132, 1133, 1134, 1143, 1144, 1145, 1146
, 1147, 1148, 1149, 1150, 1151, 1152, 1153, 1154, 1155, 1156, 1157, 1158,
1159, 1160, 1161, 1162, 1163, 1164, 1165, 1166, 1167, 1168, 1169, 1170, 11
71, 1172, 1173, 1174, 1175, 1176, 1177, 1178, 1179, 1180, 1181, 1182, 1183
, 1184, 1185, 1186, 1187, 1188, 1189, 1190, 1191, 1192, 1193, 1194

foodgroups<-as.data.frame(foodgroups)
detach(package:plyr)
```

- larger groups (groupfood) of food and drink ("Bread and cereals", "Meat, poultry and charcuterie", etc.) Mutate() is necessary to write groupfood as a factor

```
foodgroup_quantite<-foodgroups %>%mutate(groupfood=as.factor(groupfood))%>
% group_by(groupfood)%>%  summarise(sumquantite=sum(quantite_merged))
write.csv(foodgroup_quantite,file="foodgroup_qu.csv")
```

- Per product NOMEN5 for food and drink respectively

```
food_quantite2_nomen5<-francbis_merged%>%droplevels()%>%filter(nomen5%in%c
(01111:01134,01143:01194))%>%
  group_by(nomen5)%>%summarise(sumquantite=sum(quantite_merged))
write.csv(food_quantite2_nomen5,file="fo_qu2_nomen5.csv")

beverage_quantite2_nomen5<-francbis_merged%>%filter(nomen5%in%c(01141:0114
2,01211:01224,02111:02131))%>%droplevels()%>%
  group_by(nomen5)%>%summarise(sumquantite=sum(quantite_merged))
write.csv(beverage_quantite2_nomen5,file="bev_qu2_nomen5.csv")
```

- Per product NOMEN5 relabelled

```
francbis_merged<-francbis_merged%>%mutate(nomen5_recode=recode(nomen5,
                                           `01111`="rice",`01112`="bread",
`01113`="pasta",`01114`="savoury_bakery",
           `01115`="other_cereals", `01121`="beef",`01122`="pork",`01123`=
"lamb",                                                   `01124`="poultry",`
01125`="charcuterie",`01126`="preserved_meat",`01127`="other_meat",
                                    `01130`="fresh_fish",`01131`="frozen_fish",`01132
`="seafood",`01133`="smoked_fish_seafood",                                `0
1134`="canned_fish_seafood",`01141`="whole_milk",`01142`="(semi-)skimmed_m
ilk",`01143`="condensed_milk",              `01144`="yoghourt",`01145`="ch
eese",`01146`="other_dairy",`01147`="eggs",
             `01151`="butter",`01152`="margarine",`01153`="olive_oil",`011
54`="sunflower_oil",                                      `01155`="animal_f
at",`01161`="agrumes",`01162`="banana",`01163`="apple",
                           `01164`="pear",`01165`="stone_fruits",`01166`="
berries",`01167`="other_fruits",                                          `0
```

```
1168`="dried_fruits",`01169`="canned_fruits",`01171`="salade",`01172`="cab
bage",                                   `01173`="tomato",`01174`="roots",`0
1175`="legumes",`01176`="frozen_vegs",
    `01177`="canned_veg_meal",`01178`="fresh_frozen_veg_meal",`01179`="pot
ato",`01181`="sugar",                      `01182`="jam",`01183`="chocolate"
,`01184`="sweets",`01185`="ice_cream",`01186`="other_sugar",`01191`="sauce
s", `01192`="spices",`01193`="soup",`01194`="other",`01211`="coffee",`0121
2`="tea",`01213`="cacao",`01221`="mineral_water", `01222`="sparkling_water
",`01223`="fruit_juice",`01224`="vegetable_juice",`02111`="spirits",`02121
`="wine", `02122`="aperitifs",`02131`="beer"))

foodlabel_quantite2_nomen5<-francbis_merged%>%droplevels()%>%filter(nomen5
%in%c(01111:01134,01143:01194))%>%
  group_by(nomen5_recode)%>%summarise(sumquantite=sum(quantite_merged))

write.csv(foodlabel_quantite2_nomen5,file="folabel_qu2_nomen5.csv")

drinklabel_quantite2_nomen5<-francbis_merged%>%droplevels()%>%filter(nomen
5%in%c(01141:01142,01211:01224,02111:02131))%>%group_by(nomen5_recode)%>%s
ummarise(sumquantite=sum(quantite_merged))

write.csv(drinklabel_quantite2_nomen5,file="drinklabel_qu2_nomen5.csv")
```

Tables A4.6, A4.7 and A4.8 summarize quantities of products purchased by the household sample over the course of one week, respectively for food, drink and the aggregated categories food and drink.

A4.5 Socio-demographic analysis of households in francbis

