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Andrea Bortolotti, Stephan Kampelmann, Simon De Muynck, Anastasia Papangelou ...+1 more authors

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Conditions and concepts for interdisciplinary urban metabolism research–the case of an inter-project collaboration on biowaste in Brussels[1]

Authors (in alphabetical order)

Aristide Athanassiadis[1], Andrea Bortolotti[2], Stephan Kampelmann[2], Simon De Muynck[3], Anastasia Papangelou[4], Vanessa Zeller[5]

[1] *Université Libre de Bruxelles, Building, Architecture and Town Planning (BATir)*
[2] *Université Libre de Bruxelles, Faculty of Architecture, Laboratory on Urbanism, Infrastructures and Ecologies*
[3] *Université Libre de Bruxelles Faculty of Sciences, Institut de Gestion de l'Environnement et d'Aménagement du Territoire (IGEAT-GESTe), Centre d'écologie urbaine asbl*
[4] *KU Leuven, Division of Bioeconomics, SFERE group*
[5] *Université Libre de Bruxelles, Faculty of Sciences, Institut de Gestion de l'Environnement et d'Aménagement du Territoire (IGEAT-GESTe)*

Abstract
Given that many voices have argued in favour of combining insights on urban metabolism from different disciplinary angles, there seems to be no lack of general willingness to engage in interdisciplinary research on urban metabolism. Instead, we argue, the central problem lies in the nitty-gritty and mundane practicalities of working across research teams, departments and temporalities. In this paper, we offer a detailed description of an interdisciplinary collaboration that has occurred in practice: a joint effort on the study of potential transition scenarios regarding the metabolism of biowaste in the city-region of Brussels. This inter-project collaboration involved four different research teams from three faculties and two universities, each with a specific set of expertise and interests. Biowaste metabolism and nutrient recirculation is a recurring theme in the literature on urban metabolism. It relates to early studies on urban metabolism and concerns about the depletion of soil fertility and different forms of pollution. The paper describes each research project point of departure in order to allow readers with different disciplinary backgrounds to apprehend the distance that separated the projects before they decided to work together on the urban biowaste metabolism. Furthermore, we present moments of convergences that helped to bring these research processes together. Finally, we offer a critical reflection, suggesting both enabling factors and limits of the inter-project collaboration on biowaste metabolism in Brussels.

Titre (FR): Conditions et concepts pour la recherche interdisciplinaire sur le métabolisme urbain–le cas d'une collaboration inter-projets sur les biodéchets à Bruxelles

Résumé (FR)
Étant donné que de nombreuses voix se sont prononcées en faveur de combiner différents angles disciplinaires sur le métabolisme urbain, le problème central de la recherche interdisciplinaire sur le métabolisme urbain n'est pas à trouver dans le manque de volonté des

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chercheurs de s'engager dans de telles collaborations. Nous soutenons que le problème central réside dans les détails pratiques, organisationnels et parfois banaux du travail entre équipes de recherche, départements et temporalités. Dans cet article, nous proposons une description fine d'une collaboration interdisciplinaire qui s'est produite dans la pratique : un effort conjoint pour développer et évaluer des scénarios de transition concernant le métabolisme des biodéchets dans la ville-région de Bruxelles. Cette collaboration entre projets a impliqué quatre équipes de recherche différentes issues de trois facultés et de deux universités, chacune possédant un ensemble spécifique de compétences et d'intérêts. Le métabolisme des biodéchets et la recirculation des nutriments est un thème récurrent dans la littérature sur le métabolisme urbain. Notre travail fait donc écho à des études antérieures sur le métabolisme urbain et à des problèmes d'épuisement de la fertilité des sols et de différentes formes de pollution. Le papier décrit le point de départ de chaque projet de recherche afin de permettre aux lecteurs de disciplines différentes d'appréhender la distance qui les séparait avant qu'ils aient décidé de travailler ensemble sur le métabolisme des biodéchets urbains. De plus, nous présentons des moments de convergence qui ont permis de rapprocher ces processus de recherche. Enfin, nous proposons une réflexion critique, revenant à la fois sur les facteurs favorables et les limites de la collaboration entre projets sur le métabolisme des biodéchets à Bruxelles.

Introduction

One of the most attractive features of urban metabolism research is its potential for blending disciplinary perspectives and methods (Broto, Allen, Rapoport, 2012). Yet rather than combining several disciplines from a broad spectrum ranging from engineering and natural sciences to social sciences, most studies on urban metabolism rely on a single disciplinary angle. In fact, urban metabolism literature tends to cluster in isolated streams of scopes, objectives, and therefore results and insights (Newell, Cousins, 2015; Wachsmuth, 2012). This holds not only for descriptive studies about material and energy flows in given territories, but also for prospective work that questions the possibility of transforming the socio-ecological systems that underpin metabolic flows, for instance in view of rendering it more sustainable or more circular. While the former type of research has almost exclusively relied on quantifications based on available statistics and models, the latter is dominated by qualitative approaches like transition management (Fischer-Kowalski, Rotmans, 2009).
We argue that reductionist and purely analytical research is a blunt instrument for overcoming the problem of interdisciplinary collaboration on urban metabolism; indeed, the very attractiveness of urban metabolism arguably lies in its openness and relative fuzziness which render it accessible and attractive for different academic disciplines.

The purpose of this paper is twofold. Firstly, we want to provide a descriptive account of a recent interdisciplinary collaboration on the study of potential transition scenarios regarding the metabolism of biowaste in the city-region of Brussels. This case is relevant because the inter-project collaboration described here involved four different research teams with disciplinary but also different epistemological angles; our account describes how these differences have been overcome in a series of moments of convergence. Secondly, we offer an analysis of the convergence process. This is done by identifying external enabling factors that have facilitated the collaboration; we argue that the group can be interpreted as a "community of practice" which created a series of "boundary objects".

