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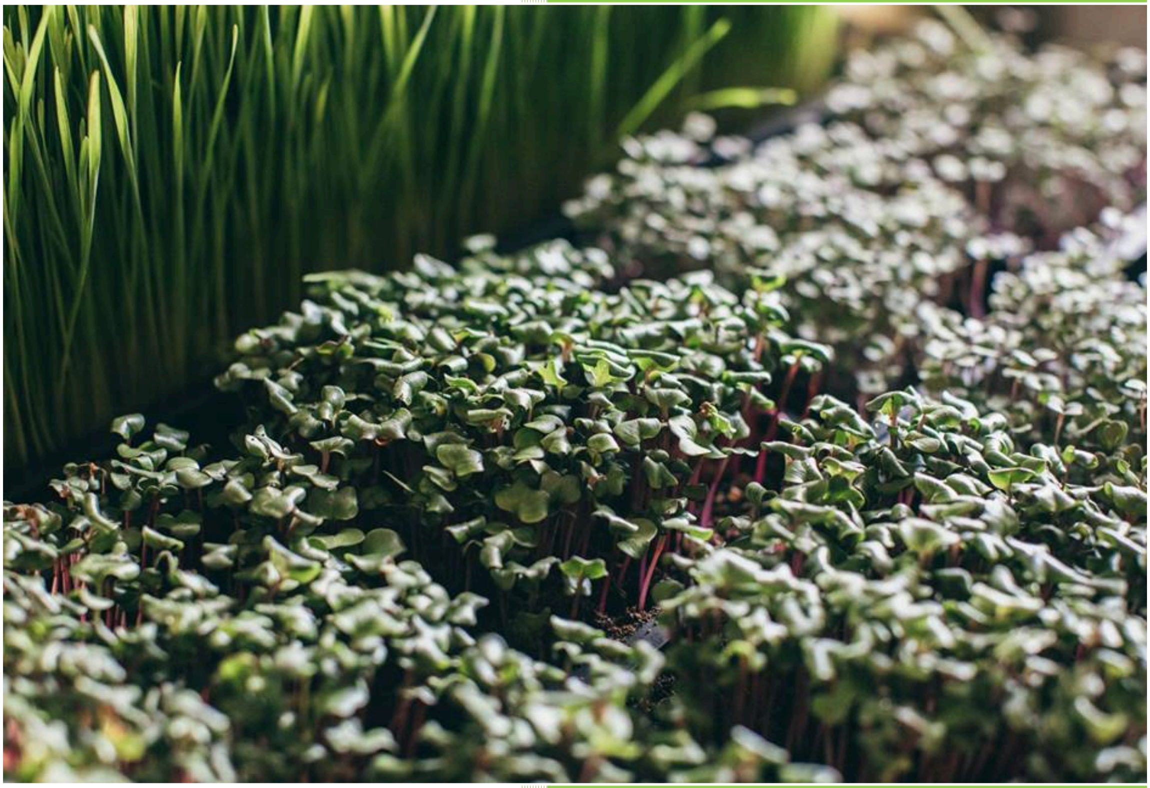
Urban and peri-urban food production facilities: using material flow to outline inter-firm exchanges and wastes management strategies



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ABSTRACT

By 2050, 66% of the world population is supposed to live in a city, with more issues rising regarding our capacity to feed those cities in a sustainable way. A socio-technical transition seems to be a necessary solution to consider, but a difficult one to initiate on a global scale. Some suitable tools emerge such as the circular economy, industrial symbiosis, but how can we evaluate those parameters in as organization or facility? Urban metabolism (UM) and material flow analysis (MFA) are the methodology used in that study to outline the flows and exchanges at *The Plant*, Chicago. The facility's aim is to make food production business function together with a circular economy background. By interviewing the different businesses working in the facility we will attempt to understand and outline the various strategies and challenges they operate with to have more sustainable practices.

Keywords : material flow analysis, urban metabolism, food production, waste management, industrial symbiosis

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Introduction

Urban spaces, food production, flows, exchanges, wastes. Some extremely common notions facing major challenges nowadays. All the intensity and tensions linked to the rapid growth of cities: occupation of agricultural lands, growing food needs without producing much themselves, wastes management, especially food wastes since the FAO (2013) estimates that one third of the food production worldwide is wasted. The globalization of food production allows consumers to have a wide range of food available anytime and in huge quantities, at least in western countries, while 800 million people are still considered to be suffering from chronic hunger. At the same time, food security is an issue that is taken care of with more or less success depending on public and private investment. Even if consumers can expect the food they buy to be safe in western countries, food scandals and livestock pandemics still happen periodically, challenging their trust toward the food they eat and the people constituting the food chain. In this context, consumers are more and more interested to know where the food they eat comes from and how it is made, putting local and organic food under the spotlight.

This internship approaches those issues by studying an atypical food system and the way it is linked to this global food context. Through an in-depth contextualization with notions such as urban-related issues, sustainability, waste, the circular economy, industrial symbiosis, urban metabolism and material flow analysis, the specific aspect of *The Plant* and its businesses are enhanced and the challenges they are facing are analysed.

1. Contextualizing the study: urban, sustainability and waste

1.1. Global context and urban areas

Evidence of climate change becomes more and more obvious, leading some scientists to recommend a global transition to decrease the actual human impact on our ecosystem. For instance, concerning the energy field, this will require using fossils fuels more effectively and increase non-fossil sources technologies use. Looking at the food production system, top priorities would be to optimize it in order to produce more food with a better quality on the surfaces already dedicated to it, process with more efficiency and respect for nutritional values and also avoid wastes and losses along the food chain. Our societies recognizing more and more that our current economic development is not generalizable, environment is so heavily used that natural capital becomes its limiting factor and sustainability an ideal to reach, that can be supported by principles such as "convergent innovation", "open innovation" or "mass innovation", themselves being the result of cooperation between different scientific and technical fields (Barnosky et al., 2012; Boye and Arcand, 2013; van der Goot et al., 2016). Cities are considered to be the main site of energy consumption and the United Nations evaluated that 54% of the world's population was residing in urban areas in 2014, this number should rise to 66% for 2050 projections. Already back in 1965, Abel Wolman was stating that the Earth being a closed ecological system, techniques to dispose of waste were not satisfying enough and were supposed to be rethought to be more sustainable.

1.2. Sustainability and socio-technical transition

This context being unsustainable, let us develop around this idea. Three different categories of sustainability can be identified: social, economic and environmental. Social sustainability (SS) relates to a systematic community participation and strong civil society that allows consequences such as social cohesion, shared values or equal rights. Economic sustainability (EcS) aims to preserve capital level through time in a defined system. Environmental sustainability (ES) is closely related to both EcS and SS because it tends to favour SS by maintaining a physical and environmental humanly viable by a good managing of its samplings and waste in natural earth ecosystem, and at the same time, it is often directly in conflict with today's EcS targets (Goodland and Daly, 1996). Given those definitions, a sustainable urban food production facility should be for example well integrated in the local network of people, employing and allowing local people to live in decent conditions, being profitable and at the same time not externalizing environmental strains.

Sustainability principle contrasting with today's societies, we can imagine that transition to another global system is going to be needed, this is where we introduce the concept of socio-technical transition. As Geels (2005) defined, "Socio-technical systems consist of a cluster of elements, including technology, regulation, user practices and markets, cultural meaning, infrastructure, maintenance networks and supply networks". Transitioning from a socio-technical system to another is a challenge because it is a multi-actor process. Actors from different social groups such as firms, universities and research institutes, public authorities, non-profit organisation and citizens who need to gather, negotiate and coordinate their interests, values, perceptions and resources. When considering the transition that needs to occur from our actual economic system toward sustainability, it is especially challenging since their objectives are often in direct conflict. Careful analysis of experimentation about new systems offers a good foundation for adapting policies so it can provide space for said transition, in order to develop both bottom-up and top-down simultaneously. Even when studying carefully successful transition examples, their application to empirical cases remain unsure. There is indeed a recognizable internal logic to transition, but which is greatly affected by every actor interaction, arguments and the need for skills balancing and updating to adapt to the project goals. The main obstacle for translation is that the niche solution is originally created as an answer to originals socio-technical configuration inadequacies, so performance criteria in niche and original system need to match to be able to translate what works in the niche into something that also work in the regime. Importance of niche idealists and regime tensions are known to be crucial ingredients, as well as committed individuals and groups to niches concepts. At the same time, policy should play a role as a mediator to confront, move and adapt ideas and practices to a more sustainable system (Geels and Schot, 2007; Smith, 2007). The niche concept and their central role in evolutionary theories of technical change is further discussed and developed by Schot and Geels (2007) and can be summarized as a "seedbed for change", as they represent the context in which new ideas and concepts emerge.

The idea of socio-technical transition and sustainability both meet in the concept of circular economy as an alternative to our traditional linear systems.

1.3. Circular economy, wastes & losses, industrial ecology and industrial symbiosis

With today's resources consumption rate and the need for socio-technical transition, circular economy is considered as a tool and solution to our linear system. It is designed to be restorative and regenerative in order to always optimize to its maximum every component and material, with the final and global aim to decouple global economic development from finite resources consumption (Ellen MacArthur Foundation, 2015). It is seen as a novelty compared to our current economic preponderant linear model: "take-produce-consume-discard", which is based on the idea that natural resources are limitless and that sustainable waste disposable is not a question to be focused on. Closing the nutrients loop related to food system is doable. With matter it is more complex due to additives, by-products and wastes, the most effective solution being to reduce the food surplus and wastes, and then automatically reducing the flow of matter incoming from the linear economic system. A circular food system would be including three interconnected stages as presented below in Figure 1, as much as this figure is incomplete, it represents the three major stages where local innovative niche solution can be implemented to develop circular economy and thus initiate socio-technical transition (Jurgilevich et al., 2016).

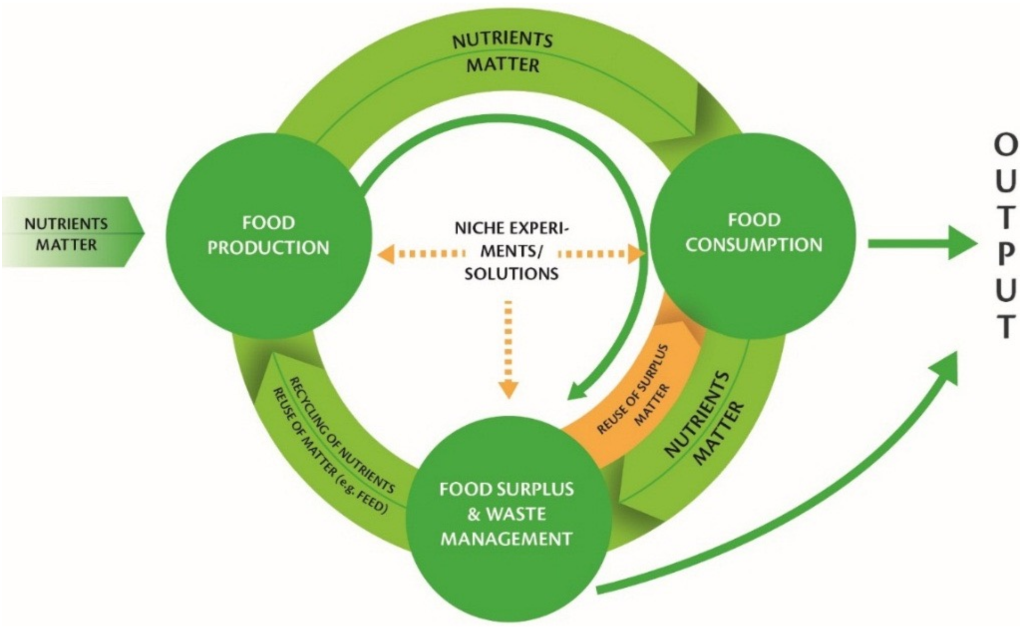


Figure 1: circular economy synthetized as trhee stages. The aim is to reduce wastes by implementing solutions and optimizations at every step (Jurgilevich et al. 2016)

Because behind the actual food wastes and wastes, there is obviously a potential to exploit, many studies are actually trying to define, identify causes, and find solutions to organize more sustainable food systems. The FAO estimates that one third of the total produced food supply is lost within the food supply chain, Kummu et al. (2012) estimated it at one quarter. It means that roughly one quarter of agricultural water resources, cropland and fertilisers are used for food being ultimately thrown away. Also, this inefficiency of the food economy is supposed to cost as much as a trillion dollars, and even two trillion dollars when social and environmental costs are included. From this observation, estimations show that if the current solution allowing minimal losses were to be applied everywhere, approximately half of the food supply chain losses could be saved and probably an extra one billion people fed with adequate food supply and critical resources could be preserved. (HLPE, 2014 ; Gustavsson et al., 2011; Kummu et al., 2012).