```
library(foreign)
MENAGE<-read.dta("MENAGE.dta")

str(MENAGE)
```

Several socio-demographic variables, such as number of household members, number of children, zone for study and development (*zone d'etude et d'amenagement du territoire, ZEAT*), highest degree of education of the reference person of the household, and household identification number, were selected from the data frame MENAGE.dta and converted into a new data frame profile_menage. Household identification numbers IDENT_MEN for households analysed in francbis were selected and used as a link to merge data frames francbis_menage and profile_menage IDENT_MEN.

```
profile_menage<-MENAGE%>%select(npers,zeat,dip14pr,ident_men,nenfants)
francbis_menage<-francbis%>%select(ident_men)
francbis_menage<-as.data.frame(francbis_menage)
francbis_menage<-unique(francbis_menage)
francbis_menage<-francbis_menage%>%left_join(profile_menage,by="ident_men"
)
```

For each socio-demographic variable, I intended to compare the household sample of francbis with the profile of households in Île-de-France. At this stage of the work, only two variables, number of household members and number of children, could be analysed by calculating mean value. More work and support of expertise in R would be necessary to analyse the remaining socio-demographic variables.

```
mean(francbis_menage$npers)

## [1] 2.415107

mean(francbis_menage$nenfants)

## [1] 0.8179471
```

Mean number of household members in franc_bis is 2.41, and mean number of children 0.82.

Tables to A4

Table A4.1. Average prices per L and KG and number of observations for selected drinks including soup

Product label	Product (NOMEN5)	Average price per L (€/L)	Number of obs in L	Average price per KG (€/KG)	Number of obs in KG	Density (KG/L) [1]
Semi-skimmed milk	01142	0.85	555	2.86	3	1.03
Soup	01193	2.47	147	6.74	63	1.05
Fruit juice	01223	1.39	1038	11.29	1	1.05
Vegetable juice	01224	2.18	6	4.65	1	1.05
Aperitifs wine	02122	15.37	52	4.72	4	1.03
Beer	02131	2.34	143	2.89	2	1.01

[1] FAO (2015)

Table A4.2. Structure of data frame francbis by product group, product, unit and number of observation

Product group (transversal nomenclature)	Product label	Short label	Product (NOMEN5)	Unit (UNITE)	Number of observations	Assignation to imputation data frame KG, L or U
Bread and cereals	Rice	Rice	1111	KG	198	KG
			1111	U	52	
			1111	NA	142	
	Bread and pastry	Bread	1112	KG	3,572	KG
			1112	L	2	
			1112	U	1,838	
			1112	NA	2,101	
	Pasta	Pasta	1113	KG	529	KG
			1113	U	117	
			1113	NA	466	
Other food	Savoury bakery products	Savoury_bakery	1114	KG	493	KG
			1114	L	2	
			1114	U	619	
			1114	NA	698	
Bread and cereals	Other cereals	Other_cereals	1115	KG	424	KG
			1115	U	84	KG
			1115	NA	299	KG

Meat, poultry and charcuterie	Beef	Beef	1121	KG	662	KG
			1121	U	223	KG
			1121	NA	393	KG
	Pork	Pork	1122	KG	183	KG
			1122	U	68	KG
			1122	NA	159	KG
	Lamb	Lamb	1123	KG	76	KG
			1123	U	20	KG
			1123	NA	39	KG
	Poultry	Poultry	1124	KG	321	KG
			1124	U	215	KG
			1124	NA	440	KG