The paper is structured as follows. Each research project point of departure is described in Section 2. These detailed descriptions allow readers with different disciplinary backgrounds to apprehend the distance that separated the projects before their teams decided to work together on the urban biowaste metabolism. A series of moments of convergences that helped to bring these research processes together are presented in Section 3. Section 4 analyses both enabling factors and boundary objects which allow for the inter-project collaboration within a community of practice. Section 5 concludes by speculating on the replicability of the case we describe.

Points of departure: different perspectives on the biowaste metabolism

Biowaste metabolism and nutrient recirculation is a recurring theme in the literature on urban metabolism. It relates to early studies on urban metabolism, the emergence of modern chemistry in the 19th century, as well as concerns about the spoliation of soil fertility led by the missed recirculation in agriculture of human and animal wastes which were in turn polluting the cities (Barles, 2005; Verger et al, 2018; Esculier et al, 2018). Such concerns occupy a prominent role in contemporary debates on sustainability and the circular economy (Cordell, Drangert, White, 2009; Kampelmann, 2016; Lehec, 2018). The topic is also of high policy relevance, as local, regional and national policies strive to divert the organic matter from incineration and landfills. The European Commission, for instance, has recently established that selective collection of organic waste will become mandatory in all Member States of the European Union by 31 December 2023. Since the collection systems will be implemented at the local or regional scale, research on urban biowaste metabolism is a useful tool for envisaging such transitions.

In this section, we present the general thrust of four research projects related to the biowaste metabolism of Brussels: BRUCETRA, SUSPLACE, LOUISE_ECO, and PHOSPHORE. For each project, we outline the main research question, methodological approach and their situation at the inception of the inter-project collaboration with the other teams. Moreover, we compare the projects with respect to their perspectives on urban metabolism research in terms of the academic disciplines they mobilise, their epistemologies, methods, and types of transition scenarios. The comparison also helps to understand the potential redundancies, tensions, and complementarities between the projects.

Environmental impact assessment of biowaste management

The BRUCETRA[2] project is concerned with the economic and environmental potential of urban waste flows for a transition towards a circular economy, and specifically with the overall research question which combinations of available waste streams, current and future recycling and treatment technologies and modes of entrepreneurship are the most promising for a more circular model of materials management in the Brussels Capital Region. One of the central objectives of BRUCETRA is to develop and evaluate alternative waste treatment scenarios with different combinations of waste sources, collection modes, and treatment technologies. After comparing the valorisation potential of different flows in the Brussels region, biowaste was selected to develop such as transition scenario and evaluate it in terms of its

[2] BRUCETRA is the acronym for' Brussels Circular Economy Transition'. The project is funded by the Brussels Institute for scientific research, Innoviris, and involves researchers from ULB (Université libre de Bruxelles) and KUL (Katholieke Universiteit Leuven). Project website: https://brucetra.be/

environmental and economic impact.[3] BRUCETRA is an interdisciplinary project combining researchers from applied science (engineering), natural sciences (environmental science) and social sciences (environmental economics). On a spectrum ranging from pure natural sciences (such as physics) to pure social sciences (such as sociology), the disciplinary perspectives involved in BRUCETRA are relatively close to each other.

To determine the environmental impacts of alternative biowaste treatment scenarios, BRUCETRA performs life cycle assessment (LCA). LCA is a method to quantitatively assess environmental impacts of goods and services from "cradle to grave." Through its holistic perspective, LCA is considered as particularly suited to support decision-making in waste management (Hellweg, Canals 2014). For the analysis of biowaste management in Brussels, BRUCETRA determined the fractional and physicochemical composition of different biowaste mixes and created a life cycle inventory for the different waste treatment options. Based on this model, the environmental impacts from the use of resources and release of emissions into soil, air, and water are assessed. The comparative LCA has the final aim to identify the waste treatment option or biowaste scenario with the lowest environmental impacts. At the start of the inter-project cooperation described in this paper, BRUCETRA had already collected an extensive database of waste flows in Brussels and identified biowaste for further in-depth study. The scope for collaboration between BRUCETRA and other research projects encompassed certain aspects of the in-depth study, in particular working with other research teams on the definition of scenarios and additional data collection.

Biochemical cycles in urban food systems

SUSPLACE[4] is a training network that employed fifteen researchers to study place-shaping practices and the ways these practices create more sustainable places. The inter-project cooperation described in this paper mobilises one of these SUSPLACE researchers from KUL working on urban food systems in a circular perspective. The project[5] is concerned with the role of cities in restoring biogeochemical cycles. The SUSPLACE researcher has a background in environmental engineering and a territorial ecology approach is used in the project. This means that, although the study is informed and cross-pollinated by approaches and notions from the social sciences, it is relatively homogeneous with respect to the dominant disciplinary perspective (natural science) and its main epistemological orientation (reductionist-positivist).

The main objective of the study is to analyse the phosphorus flows in the city of Brussels and between the city and its hinterland. By doing so, SUSPLACE aims to identify, assess and compare different ways of making the urban food system more circular. The specific objectives are to (i) quantify the nutrients needed to feed the city and the amounts of secondary sources that are generated and can be reused, (ii) spatialize Brussels' nutrient metabolism by including

[3] The inter-project cooperation described in this paper involves the ULB team within BRUCETRA and focuses on the environmental impact assessment of scenarios for biowaste flows. It should be noted that the project also studies the techno-economic aspects of the scenarios. These strands of work have, however, not (yet) been incorporated into the inter-project approach that we deal with in this paper.