When talking about food losses and waste, there is often an issue on defining what they are and in which context they should be used. Many have tried to summarize the different possibilities and it often balances between (Kummu et al., 2012; Betz et al., 2015):

- Considering that food wastes are done until the distribution level in the food chain, and then food losses can be found to the distribution and consumer level. That definition can be relevant in some cases, but not in our case where the supply chains are far for being linear on the whole building and the fact that they try to work on education and alternative solutions from the production to the consumer level without distinction.
- Taking into consideration the intention behind the food wastage: food losses can't be avoided, unlike food wastes that depend on a proper food chain management and consumer education. The issue with this definition being that the source of the responsibility is not always clear and that it implies a guilt parameter to differentiate the terms.

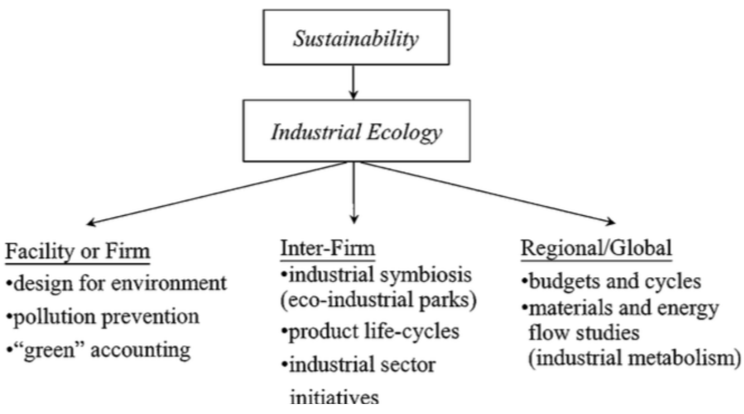
The terms and definition used in this report are those defined by the FUSIONS workshop (2016):

> "Food waste: fraction of "food and inedible part of food removed from the food supply chain" to be recovered or disposed (including – composted, crops ploughed in/not harvested, anaerobic digestion, bioenergy production, co-generation, incineration, disposal to sewer, landfill or discarded to sea).

Inedible part of food: inedible parts of food removed from the food supply chain."

If we consider circular economy's objective and today's food production, industrial ecology could be the industry's answer. Its aim is to close the loop of those components and materials and is defined by Graedel and Allenby (1995) as a concept that "requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them. It is a systems view in which one seeks to optimize the total materials cycle, from virgin materials, to finished material, to component, to product, to obsolete product, and to ultimate disposal. Factors to be optimized include resources, energy, and capital". For the businesses with an industrial ecology approach, wastes become potential resources. The scale of industrial ecology focus depends on the study's subject: facility level, inter-firm level and at the regional or global level. Through a review of potential eco-industrial parks applying industrial ecology's principle, Chertow (2000) has identified 5 types of organization: (1) through waste exchanges; (2) within a facility, firm, or organization; (3) among firms collocated in a defined eco-industrial park; (4) among local firms that are not collocated; (5) among firms organized "virtually" across a broader region. Types 3 to 5 can roughly be related to industrial symbiosis structures. Depending on how the synergy between facilities is organized, it can lead to projects with weak or strong sustainability. Focusing only on technological fixes within the existing market structure does not lead to sustainability as well as innovating both into product and process toward green growth. Industrial symbiosis is considered as a potential solution for increasing sustainability but without knowing yet the extend of the potential impact (Lombardi and Laybourn, 2012).

Industrial symbiosis is "an inter-firm level of engagement between traditionally separate entities in a collective approach, to competitive advantages involving physical exchange of materials, energy, water, and by-products". The three main scale of industrial symbiosis shown in Figure 2 are at the facility or firm level, at the inter-firm level or the regional/global level (Chertow, 2000).



The typical example for industrial symbiosis is the one from Kaldundborg in Denmark, that started in the 1960s between a few businesses and have since then developed and grown every year economically, culturally and environmentally. Multiple energy providers and industrials identified at the time that they could benefit from one another's businesses activities and started exchanging material and services, though the term "industrial symbiosis" would be used to describe the collaboration for the first time in 1989 (Symbiosis Center, 2015). The environmental argument is often brought with the economic one, even if the former is often favoured due to the global context. The environmental point of view implies a more collectivist approach of the available natural resources usage. In the Kaldundborg example, the local water usage was a key point for businesses, as well as energy efficiency optimization. It could be interesting to know in the future the exact role played by individual agency and social factors, especially during the development phase of every new industrial symbiosis project. Indeed, at this early stage benefits are unclear and many adjustments need to be made to allow economical profitability for the businesses involved (Jacobsen, 2006). That flexibility is something that can be hard to achieve from a strict business view.

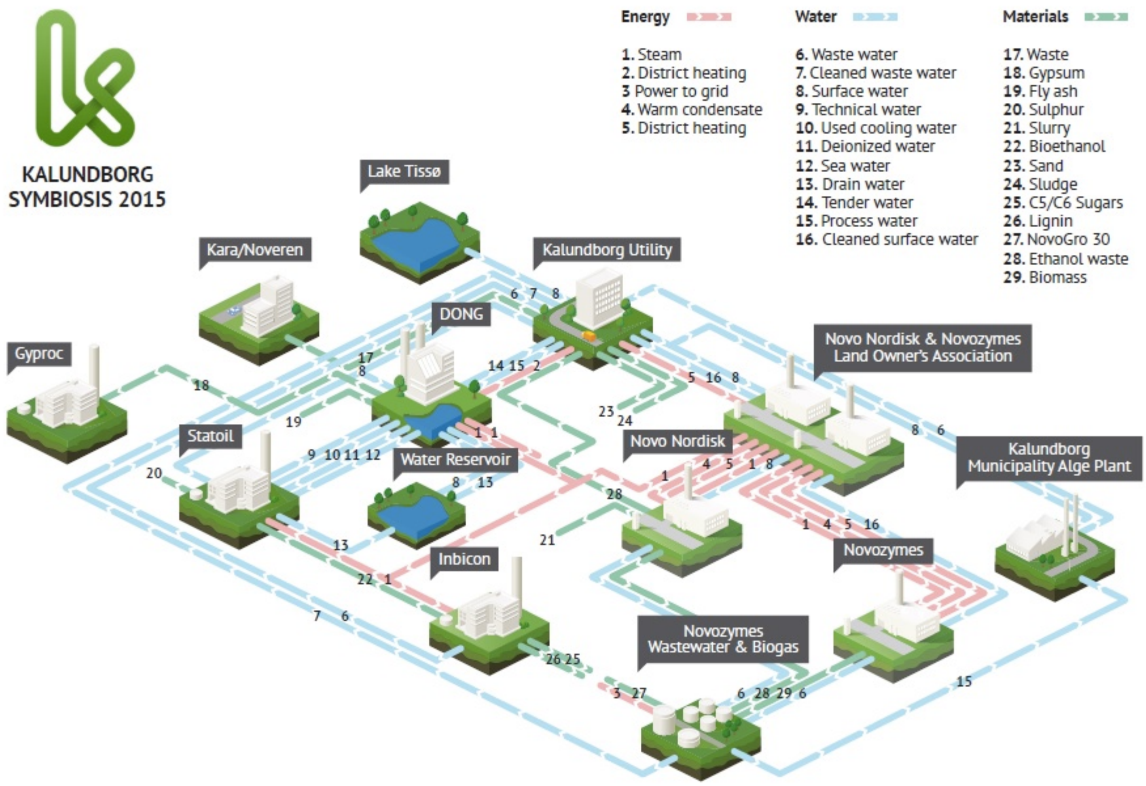


Figure 3: material flow among Kalundborg Industrial Symbiosis Facility (Symbiosis Center 2015)

As said before, if alternative and more sustainable solutions are not implemented, elements lead to expect the energy and food use in urban areas to increase rapidly and the most effective way to identify weak links in an urban system is to study it with a metabolic perspective (Zhang et al., 2010).

1.4. Urban metabolism, material flow analysis

A city can be considered as an entity composed by its inhabitants and all the facilities that compose the city itself. The metabolic cycle of this system is initiated by all the materials and commodities needed to sustain it and closed by the removal and disposal of its wastes (Wolman, 1965). In this context, the key of urban metabolism (UM) is to be used as a concept to understand urban sustainability: (1) to compare resource consumption through the years for a city, or different sectors efficiency; (2) to provide inputs to other types of analysis, calculate a city's greenhouse gas emissions or "urban sustainability indicators"; (3) to understand or model relationship in the urban environment such as how intervention of policies or technologies might change stocks and flows, or the links between urban energy and water consumption; (4) to relate consumption to other dependent variables, to identify particular environmental problems with urban resource consumption (Ravalde and Keirstead, 2015). Given those concepts and sustainability requirements, quantifying material and energy fluxes are a good approach to analyse a city development (Kennedy et al., 2007). Urban metabolism has been used a lot to measure material flows, but it begins to incorporate socioeconomic analysis, policy analysis and additional quantitative methodologies (Pincetl et al., 2012). Urban metabolism concept being the sum total of processes occurring in cities and resulting into production and managing of any kind of waste, this is a really handy tool to globally apprehend a city running and put forward potential flaws and success in said system. Kennedy et al. (2014) identified almost 30 studies of megacities that have used this method.

Material flow analysis (MFA) is based on the "law of conservation of mass and energy". Once a system is defined, it focuses on its input, consumption, storage and output of material. This kind of analysis can result in suggesting potential uses for currently disposed materials and global resources improvements. For example, an MFA application was conducted by Betz et al. (2015) to evaluate the magnitude and potential for reduction of food wastes in the Swiss food service industry. In the two companies they worked with, the annual food waste amount was about 10 and 17 tonnes, the serving losses being the main source. They concluded that more research about the reasons of those losses should be done to be able to deduce solutions and implement them in the food service industry. Doing MFA analysis also allows to produce very visual Sankey diagrams like the Figure 4 below, which was done for the cereal supply chain in France (Courtonne et al., 2015).