	Charcuterie	Charcuterie	1125	KG	887	KG
			1125	U	405	KG
			1125	NA	1,318	KG
	Preserved meat	Preserved_meat	1126	KG	206	KG
			1126	U	181	KG
			1126	NA	356	KG
	Other meat	Other_meat	1127	KG	29	KG
			1127	U	15	KG
			1127	NA	17	KG
Fish, fish products and seafood	Fresh fish	Fresh_fish	1130	KG	241	KG
			1130	U	93	KG
			1130	NA	178	KG
	Frozen fish	Frozen_fish	1131	KG	33	KG
			1131	U	11	KG
			1131	NA	34	KG
	Seafood	Seafood	1132	KG	118	KG
			1132	L	6	KG
			1132	U	53	KG
			1132	NA	153	KG
	Smoked fish and seafood	Smoked_fish_seafood	1133	KG	56	KG
			1133	U	25	KG
			1133	NA	122	KG
	Canned fish and seafood	Canned_fish_seafood	1134	KG	250	KG
			1134	L	1	KG
			1134	U	127	KG
			1134	NA	482	KG
Milk and dairy products	Whole milk	Whole_milk	1141	L	99	L
			1141	U	7	L
			1141	NA	17	L
	(semi-) skimmed milk	(Semi-)skimmed_milk	1142	KG	3	L
			1142	L	555	L
			1142	U	45	L
			1142	NA	124	L
		Condensed_milk	1143	KG	21	KG

	Condensed milk		1143	L	1	KG
			1143	U	13	KG
			1143	NA	22	KG
	Yoghourt	Yoghurt	1144	KG	438	U
			1144	L	60	U
			1144	U	459	U
			1144	NA	1,031	U
	Cheese	Cheese	1145	KG	1,165	KG
			1145	L	4	KG
			1145	U	624	KG
			1145	NA	1,049	KG
	Other dairy	Other_dairy	1146	KG	233	KG
			1146	L	211	KG
			1146	U	296	KG
			1146	NA	620	KG
Eggs	Eggs	Eggs	1147	KG	2	U
			1147	U	322	U
			1147	NA	350	U
Oil and fat	Butter	Butter	1151	KG	344	KG
			1151	U	86	KG
			1151	NA	100	KG
	Margarine	Margarine	1152	KG	97	KG
			1152	U	44	KG
			1152	NA	56	KG
	Olive oil	Olive_oil	1153	L	94	L
			1153	U	4	L
			1153	NA	18	L
	Sunflower and other oil	Sunflower_oil	1154	L	129	L
			1154	U	14	L
			1154	NA	24	L
	Animal fat	Animal_fat	1155	KG	1	KG
Fruits, vegetables and potatoe	Agrumes	Agrumes	1161	KG	521	KG
			1161	L	4	KG
			1161	U	144	KG
			1161	NA	160	KG
	Banana	Banana	1162	KG	336	KG
			1162	U	59	KG
			1162	NA	117	KG
	Apple	Apple	1163	KG	363	KG
			1163	L	1	KG
			1163	U	35	KG
			1163	NA	104	KG
	Pear	Pear	1164	KG	136	KG
			1164	U	14	KG
			1164	NA	33	KG
	Stone fruits	Stone_fruits	1165	KG	260	KG
			1165	U	141	KG

			1165	NA	138	KG
	Berries	Berries	1166	KG	319	KG
			1166	U	30	KG
			1166	NA	128	KG
	Other fruits, tropical fruits	Other_fruits	1167	KG	119	KG
			1167	L	1	KG
			1167	U	331	KG
			1167	NA	174	KG
	Dried fruits	Dried_fruits	1168	KG	175	KG
			1168	U	30	KG
			1168	NA	147	KG
Sugar and sugar-based products, and dessert	Canned fruits	Canned_fruits	1169	KG	28	KG
			1169	L	2	KG
			1169	U	8	KG
			1169	NA	45	KG
Fruits, vegetable and potatoe	Salade	Salade	1171	KG	399	KG
			1171	L	5	KG
			1171	U	415	KG
			1171	NA	382	KG
	Cabbage	Cabbage	1172	KG	82	KG
			1172	U	70	KG
			1172	NA	43	KG
	Tomato and other fruit vegs	Tomato	1173	KG	925	KG
			1173	L	6	KG
			1173	U	316	KG
			1173	NA	389	KG
	Roots	Roots	1174	KG	756	KG
			1174	L	3	KG
			1174	U	184	KG
			1174	NA	458	KG
	Legumes	Legumes	1175	KG	48	KG
			1175	L	3	KG
			1175	U	7	KG
			1175	NA	50	KG
	Frozen vegs	Frozen_vegs	1176	KG	102	KG
			1176	U	19	KG
			1176	NA	49	KG
	Canned Veg meal	Canned_veg_meal	1177	KG	274	KG
			1177	L	41	KG
			1177	U	100	KG
			1177	NA	687	KG