[4] SUSPLACE has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 674962.

[5] We are calling this project SUSPLACE from now on, although it is only one of the 15 individual research projects within the SUSPLACE training network.

the flows of nutrients between Brussels and its hinterland (food production and disposal of organic waste), (iii) identify potential interventions for closing the nutrient loops at different geographical scales (urban, regional, national) and (iv) assess and compare the different interventions in terms of nutrient (re)use efficiency, energy use and their socio-economic impacts.

Drawing on the field of territorial ecology, the core method used by SUSPLACE for studying the nutrient flows of Brussels is substance flow analysis. The analysis is performed at different scales, by expanding stepwise the system boundaries: it starts within the administrative boundary of Brussels Capital Region and expands to the agro-food system of Belgium, in order to include the local hinterland of the city. The ultimate goal is to have a comprehensive representation of the food system of Brussels and the nutrient flows through it under a functional system boundary that will account for the system's ecological, social and spatial specificities.

At the outset of the collaboration with the other teams working on biowaste in Brussels, the SUSPLACE researcher had carried out a literature review on the theoretical and empirical foundations of the analysis of urban food systems from a territorial ecology viewpoint. After initial contacts with the other teams, it became clear that a substance flow analysis of phosphorus beyond the administrative borders of Brussels would be highly complementary with the intra-urban focus of LOUISE_ECO and PHOSPORE and the system expansion approach in BRUCETRA. Moreover, SUSPLACE would have had to develop its own transition scenarios for intra-urban changes in biowaste management; rather than developing additional scenarios for the city, it was attractive for SUSPLACE to use the scenarios developed by the BRUCETRA and PHOSPHORE teams from Brussels. The scope of the collaboration, therefore, included working out the extra-urban flows of the scenarios through substance flow analysis.

Spatial analysis to support decision making on biowaste management

LOUISE_ECO is a research programme on biowaste metabolism located within LOUISE[6] , a research centre of the ULB Faculty of Architecture La Cambre-Horta. The interdisciplinary team of LOUISE_ECO includes a doctoral researcher in urban planning and a post-doc urban economist funded by the regional research agency (Innoviris) and studies commissioned by the regional government.[7] LOUISE_ECO combines insights from social and natural sciences, and its researchers have in common that they rely on a more relativist/interpretationist epistemology (see Figure 1).

Indeed, although research on waste management is mostly concerned with technological solutions and optimization models, works within LOUISE_ECO focus more on the complexity of waste–related issues, for instance, to the politics of waste infrastructure and the socio-behavioural aspects of waste generation – which demand interdisciplinary approaches. Doing so, LOUISE_ECO approaches waste management in Brussels through the urbanism

[6] LOUISE stands for Laboratory of urbanism, infrastructure and ecology.

[7] While LOUISE_ECO is not a single research project like BRUCETRA, SUSPLACE and PHOSPHORE, the programme follows in all relevant aspects the logic of research projects with a fixed time frame and ad hoc research collaboration, in particular the doctoral and post-doctoral projects that work together in LOUISE_ECO.

perspective, questioning whether and how urban planning and spatial analysis might produce knowledge on (bio)waste management.

Spatial analysis is particularly salient for the case of biowaste management and technological infrastructure siting as it contributes to a better understanding and discussion of the current centralised and industrial-scale management systems and their possible evolution. As a result, it allows for waste policy and planning decisions to be tailored for specific urban areas, for instance by differentiating between high- and low-density areas, although conventional waste management systems tend to ignore these differences. Moreover, a spatial approach is also an actor-oriented approach to waste management that accounts for the territory's complexities and contingencies, in particular those that arise in the wake of a technological transition towards food-waste-based biogas and biofertilizer.

Since 2016, the LOUISE_ECO team has developed spatial analysis and scenarios' construction in three studies commissioned by the Brussels Environment agency on the questions related to biowaste management. These studies have respectively focussed on the scope of decentralised biowaste treatment (Bortolotti, Kampelmann, De Muynck, 2018); the estimation of potential biowaste production and collection in the Brussels region (Bortolotti et al, 2018a); and the feasibility of building and operating an industrial biowaste treatment plant within the regional administrative borders (Bortolotti et al, 2018b).

At the start of the inter-project cooperation described in this paper, the three different biowaste-related studies carried out by LOUISE_ECO were near completion. The scope of the collaboration for LOUISE_ECO involved making the results available to the other research teams: this concerns the multi-producer, multi-flow GIS model of biowaste generation and collection scenarios; the results of the feasibility of different treatment options, including the potential siting of industrial plants within Brussels and the inventory of decentralised treatment techniques. In return, the LOUISE_ECO team received valuable insights on governance aspects of the biowaste management system from PHOSPHORE and environmental assessment of alternative options from BRUCETRA, which were incorporated into the ongoing dissertation on biowaste management from an urban planning perspective.

Co-creation of a transition towards ecological management of biowaste

OPERATION PHOSPHORE is a three-year action-research project funded under the Co-create Action of the Brussels Institute for Research and Innovation (Innoviris). The consortium is made up of researchers from different organisations: WORMS, a local composting network; the Brussels Environment agency and the Regional waste agency; the Urban Ecology Centre, an association that positions itself as a "bridging organization" (Folke et al, 2005) in charge of coordinating partnerships to drive complex system transitions; the ULB's research department LOUISE, which was described in the preceding section.

The consortium aims to collectively develop, discuss and experiment optimal solutions for the transformation and implementation of innovative biowaste management strategies (of collection, treatment, recovery) for Brussels. These strategies aim to be resilient and circular, and to make sense for the population of Brussels, including those who are currently excluded from decisions on waste management (De Muynck et al, 2018). To achieve these objectives, PHOSPHORE builds on disciplines such as environmental governance and transition management (Voss, Kemp, 2005; Kemp, Loorbach, Rotmans, 2007; Geels, Kemp, 2007).