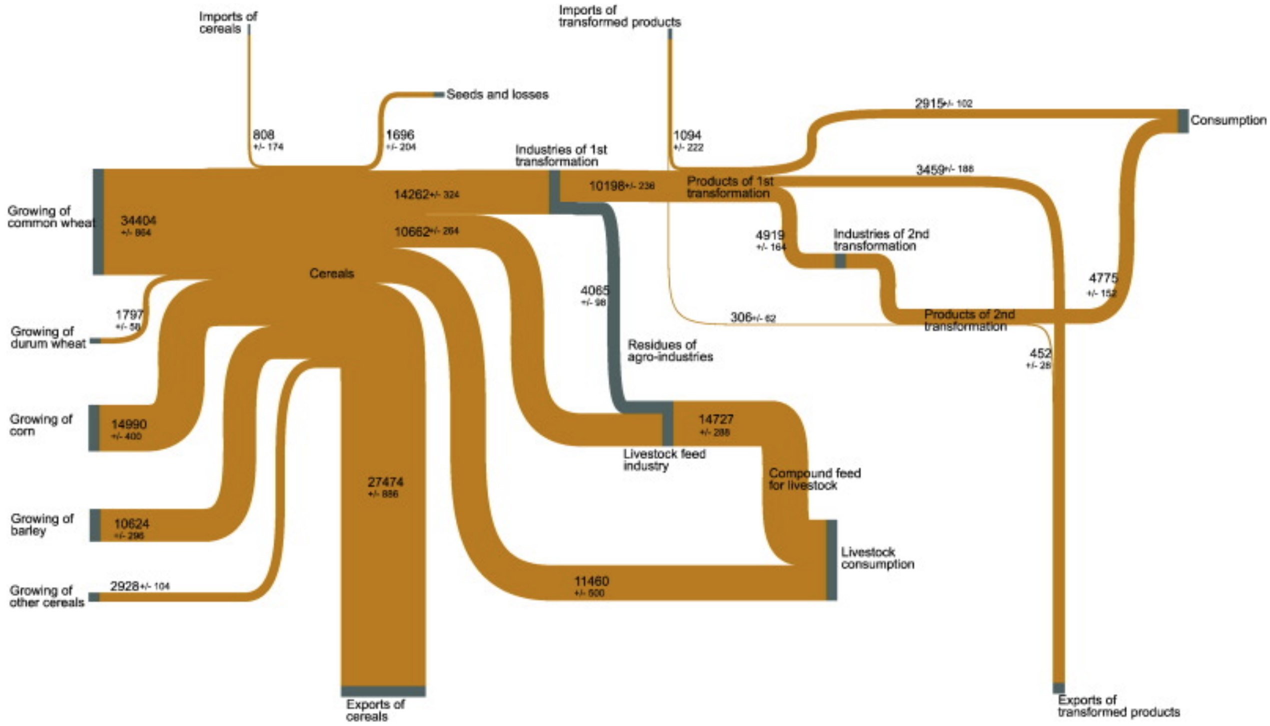


Figure 4: Sankey diagram of the cereal supply chain in France (Courtonne et al., 2015)

Urban metabolism using MFA can be performed using five global steps (Baccini and Brunner, 2012):

1) Identifying the aim of the study and the question that will lead it

2) Defining the system of the study geographically, actors and time-wise, materials that will be followed.

3) Data acquisition by measurement on-site, off-site, experts meeting, estimate the quantities as closely as possible, interviews and routine observations.

4) Materialisation of the results with table, statics or dynamics graphics.

5) Discussion of the results compared with other studies, standards, eventually make recommendation concerning sustainability and/or efficiency.

Before describing the protocol used for applying UM and MFA to this study, a few details about the origin and objectives of this study.

1.5. The study: why, where and how

1.5.1. The collaboration between INRA and CIRAD

The INRA (Institut National de la Recherche Agronomique) and the CIRAD (Organisme français de recherche agronomique et de cooperation internationale pour le développement durable des regions tropicales et méditerranéennes) have gathered their forces to mobilize knowledge about the following aim: to feed 9 billions people by 2050 and supporting the four dimensions the FAO stated about, essentially taking into consideration the planet production capacity, the nutrition issues worldwide, access to food issues and parameters to take into account when considering the food chain. The metaprogram "Transition to Global Food Security", or GloFoodS, aims to put the spotlight on each of these four dimensions, adding to the policies related to food security issues, aiming at a better understanding of the nutritional transitions occurring, agriculture's evolution and land allotment, innovations to counter food wastes, links between poverty and food accessibility.

P&G-City is part of GloFoodS and focuses on biomass cycle in cities, studying urban metabolism in the southern and northern hemisphere cities to have a better understanding of the issues related to wastes and losses, and allow a better management of food wastes in the future. The study priority is to put wastes decreasing as a priority compared to recycling and recovery, with a "zero waste, zero loss" goal and a circular economy perspective. The different systems studied are in the northern hemisphere: Chicago and Montpellier, and in the south hemisphere: Dakar, Antananarivo and Hanoi. The goal is to define and test the UM-MFA methodology on those various systems in order to collect and analyse specific data from different fields related to food production.

1.5.2. The study's localisation: The Plant, Chicago

Bubbly Dynamics is a developer and real estate business that aims to promote an applicable model to the manufacturing sector for ecologically responsible and sustainable urban industrial development. They bought *The Plant* building in 2010 to renovate it and offer a space where food-related businesses can work, innovate and share resources. The building located in Back of the Yards was originally a meat-packaging facility. It has been renovated piece by piece by Bubbly Dynamics and many volunteers ever since, some of them even became businesses located durably at *The Plant* (Bubbly Dynamics, 2016). In Figure 5 the different surfaces of the building are broke down, allowing to see the amount of work required to renovate the building but also shows the commercial potential with still almost half of the commercial spaces not leased or renovated yet.

Bubbly Dynamics aims to create an environmental-friendly building and try to reuse materials on site as much as possible. To move in that direction, they purchased an anaerobic digester and plan to generate gas and also produce electricity with a turbine. The installation can be seen in the Figure 5 in the upper corner of the triangle. They will fuel it with bio-wastes from *The Plant* and the city, and they plan to produce 4,000 MWh, 25% of which will be consumed on site and the rest will be sold to the power grid. The brewery at *The Plant* also purchased an equipment that will allow them to directly use the biogas for heating purpose in their process.

Figure 5: The Plant building numbers, unit in square meters (based on Bubbly Dynamics data, (Chancé, 2016))

Plant Chicago is a non-profit organisation located at *The Plant* to promote the facility, host research and development projects (aquaponics, bio-fermentation, mushrooms lab, algae farming, composting, farming) and create education programs. They see waste as an opportunity, innovation as a necessity, work on bringing people together as community and create open-source knowledge (Plant Chicago, 2016).

The Plant hosts a number of various, more or less collaborating businesses, which could match the industrial symbiosis categories outlined by Chertow (2000) at the facility but also at the inter-firm level. In April 2016, the different businesses located in the building and their main activities are the following:

<u>The urban and indoor farms:</u>

- Bike-a-Bee: beekeeping and promoting beehives installation in urban areas, consulting activities for people to teach them to take care about beehives
- Farm Box: research and development, consulting about indoor farming
- Fruiting Mushrooms: vertical mushroom farming
- Mycofloral farm: cut flowers farm
- New Magnolia Garden Center: cut flowers farm
- Nick Greens: research and development, consulting about indoor farming
- Patchwork Farms: urban farming
- Pleasant Farms: urban farming
- The Urban Canopy: urban farming and community gathering activities

<u>The beverage-related businesses:</u>

- Arize Kombucha: kombucha brewery
- Whiner Beer Brewery: beer brewery
- 4 Letter Word Coffee: coffee roasting

<u>Other businesses located at *The Plant*:</u>

- Great American Cheese Collection: collecting, promoting and selling artisan cheese
- Just Ice: clear ice producers for professionals
- Pleasant House Bakery: artisan bread and pastries
- Rumi Spice: partnership with afghan saffron producer to sell it in the US

1.5.3. The study's objectives

This master thesis explores the urban metabolism and material flow analysis methods to measure flows on an innovative urban food production facility: *The Plant*, Chicago. The urban metabolism method is used to contextualize *The Plant* in the urban environment and the links with that environment. For example, when studying part of the bread supply chain and the wastes it generates. The methodology used the most is the material flow analysis.

There are two specific objectives:

- Have a global overview of the whole facility and the flows and exchanges between the different businesses, based on their declarations.
- Specifically focus on a type of good and measure the local food wastes at the distribution level.

Exploring two contexts: a facility and part of a supply chain, allows to test the material flow method and outline its perks and limits on specific field conditions. The interest is also to see how that methodology can fit a new facility, with coming and going young businesses and with circular economy principle such as *The Plant*.

2. The study's protocols

2.1. *The Plant* global material analysis

The global material analysis took the months of June and July 2016 to meet the tenants, explain the methodology, get the questionnaires back and create the codes on Python for the diagrams.

The first step was to define *The Plant* limits for the study and build the questionnaire. Then ask the businesses to give their principal flows for the months of March, April and May 2016, for the different categories and using the questionnaire (Annex 1). Then collecting the data and finally including them in the code created on Python to make the diagrams.

The limits of *The Plant* were considered for this study as the geographical limits of the facility (as seen in Figure 5) and the imports and exports made on site and from the site. The aim was to try to figure out what were the activities hosted and the goods produced on the facility.

2.2. Protocol adaptations for *The Plant* data collection

Collecting the data with standardized units was the first and major issue. For the material such as compost and packaging wastes, the usage unit is often in volumes, we then used the document by the (Environmental Protection Agency et al., 2006) for volume-to-weight conversion factors. Even with the equivalences, it is still complicated for users to gather quantitative information about items they do not usually quantify, like for example different categories of garbage. This is even more noticeable if the businesses are rather small because they often perceive they wastes as insignificants. Another typical example is woodchips: the usual unit is in volume and the density of the product highly depend on the tree type, so even the company responsible for delivering woodchips was not able to give us a volume-to-weight equivalency.

This also arise the question of the unit in which garbage should be measured. Material flows are measured in weight, but garbage are often evaluated in volumes units such as a number of bags or containers, even by the public service that pick-up wastes in Chicago. Even for material that are supposed to be easy to quantify such as water or ice, it can easily become challenging for the businesses to know exactly what quantities they are using and wasting. The only official documents available are their input and energy bills, as well as the goods they are selling. Because of the unconventional and complex nature of the data gathering process, the businesses need time to collect and estimate, and often exchange with the team collecting the data to check numbers, units and labels.

Asking for the inputs and outputs on three months only causes the following issue: for some businesses, it would look like they forgot to mention some inputs because they would not have any for three months. For most of them, the reason is that they would have made the orders in January and we studied the numbers from March to May. The reasons were various depending of the business, either it was low season, their first months of activity or they ordered products that could be easily be stored in their business space. For some businesses, the material analysis would be more eloquent by asking what material they used for their processes as an input during the three months.

One of the critics of the MFA is that it aggregates data and thus looses specificity and some of its relevance for policy decision making. It is then crucial to choose the right materials to materialize flows that are related to the subject (Loiseau et al., 2012; Krausmann et al., 2015). For this reason, we choose to ask the businesses to give us all their inputs and outputs that they could think of, so we could decide which one to take into consideration depending on our focus: food, organic wastes or amount of plastic packaging.

The questionnaire was created to fit all kind of businesses of different size and types. It has proven quite complicated to fill out for them, even with one-to-one explanations. The explanations had to be specific and brief, and they sometimes were misunderstood. For example, using “water waste” was intended as “all the water that goes out of the system without being part of a finished good” and it was misleading to some people because they would only write down water that goes directly to the sink and not the water that could be evaporating off of indoor farming system, for example.

The questionnaire was forwarded to the businesses in pdf, as a word document and also on paper, and all the businesses gave it back on paper. Many reasons can be at the origin of that observed behaviour, but it has to be taken into consideration when thinking about an alternative way to gather data such as an online survey, although some of them have expressed interest toward an online survey that they could fill out every month to be able to make easy yearly review.