	Fresh or frozen veg meal	Fresh_frozen_veg_meal	1178	KG	279	KG
			1178	L	1	KG
			1178	U	106	KG
			1178	NA	200	KG
	Potato	Potato	1179	KG	591	KG
			1179	U	84	KG

			1179	NA	324	KG
Sugar and sugar-based products, and dessert	Sugar	Sugar	1181	KG	192	KG
			1181	L	3	KG
			1181	U	28	KG
			1181	NA	79	KG
	Jam, gelée, honey etc	Jam	1182	KG	261	KG
			1182	L	4	KG
			1182	U	110	KG
			1182	NA	269	KG
	Chocolat e	Chocolate	1183	KG	365	KG
			1183	U	189	KG
			1183	NA	377	KG
	Sweets	Sweets	1184	KG	198	KG
			1184	L	3	KG
			1184	U	102	KG
			1184	NA	302	KG
Ice cream	Ice cream	Ice_cream	1185	KG	15	L
			1185	L	71	L
			1185	U	89	L
			1185	NA	139	L
Sugar and sugar-based products, and dessert	Other sugar-based products	Other_sugar	1186	KG	104	KG
			1186	U	6	KG
			1186	NA	32	KG
Other food	Sauces	Sauces	1191	KG	310	KG
			1191	L	135	KG
			1191	U	202	KG
			1191	NA	454	KG
	Spices	Spices	1192	KG	85	KG
			1192	L	2	KG
			1192	U	45	KG
			1192	NA	97	KG
	Soup and other prep	Soup	1193	KG	63	L
			1193	L	147	L
			1193	U	74	L
			1193	NA	141	L
	Other and diet products	Other	1194	KG	46	KG
			1194	L	15	KG
			1194	U	65	KG
			1194	NA	96	KG
Beverages	Coffee	Coffee	1211	KG	256	KG
			1211	L	1	KG
			1211	U	115	KG
			1211	NA	224	KG
	Tea and herbal tea	Tea	1212	KG	51	KG
			1212	L	4	KG
			1212	U	42	KG
			1212	NA	136	KG

	cacao	Cacao	1213	KG	46	KG
			1213	U	3	KG
			1213	NA	28	KG
	Mineral water	Mineral_water	1221	L	853	L
			1221	U	84	L
			1221	NA	194	L
	Sparkling water	Sparkling_water	1222	L	537	L
			1222	U	52	L
			1222	NA	193	L
	Fruit juice	Fruit_juices	1223	KG	1	L
			1223	L	1,038	L
			1223	U	174	L
			1223	NA	398	L
	Vegetable juice	Vegetable_juice	1224	KG	1	L
			1224	L	6	L
			1224	U	1	L
			1224	NA	3	L
	Spirits and liqueur	Spirits	2111	L	109	L
			2111	U	24	L
			2111	NA	51	L
	Wine and cider	Wine	2121	L	378	L
			2121	U	49	L
			2121	NA	342	L
	Aperitifs wine	Aperitifs	2122	KG	4	L
			2122	L	52	L
			2122	U	21	L
			2122	NA	59	L
	Beer	Beer	2131	KG	2	L
			2131	L	143	L
			2131	U	21	L
			2131	NA	75	L

Table A4.3. Average price per L calculated in the data frame francbis_masscomL, in €/L

Product (NOMEN5)	Average price L
1141	1.1185580
1142	0.8509405
1153	5.3916405
1154	1.9247711
1185	3.6508720
1193	2.4726681
1221	0.3803922
1222	0.9415045
1223	1.3945436
1224	2.1757576
2111	15.5210607
2121	4.0278167
2122	15.3709860
2131	2.3375208

Table A4.4. Average price per KG calculated in the data frame francbis_masscomKG (for all products), in €/KG

Product (NOMEN5)	Average price KG
1111	2.827088
1112	3.901172
1113	3.039761
1114	5.987605
1115	3.167267
1121	12.828971
1122	9.215394
1123	11.399714
1124	7.184606
1125	10.740057
1126	8.953430
1127	11.209802
1130	12.026559
1131	10.932304
1132	11.154428
1133	23.671982
1134	13.670852
1142	2.853659
1143	6.678714
1144	2.519792
1145	9.795405
1146	3.621370
1147	9.455307
1151	6.216802
1152	5.621688
1155	6.000000
1161	1.995135
1162	1.591301

1163	1.935479
1164	2.191633
1165	3.232409
1166	4.227246
1167	3.592430
1168	7.680838
1169	3.815744
1171	3.561071
1172	2.325131
1173	2.505344
1174	2.459933
1175	3.464735
1176	2.205512