In particular, PHOSPHORE leverages on Participatory Action Research (PAR) methods to establish a reciprocated collaboration among active researchers and external stakeholders in the field of knowledge (Chevalier, Buckles 2013). The action-research carried out by PHOSPHORE is composed of two main phases. The first consists of documenting, developing and experimenting socio-technical innovations for decentralised biowaste management in different neighbourhoods of Brussels. Starting from three initial experimental locations, called living labs, other living labs have been identified and integrated during the first two years of the project. Living labs showing similar characteristics have been grouped together in clusters — for example, the cluster including all ongoing socio-technical innovations in schools. There are currently seventeen of such clusters.

The second phase intends to propose a narrative that combines insights from all these experiments, in order to steer the imaginary of biowaste management in Brussels. Methodologically, this narrative is based on the outcome of four large multi-stakeholder participatory workshops. During these workshops, ordinary citizens and representatives of different types of producers of organic waste (such as restaurants, hospitals, schools, offices, gardening companies, etc.) have learned about the socio-technical innovations documented by PHOSPHORE and developed a qualitative narrative about their future development in Brussels. The participants have also been asked to propose quantitative targets for different options regarding organic waste management.

At the inception of the cooperation with the other research teams, PHOSPHORE had already identified the most relevant socio-technical innovations in decentralized organic waste management and structured them into clusters. Moreover, the consortium had already decided that a series of participatory workshops would be organised to develop a qualitative and quantitative narrative for the uptake of these innovations at the regional level. Working together with the other research teams was nevertheless perceived to be highly attractive for PHOSPHORE. Firstly, the different studies on regional biowaste flows and their potential treatment through decentralised or centralised technologies that were developed by LOUISE were perceived as a valuable and essential source of information (De Muynck et al, 2019) to improve the coherence between the local/decentralised experiments developed by PHOSPHORE, on the one hand, and waste management at the regional scale, on the other. Secondly, the cooperation with SUSPLACE potentially allows to fill in a blind spot of the research set-up of PHOSPHORE. Indeed, the latter almost exclusively focussed on the elements of the waste management system *within* the regional borders of the Brussels-Capital Region (collection, treatment) without being able to address those outside of the regional borders (transportation and use of nutrients in agriculture). Thirdly, cooperation with BRUCETRA was also perceived to be beneficial for the lobbying efforts of PHOSPHORE, for instance, if the environmental impact assessment of decentralised initiatives provides additional justification of their desirability. This would make the propositions of PHOSPHORE more robust and legitimate for regional political authorities (Fransolet, 2017).

Ex-ante comparison of projects

The table below compares all four projects with respect to their research questions, dominant disciplinary perspectives, types of scenarios and methods. The table also provides data on the timeframe and funding agency of each project.

The table illustrates the high diversity between the research initiatives, especially regarding the disciplines and methods that are mobilised. While "urban biowaste metabolism" is a central object in all projects, the questions raised by this objects range from understanding the environmental impact of alternative scenarios (BRUCETRA) to understanding how to gain momentum for a transition to an alternative scenario (PHOSPHORE). There were also important differences regarding the purpose and status of transition scenarios among the projects that are analysed in more detail below (see Section 3.2).

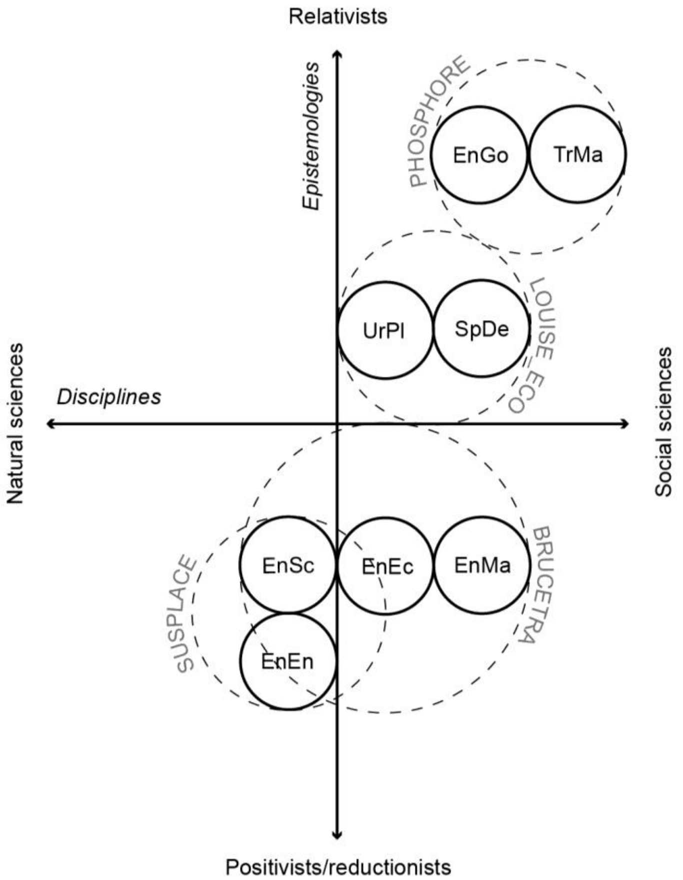
Table 1. Comparison of the main project characteristics