2.3. The bread supply-chain study

The wastes have been followed for approximately three weeks in July and August 2016, with three bread production per week, so three deliveries per week: Tuesdays, Thursdays and Saturdays. The wastes were followed at the bakery and their market at *The Plant* site, their other market, and four retailers in town.

The participants were asked, if possible to follow the wastes for every specific type of bread and also to track down the amount processed through their different selling strategies. All details about the different shops and their selling strategies can be found in Table 4.

2.4. Protocol adaptations for the bread supply-chain study

At first, the data collection was supposed to include going to every location and weight all the wastes there, but it seemed that the participants were more at ease with counting the breads themselves and reporting back the data at the end of the three weeks. The conversion from bread numbers to weight was done for some calculus and using the bakery standard weight.

I went to all the locations to interview them, know their routines, how they were presenting the bread in each store and get an idea of the atmosphere and philosophy of the retailers locations.

3. Results and discussion

3.1. Previous data collected at *The Plant*

During summer 2015, an intern from the Illinois Environmental Protection Agency collected material flows and did estimations of the energy and material consumption from May 2014 to April 2015 at *The Plant* (Table 1). He interviewed the fifteen different units and businesses at the time: there were a shrimp farm, a food scraps collector, the kombucha business participated in that study and the coffee roaster and brewery business were in the process to move in. He also estimated that without water misuse, the average water consumption of the building was of 34,800 gallons per month (Cordero, 2015).

	Inflows (lbs)	**Outflows (lbs)**
Material	713,917	
Landfill		1,555
Recycled		66,272
Composted		184,408
Goods Produced		405,026
Inventoried Items		433,051

Table 1: mass transfert analysis estimation from May 2014 to April 2015 (Cordero, 2015)

3.2. *The Plant* global material analysis

3.2.1. The Plant free exchanges material flows and water flows

The material flow analysis of *The Plant* allowed the collection of all the inputs and outputs that the businesses could think of. By doing it in June while they had been informed of the project a couple weeks beforehand, one of the most obvious factors of errors is that they may have forgotten about some of the flows. If they had been informed upstream, some of them may have been able to start collecting numbers.

At first, the material and water diagrams were supposed to be combined into one, because some of the main production in the building are water-based, such as beer, kombucha and ice. But in the end, there is such a huge differential between the quantities of water that are used compared to most of the material flows that it seemed more logical to separate them. It was also more interesting to have a full very visual water flow diagram and a material diagram representing only the effective and potential yearly free exchanges between the tenants.

The exchanges presented in Figure 6 have not been represented number-wise because almost all of them are very small experimental streams with quantities in the order of 20 to 50 pounds during the three months of collecting the data, and also exchanges for which the tenants did not necessarily think about mentioning, even less quantifying. The only regular major exchange is the flow of spent grain going to Bubbly Dynamics to be composted on site: 56,000 pounds (1 pound ~ 0,450 kg) during the three months of data collecting. There was also a 53,663 lbs compost donation from Bubbly Dynamics to Mycofloral but it is supposed to be punctual. An example of promising collaboration between tenants is the biobricks project. A summer intern has worked with Plant Chicago to use spent grain from Whiner Brewery to make biobricks that could be burned in Pleasant House Bakery's wood oven and thus reusing wastes to create a useful resource on site. The figure shows that the businesses are actually trying out lots of new ways to reuse wastes and collaborate at the facility level. It is really interesting in terms of exchanged knowledge flows, adding to the original material flows. It is also worth mentioning than depending on the size of the business, reusing a little bit of some material into its process can represent a major money saving.

Adding to the knowledge flows between tenants, there also are lots of interactions with Chicagoans, including public tours organized by Plant Chicago. Indeed, many businesses and most of all, Plant Chicago have interns and volunteers who come and work at *The Plant* all year round. Since the structure's aim is to research, inspire, educate, the knowledge flows that goes to the city and beyond through those channels would be really interesting to measure. Those features are outlined by the ISO 26000 and it would probably be useful to create a methodology to audit and outline the cultural and knowledge flows that those new atypical structures are part of to add up to more traditional audit methods such as the material flow analysis.

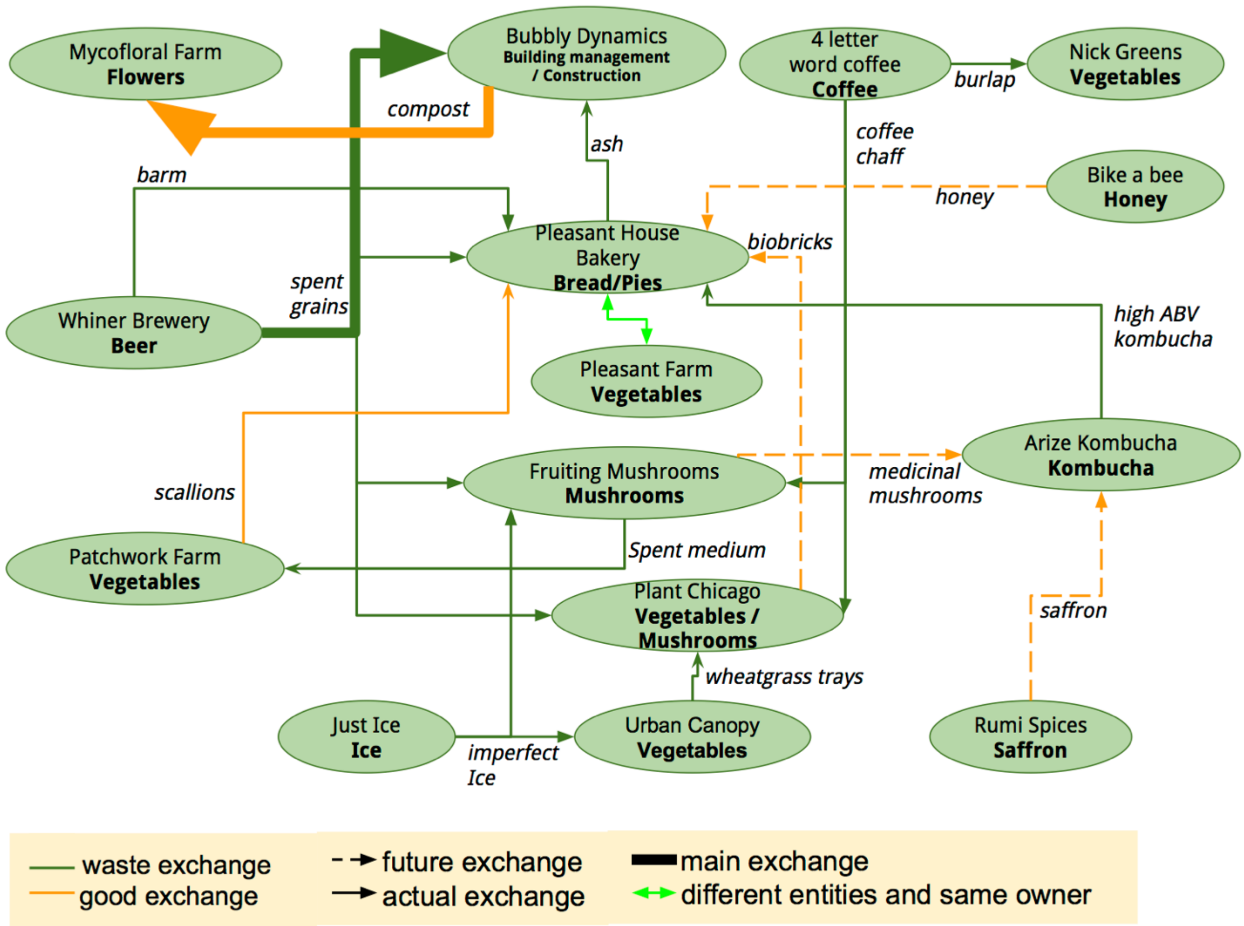


Figure 6: qualitative free flows exchanges between the businesses at The Plant (Chancé, 2016).

Specific diagrams were created for electricity (Annex 3) and water (Figure 7). The electricity diagram does not have much information on it because many businesses actually barely use any, some of them have their minor electricity use included in the rent and do not have specific meters. This was also an issue with the water diagram: some of the water numbers are from Bubbly Dynamics meters and some are from the tenants' estimations related to their process, which lead to a significant error parameter. When there was a gap between the water

going in and out of a system, it was sometimes labelled as "process water" that the businesses forgot to mention, or considered as water evaporation and so on depending on the case.
The 3 businesses with the more water usage are the brewery, the ice cubes business and the mushroom business. The brewery makes sense, because they have a large production equipment, a water consuming process and of course water as a main ingredient. At that time, they did not have the authorization to sell their beer yet, which is the reason why there is wasted beer. In normal conditions, about 35% of the water flow would go to the beer sold. The total amount of waste water is 45,086 gallons for the three months. There are university projects starting this year that are actually interested into analysing the brewery waste water to evaluate its potential to be reused on *The Plant*. The ice business uses lots of water but has a merely efficient process with almost 65% of it going to their sold finished product and they also plan to find a way to pump the waste over mineralized water up to the urban gardens. Considering the mushroom business, the water amount seems surprisingly high compared to the 600 pounds of mushroom produced during that time. It actually makes sense because the process is significantly water-demanding and there also have been some production problems causing the productivity to go down since a few months.

A secondary water system at *The Plant* is actually something that Bubbly Dynamics is considering to build. That system could allow to divert all the reusable wasted water from going straight to the drain and be used for example to water the gardens outside. It should be taken into consideration that water is not a scarce resource in Chicago. The city being located on the shore of Lake Michigan shore, that presence could relatively lead Chicago city to think they have an "unlimited" source to use and the secondary water system would probably be more expensive to install than just paying for full clean water usage. This is typically the questions raised by Jacobsen (2006), Geels and Schot, (2007) and Smith, (2007): the niche concept, here having two functional water system in the same building, and the interaction between policy, businesses and entrepreneurs' willingness and opportunities. Investigating the water usage and materializing it with the diagram is really interesting to be able to evaluate the potential of water recycling in the building and make plans to act on it.