1177	3.737610
1178	5.971641
1179	1.405549
1181	1.576888
1182	4.760115
1183	12.800079
1184	7.624118
1185	5.864557
1186	5.383694
1191	4.363704
1192	3.968701
1193	6.747199
1194	8.585838
1211	10.908927
1212	49.813441
1213	4.335264
1223	11.285714
1224	4.650000
2122	4.719192
2131	2.893519

Table A4.5. Average price per unit calculated in the data frame francbis_masscomU, in €/U

Product (NOMEN5)	Average price per U
1144	0.2612628
1147	0.2155440

Table A4.6. Total quantity of food products purchased by the household sample (n=1,732) in the course of one week, in kg

	Product (NOMEN5)	Product (labelled) _ short name	Total quantity
Bread and cereals	01111	Rice	446
	01112	Bread	3,717
	01113	Pasta	686
	01115	Other_cereals	601
Meat, poultry, charcuterie	01121	Beef	733
	01122	Pork	259
	01123	Lamb	135
	01124	Poultry	780
	01125	Charcuterie	731
	01126	Preserved_meat	346
	01127	Other_meat	61
Fish, fish products and seafood	01130	Fresh_fish	312
	01131	Frozen_fish	42
	01132	Seafood	190
	01133	Smoked_fish_seafood	43
	01134	Canned_fish_seafood	212
	01143	Condensed_milk	23
	01144	Yogurt	1,814
	01145	Cheese	800
	01146	Other_dairy	696
Oil and fat	01151	Butter	158

	01152	Margarine	77
	01153	Olive oil	103
	01154	Sunflower_oil	219
	01155	Animal_fat	0
Eggs	01147	Eggs	393
	01161	Agrumes	1,031
	01162	Banana	476
	01163	Apple	659
	01164	Pear	188
	01165	Stone_fruits	449
	01166	Berries	367
	01167	Other_fruits	478
	01168	Dried_fruits	114
	01171	Salade	567
	01172	Cabbage	182
	01173	Tomato	1,286
	01174	Roots	1,163
	01175	Legumes	60
	01176	Frozen_vegs	175
	01177	Canned_veg_meal	472
	01178	Fresh_frozen_veg_meal	254
	01179	Potato	1,561
Sugar-based products and dessert	01169	Canned_fruits	59
	01181	Sugar	310
	01182	Jam	319
	01183	Chocolate	240
	01184	Sweets	195
	01186	Other_sugar	91

Other products	01194	Other	137
	01191	Sauces	416
	01114	Savoury_bakery	778
	01193	Soup	358
	01192	Spices	87
	01185	Ice_cream	170
Total			**26,217**

Table A4.7. Total quantity of drink products purchased by the household sample (n=1,732) in the course of one week, in kg

	Product (NOMEN5)	Product	Total quantity
Drink	01141	Whole milk	309
	01142	(Semi-) skimmed milk	2,407
	01211	Coffee	231
	01212	Tea and herbal tea	22
	01213	Cacao	49
	01221	Mineral water	6,695
	01222	Sparkling water	1,936
	01223	Fruit juice	2,666
	01224	Vegetable juice	10
	02111	Spirits	165
	02121	Wine	1,130
	02122	Aperitifs	156
	02131	Beer	439
Total			**16,216**

Including whole milk and semi-skimmed milk

Table A4.8. Total quantity of food and drink purchased by the household sample (n=1,732) in the course of one week, in kg

Product category	Total quantity
Food [1]	26,217
Drink [2]	16,216
Total food and drink	**42,433**

[1] excluding milk , [2] including milk

Table A4.9. Mean quantity of wasted food calculated from a dataset provided by *Excellents Excédents*

ID	Year	Type of establishment	Meal preparation	Number of days of weighing	Total quantity of wasted food (kg)	Total number of end users for all days of weighing	Wasted food per client and meal (g/end user/meal)