Project acronym	Urban metabolism related research question	Dominant disciplinary perspective	Scenarios developed in the project	Methods	Start / end date	Funding agency / Project call
BRUCETRA	What is the environmental performance of urban biowaste flows and their treatment under different waste management scenarios?	Environmental sciences Environmental economics Environmental management	Alternative waste treatment scenarios with different combinations of waste sources, alternative collection modes, and treatment technologies	Material flow analysis Environmental impact assessment Life cycle analysis	2016-2019	Innoviris / Anticipate prospective research
SUSPLACE	What role for cities in restoring biogeochemical cycles? What are the system boundaries of circular urban food systems?	Environmental sciences Environmental engineering	Scenarios for higher reuse rates of phosphorus 'produced' in Brussels	Substance flow analysis (intra-urban and city-hinterland phosphorus flows)	2016-2019	EU / Horizon 2020
LOUISE_ECO	How can spatial analysis and urban planning support decision making in (bio-)waste management?	Urban planning Spatial design	Scenarios of biowaste separate collection and treatment for Brussels	Fine-grain GIS model of biowaste flows Feasibility analysis of biowaste treatment infrastructure siting	2017-2019	Innoviris Commissioned studies / Brussels Environment
PHOSPHORE	How to transition towards more ecological management of organic resources in Brussels?	Environmental governance Transition management	Scenario for the upscaling of decentralised (sub-industrial) biowaste collection and recycling within Brussels	Participatory action-research Use of living labs for experimentation with socio-technical innovations	2017-2019	Innoviris / Co-create urban resilience

It is worth noting that collaborating across such diverse projects goes beyond combining different methods to explore different questions regarding biowaste metabolism. Indeed, the inter-project collaboration had to overcome more fundamental differences related to the schism between social and natural sciences, on the one hand, and epistemologies, on the other hand.

Figure 1 compares all four projects with respect to these two aspects. While it is true that all of the involved projects are in themselves interdisciplinary, the within-project cooperation involves collaborations with neighbouring disciplines that are situated on a similar position on a range from natural to social sciences (the horizontal axis in Figure 1) and on a spectrum from positivist/reductionist to relativist epistemologies (the vertical axis in Figure 1). Indeed, BRUCETRA and SUSPLACE are similar in their respective epistemologies, while LOUISE_ECO and PHOSPHORE employ more relativist approaches and are thus situated further up in the graph. When setting up a research project on urban metabolism, even if its purpose is to combine different disciplines and/or epistemologies, it is arguably easier to bring together researchers from neighbouring rather than very distant positions. However, collaborations spanning wider distances in the discipline/epistemology diagram can offer higher gains in terms of avoided redundancies and exploited complementarities.

Figure 1: Disciplines and epistemologies of the projects



Legend of involved disciplines:

EnEn: Environmental Engineering
EnSc: Environmental Science
EnMa: Environmental Management
EnEc: Environmental Economics
SpDe: Spatial Design
UrPl: Urban Planning
EnGo: Environmental Governance
TrMa: Transition Management

To see that this was the case in the inter-project collaboration discussed in this paper, Table 2 summarizes the set of potential redundancies, tensions, and complementarities between the projects. The strongest complementarity is the common topical focus on Brussels' biowaste management system and the common objective of supporting the transition towards more sustainable or circular social-ecological systems. All projects study potential impacts of alternative biowaste-to-resource management system in Brussels, although with different scopes and system boundaries. The notions shown in this table have emerged during the informal discussions at the inception of the inter-project collaboration; they are therefore not based on a theoretical framework but have been created ad hoc in order to understand and anticipate the implications of cooperation between the different four projects. This being said, in the next section we propose a first analysis of the enabling factors that supported the emergence of this collaboration.

Table 2. Summary of potential redundancies, tensions, and complementarities across projects

Potential redundancies	Potential tensions	Potential complementarities
Overlapping data collection: BRUCETRA and LOUISE_ECO collect data on biowaste flows within Brussels. **Overlapping scenario development:** BRUCETRA and PHOSPHORE envisage scenarios for waste collection and treatment within Brussels; LOUISE_ECO has already developed such scenarios. **Identification and research on collection and treatment options:** BRUCETRA, PHOSPHORE and LOUISE_ECO collect information on options.	**Different assumptions about quantities:** LOUISE_ECO and BRUCETRA estimate sorting efficiencies and collection quantities. **Differences in system boundaries:** SUSPLACE uses functional system boundary; BRUCETRA system expansion approach; LOUISE_ECO and PHOSPHORE have focused on the administrative boundary of the Brussels region. **Incommensurability of content:** the diversity of disciplines and types of knowledge across the projects might stand in the way of integrating all content in a comprehensive approach. **Conflicting interdisciplinarities**: each project in itself claims to be interdisciplinary, but the type and scope of interdisciplinarity differ across projects. **Project-oriented scenarios**: BRUCETRA, LOUISE_ECO & PHOSPHORE all wanted to produce a prospective scenario from their own research agenda.	**Topical foci:** all projects are concerned with topics that are reasonably close to each other to allow for mutual identification and joint efforts. **Geographical perimeters for spatialisation:** SUSPLACE spatializes flows of nutrients between Brussels and its hinterland; LOUISE_ECO spatializes flows within the Brussels region. **Complementary data collection:** SUSPLACE uses the data on biowaste flows compiled by BRUCETRA and LOUISE_ECO. **Research questions:** each research project's question covers a blind spot of the other projects. **More encompassing scenarios:** combining knowledge and data from all projects allows to define scenarios that transcend the topical and geographical scope of each project.

Moments of convergence

Despite personal contacts between the researchers of the different teams, the four research projects described in Section 2 were conceived independently from each other and were driven by the outlook and interests of their respective protagonists and general policy interest in circular economy and biowaste management from regional and European funding agencies. In this section, we describe three moments of convergence between the different research dynamics on urban biowaste metabolism in Brussels: developing joined scenarios; sharing a common database; agreeing on terminology.