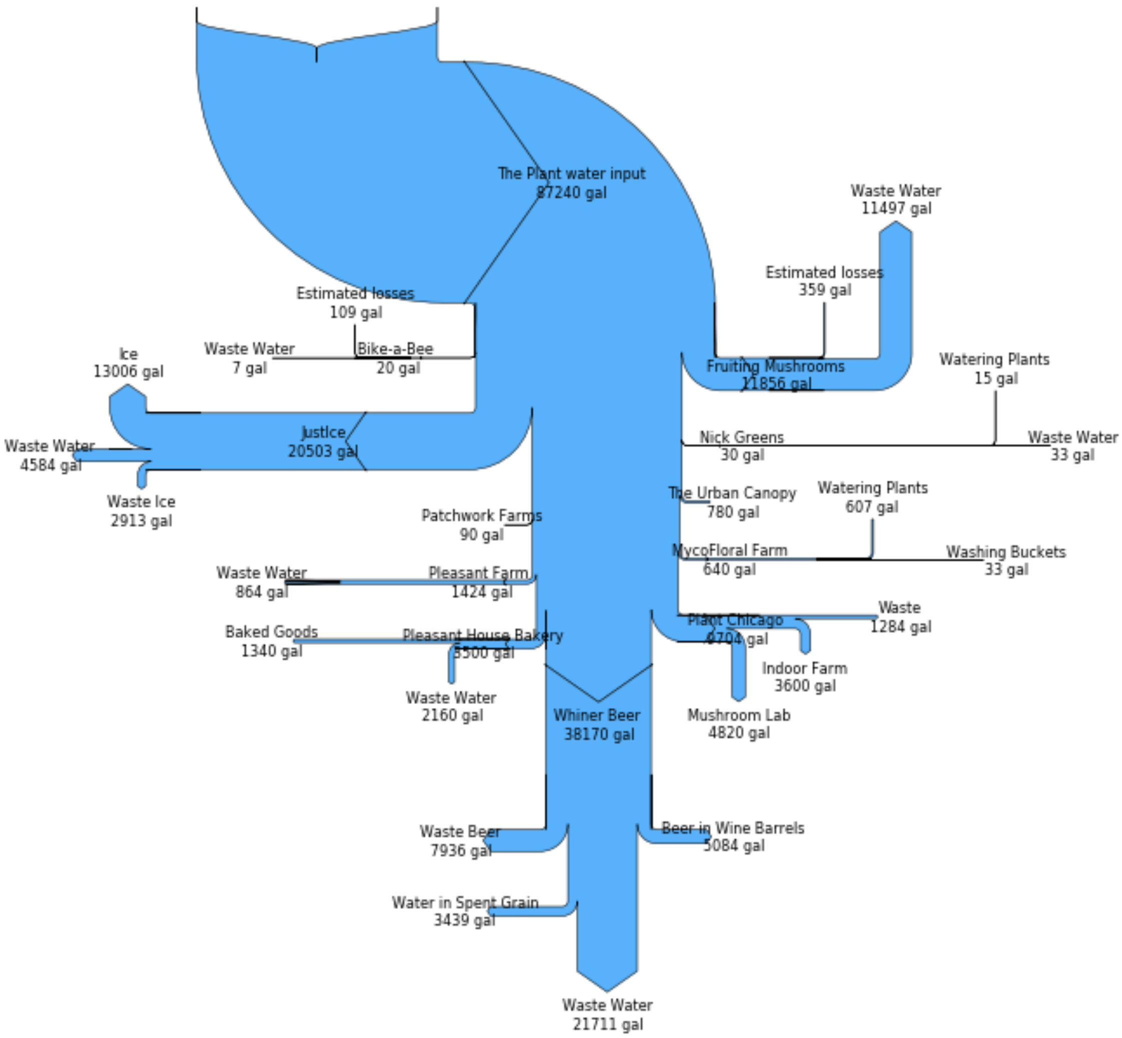


Figure 7: The Plant water flows in gallons (1 gallon ~ 3,8 liters) for the months of March to May 2016 (Chancé and Noberto, 2016).

3.2.2. The individual businesses' diagrams

Having individual business questionnaires allowed to build input and output diagram for each of them. Out of a total of 16 businesses, 13 were able to participate into the study. Only three of them are being presented here as samples of the diversity located on *The Plant*. The rest of the other diagrams can be found in Annex 2.

The bakery is the typical example of a business based on a multiplicity of products with two core ones being the pies sold in Pleasant House Pub and the breads sold on site, through a local market and in retailer's shop. They are a well-established in Chicago, with a solid customer base. The diagram (Figure 8) shows that it is difficult to keep track of all the input and output when there is such a diversity of products and especially the small flows. The bakery was able to give that level of details because they themselves are tracking most of their material flows.

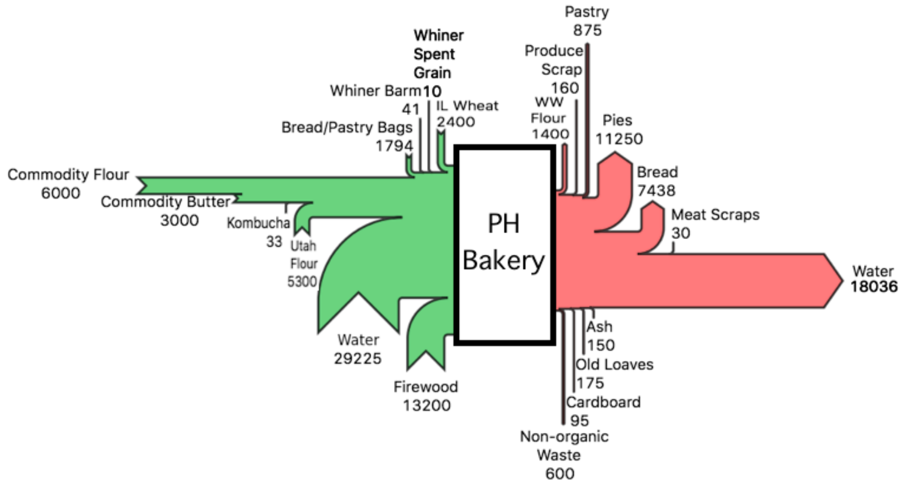


Figure 8: material flow diagram of Pleasant House Bakery, unit in pounds (1 lb ~ 0,450 kg)) for the months of March to May 2016 (Chancé and Noberto, 2016).

The diagram for Mycofloral business (Figure 9) shows different information. First, that the food-related business, especially the outdoors ones, are often highly seasonal. Chicago is located in the north of the United States, with temperature ranging between -30°C in winter to more than 35°C in summer, the precipitation frequency is quite irregular but with heavy and short rain period, especially in summer, often paired with storms. It means that the period for the data gathering being from March to May 2016, this is the beginning of the season for all the outdoors products. The farmers are mainly preparing soil, sowing and are barely harvesting yet.

Adding to that, a few businesses moved in or started their activity during that time, like Mycofloral, Just Ice, Whiner Brewery. The data give an estimation of what the businesses do, but they cannot represent their regular business activity and they cannot be translated to a monthly ratio. It would then be interesting to collect the same data during the summer season or even to do it for a full year. At the facility scale, the main difficulty for yearly comparison would be the coming and going rhythm of the business installation in the building. Even for this study, the mushroom business has moved out to another location this September 2016 and the kombucha business may have time to give its data for the next study, changing the whole water and material flow.

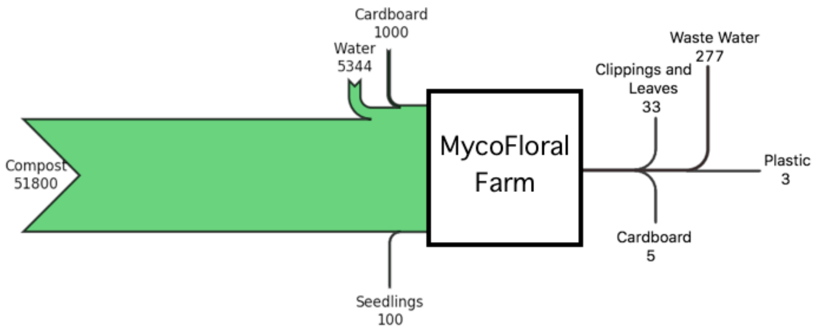


Figure 9: material flow diagram for Mycofloral Farm a new cut flowers business, unit in pounds (1 lb ~ 0,450 kg)) for the months of March to May 2016 (Chancé and Noberto, 2016).

Figure 10 was interesting to create because Plant Chicago has two major activities which are the indoor farm and the mushroom lab, both requiring lots of time because they are continuously experimenting to be more efficient or to try new medium and technics. Like in every business growing plants, the main input and output is water. It also shows the amount of water required to grow mushrooms from inoculation to finished product and also waste water as a potential input for outdoors gardening because it could be packed with nutrients. If an entity has two distinct activities, it is really useful to visualize them separately.

This also shows that when calculating and estimating water wastage amounts, the results can be unexpected. Indeed, the water flow going in the system is smaller than the one going out. While the total water input was calculated from Bubbly Dynamics water bills, the water output was estimated from equipment manual and professionals' estimations.

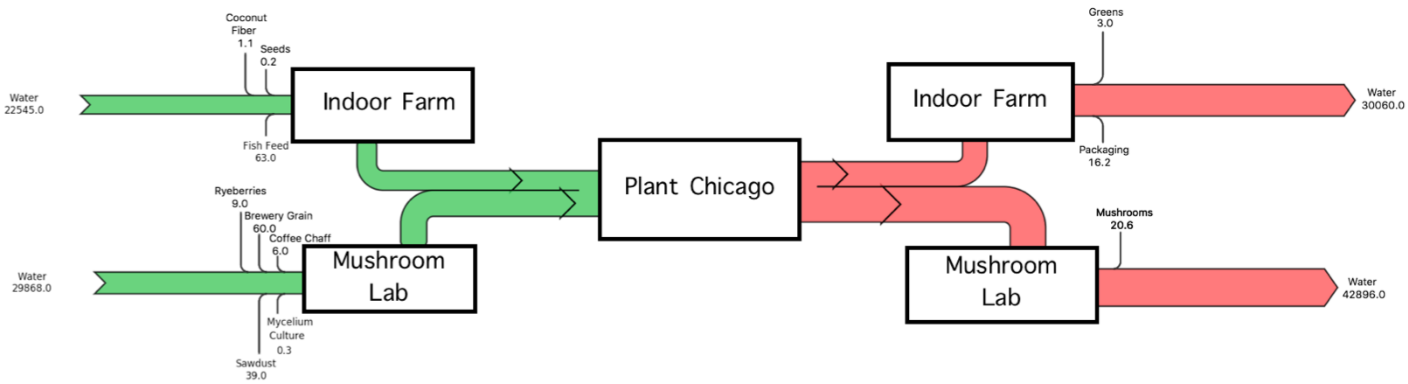


Figure 10: material flow diagram for Plant Chicago the non-profit organisation at The Plant, unit in pounds (1 lb ~ 0,450 kg)) for the months of March to May 2016 (Chancé and Noberto, 2016).

3.2.3. Conclusion for The Plant global material flow analysis and perspectives

Last year estimations were done in average number per month and for the total year by Cordero's audit (2015), which does not let us strictly compare numbers to numbers. But we can observe that the data collected in three months (Table 2) represents way less materials and water than last year estimations for a similar period. The distribution of the various categories is different too. The differences can come from the facts that the main activities have changed at *The Plant*, or the way the data are collected and estimated, or the seasonality were unlike.

For this study, the mass balance is obviously distorted with 53% more outflows than inflows. This is probably because of various data collecting bias mentioned in the protocol that need to be addressed to find a better collection strategy. For example, collect data month by month for a whole year, interview the businesses upstream so they can thing about mentioning all the items, choose if the data should be what is imported/exported or what is used/produced, or find a convenient way for weight and wastes managing in the building.

The two major wastes outflows are the amount of material directly reused on site with 57,065 lbs and the landfill with 42,817 lbs, closely followed by the goods sold outside the facility with 35,211 lbs, respectively 42%, 31% and 26% of the total material outflow. Although the landfill and sold goods amounts are composed of multiple and small streams, almost 98% of the material circled back in the system are in fact the spent grains from the brewery. This business has a capacity production of more than 5580 gallons of beer in six batches per months. If the production rate rise, it could have even more spent grains to process as organic waste in the year to come than the 24,000 pounds in the most intense month and the total 56,000 pounds managed from March to May 2016 by Bubbly Dynamics. Spent grains is a major bio-waste at *The Plant* on which a handful of projects are focused (Figure 6). When the anaerobic digester will be operational, it is supposed to be able to process 13 US tons per day, so about 26,000 pounds of bio waste. It shows the importance of such a project to assimilate bio-waste at *The Plant*. Even if the compost made with the spent grains at the moment is valuable for urban farming, producing energy to use and sell would be even more profitable and efficient.