1	2017	Middle school	On-site preparation	1	31.5	656	48
2	2015	Middle school	On-site preparation	1	17.9	353	51
3	2017	Middle school	On-site preparation	1	19.7	360	55
4	2016	High school	On-site preparation	5	260.3	4,186	62
5	2016	Middle school	On-site preparation	1	41	550	75
6	2017	Primary school	Delivery	1	7	65	108
7	2015	Primary school	Delivery	1	11.7	108	108
8	2014	High school	On-site preparation	1	36.4	330	110
9	2015	Retirement home	On-site preparation	1	9.2	78	118
10	2017	High school	On-site preparation	5	395	3,250	122
11	2014	High school	On-site preparation	1	55	450	122
12	2016	Primary school	Delivery	4	80.3	636	126
13	2014	High school	On-site preparation	1	74.9	590	127
14	2014	Middle school	On-site preparation	1	59.3	466	127
15	2016	Primary school	Delivery	1	37	286	129
16	2014	High school	On-site preparation	9	181	1,368	132
17	2014	High school	Delivery	1	14.8	110	135
18	2016	Middle school	On-site preparation	1	71.7	499	144
19	2017	Middle school	On-site preparation	1	159.7	1,106	144

20	2014	High school	On-site preparation	1	30	182	165
21	2014	High school	On-site preparation	5	120	680	176
22	2017	Primary school	Delivery	1	15.3	85	180
23	2017	Kindergarten	Delivery	1	17	92	185
24	2017	Primary school	Delivery	1	59.2	317	187
25	2016	Primary school	Delivery	1	17.3	90	192
26	2017	Primary school	Delivery	1	29.1	138	211
27	2017	Primary school	Delivery	1	21.8	90	242
28	2017	Middle school	On-site preparation	1	104	400	260
29	2017	Primary school	Delivery	1	14.04	52	270
30	2014	High school	On-site preparation	1	125	405	309
31	2016	Primary school	Delivery	1	48.1	116	415

Source: *Excellents Excédents*, extracted 12/10/2017

Observations underlined in blue were retained for the calculation of the mean quantity of wasted food per meal

Establishments tagged with "delivery" usually have the main dish delivered, but they frequently prepare first course and desserts.

B4. Tables Integration food and drink

Table A4.10. Inner-urban food and drink flows, eating population, Paris Petite Couronne, in 2014, in kilotonnes

	In-home consumption		Out-of-home consumption	
	HH1	**HH2**	**FS1**	**FS2**
Supply	4,652,570	4,767,322	2,705,903	1,223,047
Intake	4,582,194	4,582,194	2,137,134	964,228
Food waste	70,375	185,127	568,770	258,819
combined HH FS	**HH1+ FS1**	**HH1 + FS2**	**HH2 + FS1**	**HH2 + FS2**
Total supply	7,358,473	5,875,617	7,473,225	5,990,369
Total intake	6,719,378	5,546,422	6,719,328	5,546,422
Total food waste	639,145	329,194	753,897	443,947

No drink waste considered in out-of-home consumption

Table A4.11. Inner-urban food and drink flows, eating population, Ile-de-France, in 2014, in kilotonnes

	In-home		Out-of-home	
	HH1	**HH2**	**FS1**	**FS2**
Supply	8,202,021	8,404,387	4,381,963	2,111,889
Intake	8,114,572	8,114,572	3,456,607	1,664,975
Food waste	87,449	289,815	925,356	446,914
combined HH FS	**HH1+ FS1**	**HH1 + FS2**	**HH2 + FS1**	**HH2 + FS2**
Total supply	12,583,984	10,313,910	12,786,350	10,516,276
Total intake	11,571,179	9,779,547	11,571,179	9,779,547