Joined scenario development

All projects had foreseen scenarios that would have been partially overlapping (and potentially redundant) if carried out in parallel (see Table 2). The scenario development, data collection, treatment, and analysis related to scenarios form a substantial part of each project's workflow so that returns from collaborating on scenario development were high for all partners. As a consequence, it was decided that the transition scenarios will be used as a vector for cooperation; the idea was to define joined scenarios to which each research projects can apply its specific methodologies to carry out an in-depth analysis. The development of joined scenarios has been central in the collaboration and required negotiations between the different project teams to accommodate their respective (research) interests, but also arrangements and expectations vis-à-vis their projects' outcomes from external stakeholders. A key difficulty for convergence on scenarios was that the different teams were interested in different aspects and uses of scenario development. In other words, the epistemological status and functions of scenarios were not the same in all projects.

Despite the divergence of intentions and uses, it turned out to be possible to agree on the content of a common set of scenarios that all teams would work with. It was agreed that all scenarios would envisage a transition of the biowaste management system until 2025, which was regarded sufficiently distant to allow for significant changes and at the same time close enough to allow for extrapolation of the current situation.

For this time horizon, the following three scenarios were developed:

- **Scenario A: Extrapolation of current trends (baseline).** This scenario extrapolates current trends in urban biowaste management until 2025. Some of these trends will lead to significant changes in the overall functioning of the biowaste metabolism, notably the introduction of an obligation to source-separating organic waste by households and business starting from 2023, which is likely to increase considerably the quantity of biowaste that will be diverted from incineration. However, no other major changes are projected in this scenario. For instance, it is assumed that the region will make no major investments in collection or treatment capacity of biowaste and therefore it will continue to export biowaste to treatment plants in other Belgian regions (Wallonia or Flanders). Moreover, it is assumed that decentralised approaches to biowaste management would remain marginal in terms of treatment capacity. This scenario was regarded as essential for the BRUCETRA team to establish a benchmark against which policy proposals could be compared in terms of their environmental and economic impacts; the other teams were arguably less interested in this scenario as they initially did not envisage to carry out a full-fledged impact assessment on their own. But given that BRUCETRA would deliver this assessment, they agreed on the usefulness of defining a baseline scenario and participated in defining it.

- **Scenario B: Investment in regional industrial infrastructures.** This scenario also extrapolates current trends (introduction of sorting obligation) but introduces changes in the industrial waste management infrastructures in the region of Brussels. The development of this scenario built on research by LOUISE_ECO on the feasibility of new treatment infrastructures in Brussels and the inventory of process in- and outflows by BRUCETRA. The team explored different types of infrastructures, including an intermodal logistic transfer centre for moving biowaste from the municipal collection trucks onto barges or larger trucks; the extension and redesign of the existing composting facility for green waste; and the creation of a new treatment plant for municipal biowaste from Brussels through either industrial composting or anaerobic digestion. In the end, the scenario B only included the latter infrastructure. Several factors influenced this choice: firstly, PHOSPHORE had started to incorporate some of the smaller infrastructural changes in its own narrative/scenario (see scenario C below), so that there would have been some overlap between scenario B and C. Moreover, focussing on one important infrastructural change had the merit of allowing to compare the impact of this infrastructure with respect to the baseline scenario A. Finally, an important factor influencing the content of this scenario was that parts of the regional government of Brussels were inclined to invest in a large anaerobic digestion plant. Retaining such an investment as scenario B would therefore be relevant for on-going policy discussions.
- **Scenario C: Larger implication of local decentralised initiatives.** The third scenario also extrapolates current trends, but instead of considering only centralised, industrial-scale investments it also explores the possibilities of a wider implementation of decentralised initiatives. The latter can take the form of localised actions on food waste reduction; decentralised collection and treatment, for instance by composting at the neighbourhood or municipal scale; and the installation of individual devices by households and business (vermicomposting, composting, animal husbandry, dehydration, etc). The development of the quantitative and qualitative content of this scenario was provided by PHOSPHORE, notably through the output of participatory workshops with different groups of stakeholders during which qualitative narratives of transitions and quantitative targets for reduction, decentralised collection and treatment will be developed with the participants. To be sure, scenario C was used to give form to the narrative developed and proposed by the participatory process in PHOSPORE. As a consequence, it was often referred to as “scenario PHOSPHORE”.

Sharing a common database

Working together on the development of scenarios quickly led to the need to collaborate in a second way, namely by sharing a common database across all projects. To define, describe, and evaluate the different scenarios in a coherent way, it was clear that data harmonisation was necessary. Without this additional moment of convergence, the scenarios developed from disciplinary angles are likely to produce incommensurate data and information. For example, scenario C developed by PHOSPHORE mainly builds on input from participatory processes such as estimations and objectives regarding the future performance of community composting or food waste prevention in Brussels. These estimations needed to be coherent with estimations regarding the evolution of these activities in scenario A and B — an outcome that is not self-evident given that different methodologies and data sources could be used to establish estimations about the projection of biowaste (cf. Bortolotti et al, 2018a). In order to allow for the application of analytical tools such as the environmental impact assessment by BRUCETRA to all scenarios in a comparable and compatible way, it was therefore necessary to define a common database in which the most important quantitative and qualitative elements are recorded.