It is worth noticing that the composting activity at *The Plant* has been separated in two categories : the “Composted” material flows category represents all the small amount of various food scraps that are collected and composted in a container and can be considered as non-intensive composting that is not yet reused by the farm businesses. On the contrary, the spent grains composted by Bubbly Dynamics are included in the “Reused on site” category. The flow is really intensive, spent grains are mixed with collected woodchips from the city, this compost requires lots of care and mechanical work to be processed through. It is a very demanding process

		Inflows	Outflows	
			Out of the facility	Circled back
Material flows	Material (lbs)	59,810		
	Landfill (lbs)		42,817	
	Recycled (lbs)		697	
	Composted (lbs)		1,723	
	Reused on site (lbs)			57,065
	Sold goods (lbs)		35,211	
Water flows	Water (gal)	87,240		
	Waste water (gal)		45,086	

Table 2: material and water total estimated usage from the months of March to May 2016 at The Plant (1 lb ~ 0,450 kg; 1 gallon ~ 3,8 liters) (Chancé, 2016).

The questionnaires were a great source of data about what is going on in *The Plant*: to visualize the flows between the businesses and the potential reusable wastes, to show the businesses that they are part of a more global system, thus increasing the “closed loop system”. The questionnaires also collected the projects that they plan to implement short and long term. A few example to add to the one already mentioned above are building a landscape berm at the back of *The Plant*, collecting rain water and build a bee water and flower garden on the rooftop, or increasing recycling and reduce wastes.

The second project was in close partnership with Pleasant House Bakery to follow their bread sells and wastes at their own shop and also to some of their retailers’ shops.

3.3. Bread supply chain study: local wastes management strategies

3.3.1. The choice of the bread supply chain

Among all the goods produced at *The Plant*, the bread from Pleasant House Bakery (PHB) was selected because it is a fresh product with a limited shelf life and a staple food product. For that reason, it has a good turnover in the shops and the retailers may not take a special care to not waste it.

3.3.2. Specificities of the Pleasant House Bakery bread

The main types of breads that are sold by PHB are listed in the Table 3 below, the baguette (380 grams) and half baguette (150 grams) were included in the study even if they are not in the table. PHB also sells pastries and savoury goods such as sandwiches and focaccias.

				
Breslin wheat sourdough: house levain mixed with locally grown, organic heirloom wheat from Breslin Farms	**Multigrain**: levain boule with sesame, Wisconsin cornmeal, poppy, organic oats and local rye	**Rugbrød**: traditional Danish, dense rye bread with 100% local rye milled in the bakery seeded with flax, sunflower, and millet	**Durum**: North Dakota durum wheat levain with natural nuttiness and slight tang	**Ciabatta**: traditional chewy, light loaf mixed with local rye flour
720 grams	720 grams	850 grams	720 grams	510 grams

Table 3: the principal kind of breads sold by Pleasant House Bakery (Chancé, 2016)

PHB aim is to produce a high quality bread, with carefully chosen, sometimes locals ingredients, great technics to respect ingredients and consumers. For example, they make their own phyllo pastry with which they prepare all kind of pastries, including excellent croissants.

3.3.3. PHB's sells and strategies

PHB is selling its products on site at *The Plant* in the bakery, at Plant Chicago's Farmers market and at the 61st St. market every Saturday, and also at the Pleasant House Pub where the goods are included in some of the items on the menu. Their selling strategy is the following: they usually sell the most at the 61st St. market and through the retailers so they base their production amounts on those two, using *The Plant* as a buffer amount where they can sell the leftovers and eventually have less products available to favour the best-selling units. The retailers' weekly orders being quite steady and the 61st St. being close geographically from *The Plant*, they can plan their production quite easily and restock the market during the morning if sells are good. The breads unsold during bakery days are either given for free to the employees, to close friends or people from *The Plant* and finally all the leftovers are composted on site. With those strategies and the wastes considered as "all the breads not being sold", the wastes amount for the 61st St. market in 3 weeks is 2,5%, most of them being sampled for customers. The wastes at *The Plant* are around 20-30% which is understandable since the potential wastes from the 61st St. market are transferred on *The Plant* numbers.

PHB are extremely concerned by sustainability and quality issues, they are very transparent and take every opportunity to reflect and search better ways to do business. They also closely work with volunteers at *The Plant*, doing workshops, training bread makers to good business practices.

3.3.4. The retailers' specificities and strategies

The retailers participating in the study are all listed with their characteristics in Table 4. They are what would be considered as "organic shops" in France, although the regulation for selling organic food products is not the same in the United States. For instance, the shops all have the willingness to sell organic and local products, sometimes both combined. Two of the shops are also co-op organisations, with consumers eager to be included in the products choice. Considering those parameters, we can assume that their customers are going to be looking for high-quality goods such as PHB breads, which are different than traditional and mainstream “American bread” which is whiter with a softer crust.

Anonymous code	R1	R2	R3	R4
Type of structure	Co-op	Co-op	Independent	Independent
First year of activity	2009	2015	2008	2008
Shop size (m^2)	102	511	74	74
Customers/week	1400	2300	1000	327
Bread selling routine	a) full price for 2 days b) on the 50% shelf for 1 day c) pantry donation for the appropriate products	a) full price for 3 days b) on the 50% shelf for 2 days c) staff room / composting	a) full price for 2 days b) on the 50% shelf for 1 day c) on the free shelf for 1 day d) donation box (collected 2 times /week)	a) full price for 2 days b) on the 25% shelf for 1 day c) giveaway to staff / clients, composting
Average share of organic and local goods sold in the shop	60% organic, 40% conventional 40% local (160 miles radius from Chicago) on the total	50% organic, 30% local	About 1/3 local, 1/3 organic, 1/3 local & organic	10% local (regional) and a bit more in summer, 15-20% organic. Some local produces can be organic but not certified.

Table 4: characteristics of the four retailers participating in the bread supply chain wastes study for 3 weeks in July and August 2016 (Chancé, 2016).

As described in Table 4, the shops all have various strategies to avoid food wastes and they all seem very concerned with finding ways to waste as little food as possible and to avoid landfilling it. They compost and also have partnerships with collecting organisations. In general, they sell breads full price for a few days, then half the price for one or two days, and then they either give breads to their customers, their employees, to food scraps collecting network or compost it. With all those strategies, during the 3 weeks of the data collecting, no breads went to landfill so about 21.5% of the total delivery amount, which represents 65 kg, was diverted from it compared to a situation where bread would be landfilled after 1 or 2 days on the shelf.

Having a closer look at the different shops strategies, R1 reported that they were ordering just enough bread so they would not have to find a way to dispose of it if not sold. They actually preferred to be out of stock for a day between two deliveries. That strategy seems to pay off since they sold all their orders full price during the 3 weeks, that also means that they may have a potential to sell even more bread. R2 is a new Co-op in Chicago with already a solid customers base. They seem to have a good ordering strategy since they sold 91,5% of the breads full price. R3 is the shop that seems to struggle the most with the ordering amount they have. Indeed, they only sell 50% of their orders at full price, which represent an obvious loss for them. Plus, they sell 36% of their order with a 50% discount. That situation can be explained because they seemed to be in financial difficulties last year and the management position changed a few months back this year. When meeting one of the co-manager, she said that they were really looking at ways to reduce wastes in the shop. Finally, R4 are selling 95% of the deliveries full price. It seems that they have a solid customer base coming to specifically shop for PHB bread at delivery days, because many of them were very confused when one of the delivery days switched from Monday to Tuesday in June.

The retailer part of the study was really interesting to conduct because it shows that when businesses want to avoid food wastes, numerous strategies emerge and are actually efficient to divert food from landfills.

3.3.5. Conclusion for the bread supply chain study

The strategies of the retailers and PHB seems to fit the three different categories of the Food Recovery Hierarchy created by the US environmental protection agency (Figure 11) :

carefully choosing the amounts ordered, mostly keeping the same order from one week to the other so production is easier to plan for PHB, and different strategies to sell day old bread (with a discount, giving it out for free and composting). They also concord with the diversity of solutions that seems to exists in the retail sector (Figure 12) (Dou et al., 2016).

Figure 11: different food recovery hierarchy strategies to reduce food waste (United States Environmental Protection Agency 2016)

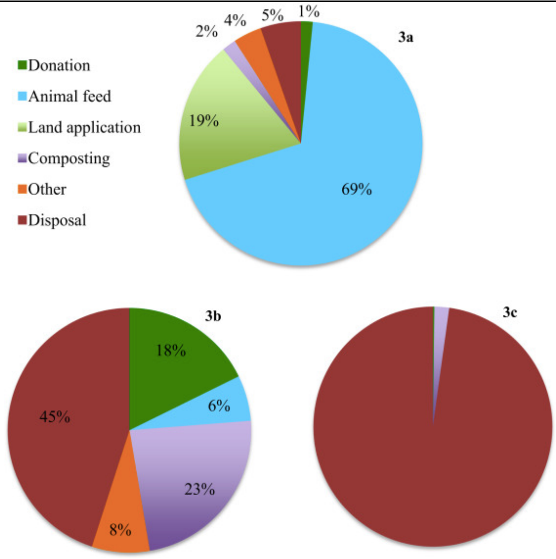


Figure 12: Recovery and diversion of wasted food in food manufacturing (3a), retail-wholesale (3b), and consumer sectors (Dou et al. 2016).

In (Tesco and Society and Waste and Resources Action Programme, 2014) the retailer Tesco did a data collecting operation on its value chain network in the UK. It has evaluated the wastes profiles for its 25 most purchased products and compiled them with the numbers collected by WRAP for household's wastes. WRAP or Waste and Resources Action Programme is a non-profit organisation that works in the UK with governments, businesses and communities to improve resource efficiency. They found out that retailers are responsible for 1% or less of the losses, and when considering white sliced bread, that producers and consumers are mainly responsible for those losses (respectively 16 and 23% of the total production). This is far less than the 21.5% that we found in our study. Although, R3 could be considered as in transition phase to a better waste management. In that case, when doing the numbers again with the 3 retailers left, the wastes numbers drop to 5%.

It is worth mentioning that although official retailer numbers seem to be encouraging, the main reason is that they transfer some of their wastes down and upstream in the food chain. By trying to answer to the consumers' every needs and trying to sell as much products to them, they have a great operating level on the amount of food that ends up in the consumers' kitchen and also on the orders with the food industry. In its report *Reducing food wastes – How can retailers help?*, the management consulting company specialized in industry strategies (Oliver Wyman, 2014), outline those elements in four measures that can help retailers decrease the pressure on suppliers and consumers. At the supplier level it translates with possibilities such as collaborating more on demand planning to avoid orders peak effect caused by weather and promotions, also manage grading requirements and quality control to ensure that products are not refused by the retailer without a good reason. As for helping consumer to waste less, they can have fresher food with a longer shelf life, but also help customers buying only what they will eat by providing clearer information on the shelf life for the products they are buying and provide them with packaged amount that they can reasonably consume, an issue that can be risen in some promotions with extra large amount of fresh food sold at once.

To go further into this subject, it would be really interesting to study the customers' behaviour regarding the bread once they bought it and to see if they waste it less than the white sliced bread sold at Tesco. Indeed, it seems that since PHB is a locally made bread with high quality ingredients, people could be more careful about not wasting it. Consumer studies are of major importance when transitioning to more sustainable practices, to see if people's behaviour can be impacted in the right direction.

Conclusion

By using the UM-MFA methods on *The Plant* structure with two objectives: a global overview and a supply chain study, many subject, challenges, potential explorations are addressed and raised. This is especially complex because the facility and the tenants are part of a global economical, ecological, social and political ecosystem that has challenges and issues at the local but also national and international scale. It is challenging, but also exciting and *The Plant* represents a serious alternative to traditional linear business. Being in a transition with lots of research and development, the facility needs time, work, flexibility, commitment, money and also policy support. Indeed, some specific authorisations were delivered for the first time to fit the innovations needs, such as the one to be able to raise animals destined to human food indoors in the aquaponics farming system.