Total food waste	1,012,805	534,363	1,215,171	736,729

No drink waste considered in out-of-home consumption

Table A4.12. Inner-urban food flows (excluding drink), eating population, Paris Petite Couronne, in 2014, in kilotonnes

	In-home		Out-of-home	
	HH1	**HH2**	**FS1**	**FS2**
Supply	1,827,308	2,068,112	1,417,680	644,510
Intake	1,828,346	1,828,346	848,910	385,691
Food waste	-1,038	239,766	568,770	258,819
combined HH FS	**HH1+ FS1**	**HH1 + FS2**	**HH2 + FS1**	**HH2 + FS2**
Total supply	3,244,988	2,471,818	3,485,792	2,712,622
Total intake	2,677,256	2,214,037	2,677,256	2,214,037

Total food waste	567,732	257,781	808,536	498,586

Table A4.13. Inner-urban food flows (excluding drink), eating population, Ile-de-France, in 2014, in kilotonnes

	In-home		**Out-of-home**	
	HH1	**HH2**	**FS1**	**FS2**
Supply	3,221,819	3,646,393	2,306,485	1,112,904
Intake	3,245,887	3,245,887	1,381,129	665,990
Food waste	-24,068	400,506	925,356	446,914
combined HH FS	**HH1+ FS1**	**HH1 + FS2**	**HH2 + FS1**	**HH2 + FS2**
Total supply	5,528,304	4,334,723	5,952,878	4,759,297
Total intake	4,627,015	3,911,877	4,627,015	3,911,877
Total food waste	901,289	422,847	1,325,863	847,421

Table A4.14. Inner-urban drink flows, eating population, Paris Petite Couronne, in 2014, in kilotonnes

	In-home						Out-of-home	
	HH1P [1]	HH2P [1]	HH1T [1]	HH2T [1]			FS1	FS2
Supply	1,393,087	1,267,035	1,436,180	1,436,180			1,288,223	578,537
Intake	1,314,382	1,314,382	1,436,180	1,436,180			1,288,223	578,537
Food waste	78,705	-47,348	0	0			0	0
combined HH FS	HH1P + FS1+HH1T	HH1P + FS2+HH1T	HH1P + FS1+HH2T	HH1P + FS2+HH2T	HH2P + FS1+HH1T	HH2P + FS2+HH1T	HH2P + FS1+HH2T	HH2P + FS2+HH2T
Total supply	4,117,490	3,407,804	4,117,490	3,407,804	3,991,438	3,281,752	3,991,438	3,281,752
Total intake	4,038,786	3,329,099	4,038,786	3,329,099	4,038,786	3,329,099	4,038,786	3,329,099
Total food waste	78,705	78,705	78,705	78,705	-47,348	-47,348	-47,348	-47,348

[1] Drink consumed in-home is distinguished in purchased drink (HH1P, HH2P) and tap water to drink (HH1T, HH2T). Drink consumed out-of-home is not distinguished.

Table A4.15. Inner-urban drink flows, eating population, Île-de-France, in 2014, in kilotonnes

	In-home						Out-of-home	
	HH1P 1	HH2P 1	HH1T 1	HH2T 1			FS1	FS2
Supply	2,456,222	2,233,973	2,528,777	2,528,777			2,075,478	998,985
Intake	2,334,229	2,334,229	2,528,777	2,528,777			2,075,478	998,985
Food waste	121,992	-100,256	0	0			0	0
combined HH FS	HH1P + FS1+HH1T	HH1P + FS2+HH1T	HH1P + FS1+HH2T	HH1P + FS2+HH2T	HH2P + FS1+HH1T	HH2P + FS2+HH1T	HH2P + FS1+HH2T	HH2P + FS2+HH2T
Total supply	7,060,477	5,983,984	7,060,477	5,983,984	6,838,228	5,761,735	6,838,228	5,761,735
Total intake	6,938,485	5,861,991	7,140,282	5,861,991	6,938,485	5,861,991	6,938,485	5,861,991
Total food waste	121,992	121,992	121,992	121,992	-100,256	-100,256	-100,256	-100,256

[1] Drink consumed in-home is distinguished in purchased drink (HH1P, HH2P) and tap water to drink (HH1T, HH2T). Drink consumed out-of-home is not distinguishe