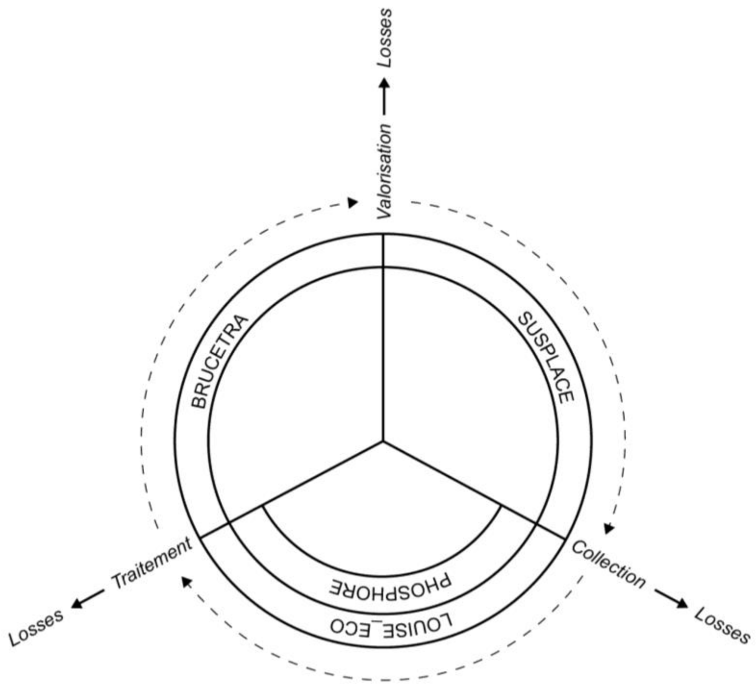
In practice, sharing a common database involved choices as to which team would provide which part of the necessary data to define and evaluate the common scenarios. Given that PHOSPHORE had the most expertise on decentralised biowaste management, this team provided the qualitative description and quantitative estimations for scenario C. By contrast, the data used in scenario A, relied heavily on the studies on biowaste potential collection carried out by LOUISE_ECO, but was also complemented by the inventory of existing treatment facilities by BRUCETRA and research on the valorisation of post-treatment flows in Belgian agriculture by SUSPLACE. This kind of choices again modified the research of all projects, as it is unlikely that idiosyncratic databases would have been coherent; moreover, the division of work in collecting and harmonising data allowed the projects to free resources for other purposes.

Shared terminology

The decision to share a common database led to a third moment of convergence: agreeing on the terminology for the different variables, nomenclatures, and classifications of which the database is made of. In a similar way that working on joined scenarios led to the need for a common database, the need for a shared terminology emerged “organically”, in the sense that it was not a premeditated decision but rather an activity that appeared spontaneously during the convergence of individual databases.

The first exchanges on databases showed that without reference to common typologies for flows, producers, zones, etc., the teams would have developed their own typologies to express different scenarios. In other words, comparable data required comparable (shared) terminology for the variables in the database and, to some extent, to research on biowaste flows in general. One of the first efforts towards this end was the concept an “ideal integrated cycle of (bio)resource management” in which all projects were represented using the same terminology of “collection”, “treatment”, and “valorisation”. LOUISE_ECO proposed a schematic representation that positioned the different projects across these three stages of (see Figure 2). This diagram turned out to be a useful tool for creating a common understanding of the (potential) relationships across projects.

Figure 2. Schematic representation of the position of each research project along the bioresources management cycle



Based on this general understanding, the database architecture was structured using the terminology of the “Unified Materials Information Systems” (UMIS) developed by Myers et al (2018). The team adopted a terminology distinguishing three types of database entries: *processes*, which represent transformation, distribution or storage of a material; *flows*, which represent the exchange of materials between processes or between processes and the environment; and *nodes*, which are analogous to subsystems (Myers et al, 2018).

Each of these categories is in turn related to specific nomenclatures, as well as the format of information recorded for each of these items. For example, the database architecture distinguishes between three types of biowaste flows (green waste, kitchen waste including substances of animal origin, and kitchen waste without substances of animal origin), eight types of biowaste producers and five urban zones with different population densities. Most of the typologies incorporated in the shared database architecture had been developed previously by LOUISE_ECO, which allowed to easily transfer existing data into the scenario development. Other typologies for the post-treatment valorisation phase and environmental impact analysis had to be developed. The most central nomenclature that was developed during the cooperation was arguably the one describing different categories of biowaste treatment including both large-scale (industrial) treatments and low-scale (decentralised treatments.

A community of practice creates its boundary objects

The previous section described moments in which different research dynamics on urban biowaste metabolism converged towards collaborating with each other. In this section, we interpret this collaboration as a community of practice, which can be defined as a group of people interested in sharing knowledge on a subject of mutual interest through regular interactions (Cundill, Roux, Parker, 2015). We first offer reflections on the meta-conditions which have enabled this particular community of practice to emerge; we then show how the different moments of convergence described above have created boundary objects across different epistemological angles.

Enabling factors for inter-project collaborations

Taking into account the metaconditions of inter-project collaboration, we offer reflections on the special circumstances that might have fostered or enabled collaboration on studying the biowaste metabolism of Brussels. These circumstances include the synchronicity of research projects' funding and agendas, the role of the funding donors, personal relationships and trust across research teams, previous experience with cross-disciplinary projects, and the interventions of bridging actors in the set-up of the collaboration. First, the regionalisation and fragmentation of the Belgian state have created multiple and sometimes overlapping research institutions, agencies, and programmes, that often work without central (national) coordination. At the same time, these institutions are responsive to European and national objectives, for instance, the general trend to apply circular economy thinking to regional policies (Kampelmann, Athanassiadis, forthcoming). This tends to produce multiple projects focusing on the same topics of interest for the city of Brussels with different results: either undesirable redundancies and a maze of individual institutions or desirable diversity.