Collecting material flows data and being able to materialize those flows is really useful for the facility and also for some individual businesses in order to have an overview their activity, see the potentials and plan for the future. Those data and observation are also going to be reused by the next interns, for the future collaborations with different universities and for communication and education purpose to promote *The Plant*.

Finally, as mentioned before, although the material and wastes-related projects that will arise following the data collect are of major importance, it would also really be interesting to dig into the customers' behaviour subject. To investigate more directly and more intimately how much influence is *The Plant* having on the local and global ecosystem, acting for a sustainable socio-technical transition.

Bibliography

Åsa S., Jensen C., Quested T., and Moates G.. 2016. “FUSIONS - Estimates of European Food Waste Levels.” IVL Swedish Environmental Research Institute.

Baccini, P., Brunner, P.H., 2012. Metabolism of the anthroposphere: analysis, evaluation, design, 2nd ed. ed. MIT Press, Cambridge, Mass.

Barnosky, A.D., Hadly, E.A., Bascompte, J., Berlow, E.L., Brown, J.H., Fortelius, M., Getz, W.M., Harte, J., Hastings, A., Marquet, P.A., Martinez, N.D., Mooers, A., Roopnarine, P., Vermeij, G., Williams, J.W., Gillespie, R., Kitzes, J., Marshall, C., Matzke, N., Mindell, D.P., Revilla, E., Smith, A.B., 2012. Approaching a state shift in Earth’s biosphere. Nature 486, 52–58. doi:10.1038/nature11018

Betz, A., Buchli, J., Göbel, C., Müller, C., 2015. Food waste in the Swiss food service industry – Magnitude and potential for reduction. Waste Manag. 35, 218–226. doi:10.1016/j.wasman.2014.09.015

Boye, J.I., Arcand, Y., 2013. Current Trends in Green Technologies in Food Production and Processing. Food Eng. Rev. 5, 1–17. doi:10.1007/s12393-012-9062-z

Bubbly Dynamics, 24th of June 2016. Chicago Sustainable Manufacturing Center. Seen on: http://www.bubblydynamics.com/index.html.

Chertow, M.R., 2000. Industrial symbiosis : literature and taxonomy. Annu. Rev. Energy Environ. 25, 313–337. doi:10.1146/annurev.energy.25.1.313

Cordero K., 2015. IEPA final report: Plant Chicago. Illinois Environmental Protection Agency, Chicago.

Courtonne, J.-Y., Alapetite, J., Longaretti, P.-Y., Dupré, D., Prados, E., 2015. Downscaling material flow analysis: The case of the cereal supply chain in France. Ecol. Econ. 118, 67–80. doi:10.1016/j.ecolecon.2015.07.007

Dou, Z., Ferguson, J.D., Galligan, D.T., Kelly, A.M., Finn, S.M., Giegengack, R., 2016. Assessing U.S. food wastage and opportunities for reduction. Glob. Food Secur. 8, 19–26. doi:10.1016/j.gfs.2016.02.001

Environmental Protection Agency, FEECO International, Inc., California Integrated Waste Management Board, 2006. National Recycling Coalition Measurement Standards and Reporting Guidelines : volume-to-weight conversion factor.

FAO, 2013. Food wastage footprint: impacts on natural resources: summary report. Rome.

Geels, F.W., 2005. The dynamics of transitions in socio-technical systems: A multi-level analysis of the transition pathway from horse-drawn carriages to automobiles (1860–1930). Technol. Anal. Strateg. Manag. 17, 445–476. doi:10.1080/09537320500357319

Geels, F.W., Schot, J., 2007. Typology of sociotechnical transition pathways. Res. Policy 36, 399–417. doi:10.1016/j.respol.2007.01.003

Goodland, R., Daly, H., 1996. Environmental Sustainability: Universal and Non-Negotiable. Ecol. Appl. 6, 1002–1017. doi:10.2307/2269583

Graedel, T.E., Allenby, B.R., 1995. Industrial ecology. Prentice Hall, Englewood Cliffs, NJ.

Jacobsen, N.B., 2006. Industrial Symbiosis in Kalundborg, Denmark: A Quantitative Assessment of Economic and Environmental Aspects. J. Ind. Ecol. 10, 239–255. doi:10.1162/108819806775545411

Gustavsson, J.; Cederberg, C.; Sonesson, U.; van Otterdijk, R.; Meybeck, A. Global Food Losses and Food Waste—Extent, Causes and Prevention; FAO: Rome, Italy, 2011.

HLPE, 2014. Food losses and waste in the context of sustainable food systems. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome 2014, 117p.

Jurgilevich, A., Birge, T., Kentala-Lehtonen, J., Korhonen-Kurki, K., Pietikäinen, J., Saikku, L., Schösler, H., 2016. Transition towards Circular Economy in the Food System. Sustainability 8, 69. doi:10.3390/su8010069

Kennedy, C., Cuddihy, J., Engel-Yan, J., 2007. The Changing Metabolism of Cities. J. Ind. Ecol. 11, 43–59. doi:10.1162/jie.2007.1107

Ellen MacArthur Foundation, 2015. Towards the circular economy: business rationale for an accelerated transition. United Kingdom.

Kennedy, C., Stewart, I.D., Ibrahim, N., Facchini, A., Mele, R., 2014. Developing a multi-layered indicator set for urban metabolism studies in megacities. Ecol. Indic. 47, 7–15. doi:10.1016/j.ecolind.2014.07.039

Krausmann F., Weisz H., Eisenmenger N., Schütz H., Haas W., Schaffartzik A., 2015. Economy-wide Material Flow Accounting Introduction and Guide. Social Ecology Working Paper, issue 151, 133 p.

Kummu, M., de Moel, H., Porkka, M., Siebert, S., Varis, O., Ward, P.J., 2012. Lost food, wasted resources: Global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. Sci. Total Environ. 438, 477–489. doi:10.1016/j.scitotenv.2012.08.092

Loiseau, E., Junqua, G., Roux, P., Bellon-Maurel, V., 2012. Environmental assessment of a territory: An overview of existing tools and methods. J. Environ. Manage. 112, 213–225. doi:10.1016/j.jenvman.2012.07.024

Lombardi, D.R., Laybourn, P., 2012. Redefining Industrial Symbiosis: Crossing Academic-Practitioner Boundaries. J. Ind. Ecol. 16, 28–37. doi:10.1111/j.1530-9290.2011.00444.x

Oliver Wyman, 2014. Reducing Food waste - How can retailers help?

Pincetl, S., Bunje, P., Holmes, T., 2012. An expanded urban metabolism method: Toward a systems approach for assessing urban energy processes and causes. Landsc. Urban Plan. 107, 193–202. doi:10.1016/j.landurbplan.2012.06.006

Plant Chicago, 24th of June 2016. Plant Chicago: closed loop, open source. Seen on: http://plantchicago.org.

Ravalde, T., Keirstead, J., 2015. Comparing performance metrics for multi-resource systems: the case of urban metabolism. J. Clean. Prod. doi:10.1016/j.jclepro.2015.10.118

Schot, J., Geels, F.W., 2007. Niches in evolutionary theories of technical change: A critical survey of the literature. J. Evol. Econ. 17, 605–622. doi:10.1007/s00191-007-0057-5

Smith, A., 2007. Translating Sustainabilities between Green Niches and Socio-Technical Regimes. Technol. Anal. Strateg. Manag. 19, 427–450. doi:10.1080/09537320701403334

Symbiosis Center (Symbiosis Center Denmark). 2015. Diagram | Kalundborg Symbiosis. Kalundborg Symbiosis. http://www.symbiosis.dk/en/diagram. Accessed May 30, 2016.

Tesco and Society, Waste and Resources Action Programme, 2014. Food Waste Hotspots.
van der Goot, A.J., Pelgrom, P.J.M., Berghout, J.A.M., Geerts, M.E.J., Jankowiak, L., Hardt, N.A., Keijer, J., Schutyser, M.A.I., Nikiforidis, C.V., Boom, R.M., 2016. Concepts for further sustainable production of foods. J. Food Eng. 168, 42–51. doi:10.1016/j.jfoodeng.2015.07.010

United States Environmental Protection Agency, 29th of July 2016. Food recovery hierarchy. Seen on: https://www.epa.gov/sustainable-management-food/food-recovery-hierarchy

Wolman, A., 1965. The metabolism of cities. Sci. Am. 213, 179–190.

Zhang, Y., Yang, Z., Fath, B.D., Li, S., 2010. Ecological network analysis of an urban energy metabolic system: Model development, and a case study of four Chinese cities. Ecol. Model. 221, 1865–1879. doi:10.1016/j.ecolmodel.2010.05.006

Annexes

Annex 1: the questionnaire used to collect every businesses' data for the first part of the project.

Businesses questionnaire

Name of the business : Arrival date in *The Plant* : Roles and/or number of every full/part time/temporary employees :   Type of business (goods and/or services) :

PLEASE FILL THE FOLLOWING TAB WITH THE UNITS THAT SUITS BEST THE MATERIAL CONCERNED (POUNDS, OUNCES, CUBIC FEET, WATTS…). THE MOST IMPORTANT DATA TO GATHER FIRST ARE THE MAIN INPUTS AND OUTPUTS (COLUMN 1), WE WILL FOCUS ON MONTHLY QUANTITIES (COLUMNS 2-4) LATER ON.			
Type of material flow	Amount of material for each time period		
	March 2016	April 2016	May 2016
1	*2*	*3*	*4*
Organic material with a food purpose or origin			
Inputs			
From outside of *The Plant*			
From another business in *The Plant*			
Outputs			
Goods (your products)			

Wastes reused by another business in *The Plant*			
Wastes composted			
Landfill			

Other resources			
Inputs			
Non-organic materials			
Organic materials non-food related			
Electricity			
Water			
Gas			
Outputs			
Goods packaging			

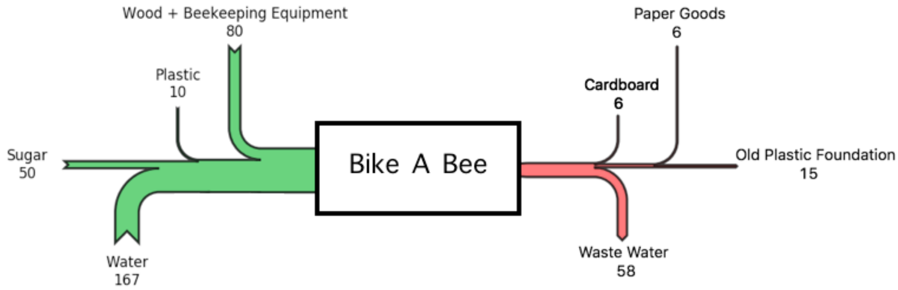
Non-organic wastes recycling			
Non-organic wastes to landfill			
Organic non-food wastes recycling			
Organic non-food wastes to landfill			
Waste water			

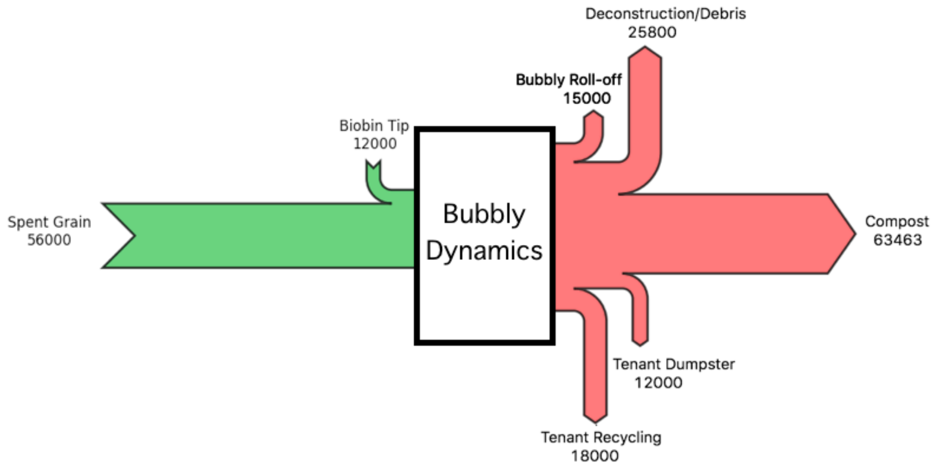
WHAT PROJECTS ABOUT WASTE MANAGEMENT HAVE YOU ALREADY THOUGHT ABOUT IMPLEMENTING? (PAST, REJECTED, FUTURE PROJECTS)

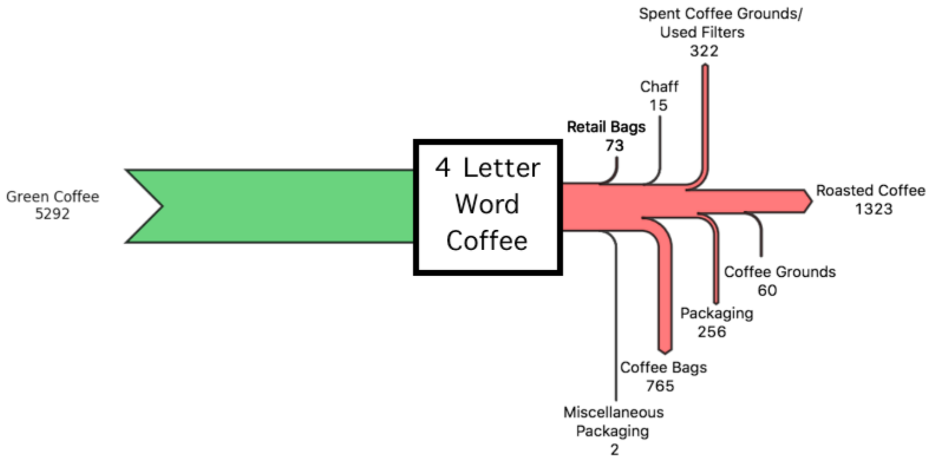
NB : <u>**complementary description of the different terms**</u>

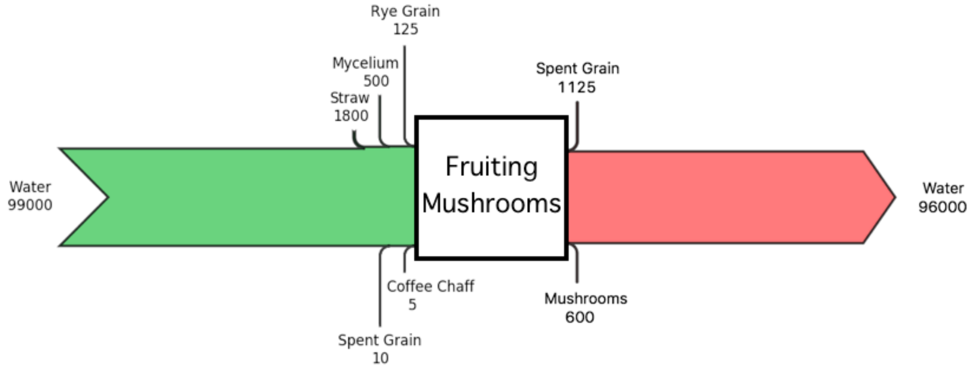
- **Organic material with a food purpose or origin** : everything that will be used to produce food, from virgin material to previously used for another process, such as seeds, flour, coffee grounds…
- **Organic non-food materials or wastes** : from an organic source but that aren't part of food, such as paper, cardboards…
- **Non-organic materials or wastes** : those would be all the peripheral material used in food production but that aren't from organic sourcing, such as glass bottles, plastic containers…

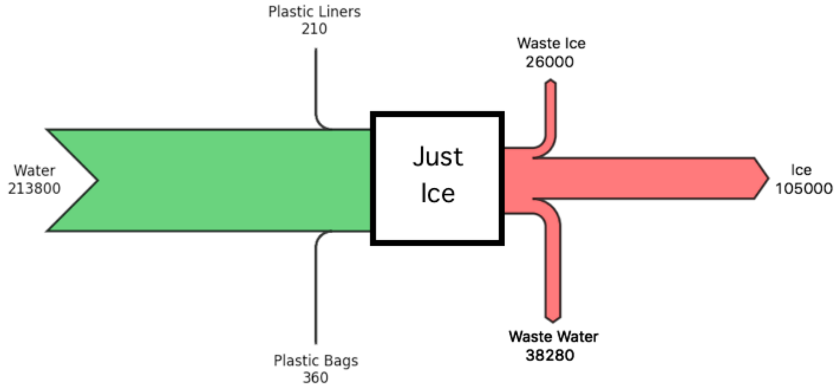
Annex 2: material flow diagrams for the eleven other businesses at *The Plant*, unit in pounds (1 lb ~ 0,450 kg) for the months of March to May 2016

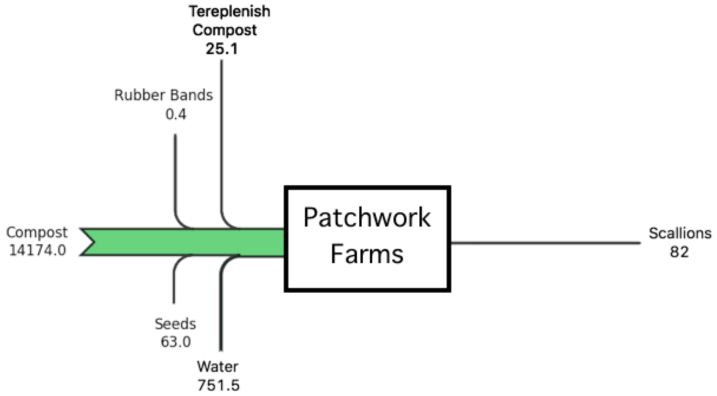


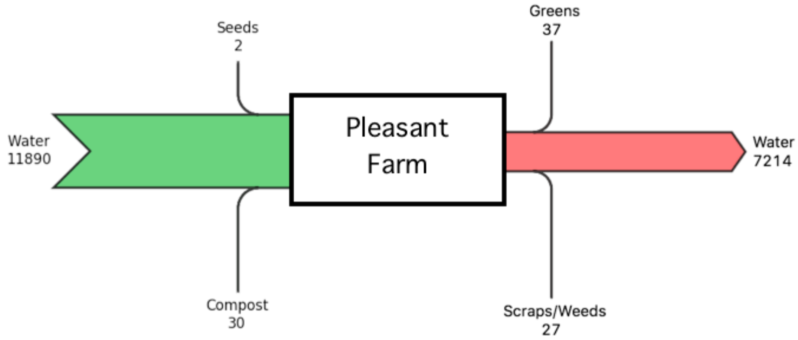


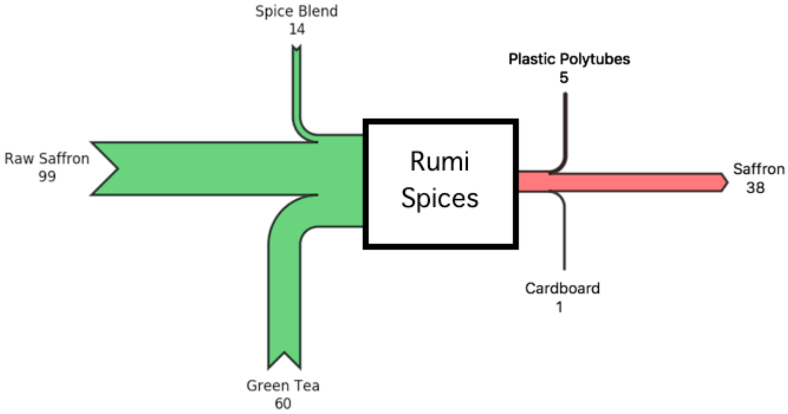


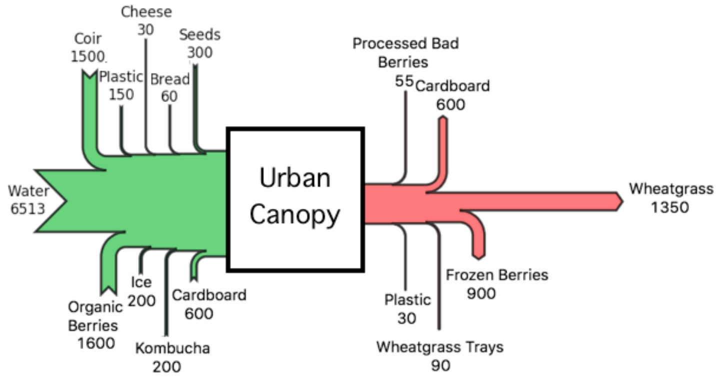

Rye Grain
125
Mycelium
500
Straw
1800
Spent Grain
1125
Water
99000
Fruiting
Mushrooms
Water
96000
Coffee Chaff
5
Mushrooms
600
Spent Grain
10

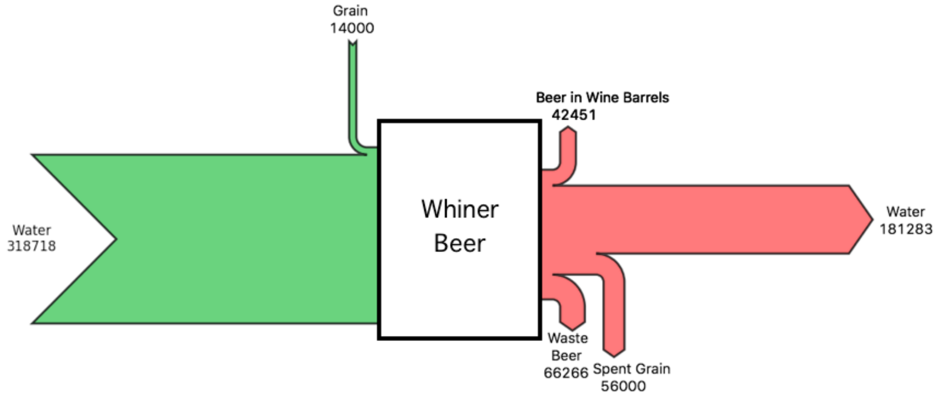

Plastic Liners
210
Waste Ice
26000
Water
213800
Just
Ice
Ice
105000
Waste Water
38280
Plastic Bags
360


Tereplenish
Compost
25.1
Rubber Bands
0.4
Compost
14174.0
Patchwork
Farms
Scallions
82
Seeds
63.0
Water
751.5


Seeds
2
Greens
37
Water
11890
Pleasant Farm
Water
7214
Compost
30
Scraps/Weeds
27


Spice Blend
14
Plastic Polytubes
5
Raw Saffron
99
Rumi Spices
Saffron
38
Cardboard
1
Green Tea
60


Cheese
30
Coir
1500
Seeds
300
Plastic
150
Bread
60
Processed Bad Berries
55
Cardboard
600
Water
6513
Urban Canopy
Wheatgrass
1350
Ice
200
Cardboard
600
Organic Berries
1600
Kombucha
200
Frozen Berries
900
Plastic
30
Wheatgrass Trays
90


Grain
14000
Beer in Wine Barrels
42451
Water
318718
Whiner
Beer
Water
181283
Waste
Beer
66266
Spent Grain
56000

Annexe 3: electricity flow at *The Plant*, unit in kW, for the months of March to May 2016.