Second, there has been some cross-fertilization through cross-participation: some researchers who work on PHOSPHORE also participated as independent experts in the study carried out by LOUISE_ECO. LOUISE_ECO, in turn, is partner of PHOSPHORE with one researcher which is simultaneously involved in both projects. Moreover, the project coordinator of PHOSPHORE is also an associated researcher in the department involved in BRUCETRA. Finally, members of PHOSPHORE participated in the steering committee of the feasibility study for an industrial biowaste treatment plant in Brussels conducted by LOUISE_ECO (Bortolotti et al, 2018b). Frequent and repeated collaborations were arguably instrumental in creating the mutual trust that is necessary to engage in a collaboration which does not generate additional funding. On any account, the cross-participation allowed for content and results to move across projects. For instance, PHOSPHORE incorporated the results from the studies by LOUISE_ECO on decentralised biowaste treatment techniques (Bortolotti, Kampelmann, De Muynck, 2018) and the quantification of biowaste flows within the Brussels region (Bortolotti et al, 2018a).

Overall, we are looking at a tightly knit ecosystem of researchers who have repeatedly collaborated with each other in different constellations. This cross-collaboration among researchers has enabled getting acquainted with each other's work as well as staying informed about the progress of respective projects, a main condition for developing communities of practice (Cundill, Roux, Parker, 2015), and which allows to seizing rare windows of opportunity as soon as they open. These changes in constellations probably reflect (i) the mobility and precarity that comes with the fact that the whole group is made up of young researchers (all but the civil society representatives are docs or post-docs) and (ii) the openness to and experience with interdisciplinary collaboration among the researchers.

Another enabling factor was the presence of “bridging actors” who supported the process of convergence described in Section 3. Firstly, the regional funding agency Innoviris participated in the first meetings with all projects and signalled to all potential partners that it was interested in this inter-project collaboration. Since most involved research departments are to some extent dependent on Innoviris for their funding, this created a strong incentive to overcome barriers to collaboration. The representative of the funding agency also suggested the submission in a regional academic journal (funded by the agency) as an outlet for the results of the collaboration. Another bridging actor that intervened in the process was the Chair for circular economy and urban metabolism that provided help to the consortium on the database architecture and scenario definition.

The emergence of boundary objects

The notion of “boundary objects” was proposed by Star and Griesemer (1989) to indicate concepts or items that can be approached from different epistemological angles as they are subject to interpretative flexibility and thus allow “collaboration without consensus” (see also Mélard, 2008; Star, 2010). In our experience, boundary objects emerged in problem-solving and research practice as a way for addressing a complex issue (such as waste management transition) in a situated manner (on Brussels), leveraging on the mutual insights collected by a diversity of ongoing projects, while avoiding engaging research from scratch. As the enabling factors of the inter-project collaboration are situated within the research context of Brussels — characterized by all the aforementioned conditions of synchronicity of projects’ funding and agendas, personal relationships, and existence of bridging actors — similarly, boundary objects of the cooperation emerged throughout the specific collaborative situations rather than from an ex-ante theoretical framework.

We assume the merits of boundary objects in a case study assessment of collaborative urban metabolism research lay in their capacity to be positioned to form a common boundary between diverse scientific worlds and research methodologies (from material flow analysis to participatory research). In our experience, the scenarios emerged as the first and foremost boundary object of the inter-project collaboration, being used in different ways and to different ends within each research project. Indeed, the process of scenario construction, and sharing of a common database, and terminology, is what enabled to translate, negotiate, debate, and simplify in order to work together, without preventing each research team from pursuing its own disciplinary research objectives.

For SUSPLACE, the scenarios serve as a means to strengthen the research with a real-word case, instead of using only theoretical scenarios. SUSPLACE could have worked on another city than Brussels in its scenario development, as the latter was a tool to further research on biogeochemical cycles related to urban centres in general, rather than in any particular city. This was different for BRUCETRA and LOUISE_ECO, which specifically focus on management transition in Brussels. For those teams, scenarios are mainly a heuristic tool to evaluate a broad set of alternatives of biowaste management in the city, which is why, for instance, researchers from BRUCETRA were inclined to define very contrasting scenarios that allow capturing the main differences between alternative management options. Moreover, BRUCETRA, like LOUISE_ECO, uses the scenario analysis to explore alternative futures and formulate policy recommendations for the Brussels Region: in this view, scenarios articulate and forecast alternative trends, unfolding possibilities, risks, and uncertainties. The scenario development by LOUISE_ECO embraces both qualitative and quantitative data and, most importantly, is meant to create a learning process with the regional stakeholders and common vocabulary to communicating complex conditions (Mietzner, Reger, 2005). This perspective contrasts with the status and function of scenario development by PHOSPHORE. In this project, the team was interested in developing a scenario as a storytelling device to lobby for its vision of an alternative biowaste management system for Brussels. Rather than the exploration of options, the PHOSPHORE scenario is more a description of a proposal.

The developed scenarios, therefore, remain detailed enough to allow for relevant estimations of urban biowaste flows, whereas material flow analysis and participatory research approaches are set to cooperate and create a minimal common understanding of the internal diversities for the benefit of both. Working with the same set of scenarios definitely modified the content of the projections developed by all projects; for example, without the collaborations, it is likely that PHOSPORE would have developed only one argumentative scenario, whereas BRUCETRA and SUSPLACE would not have explored decentralised biowaste treatment options in such detail. This being said, the epistemological status and function of the scenarios did not change within the projects: each team still refers to the methods and research questions it set out with but allowed itself to be influenced in a range of choices as to the scenarios to which these methods will be applied.

Conclusion

This paper provides an account of a promising research collaboration on the study of the Brussels biowaste metabolism. We argue that the collaboration we described in this paper was probably the result of the serendipitous presence of many enabling factors like the complementary of research agendas, relationships of trust between researchers, and the presence of bridging actors who have the capacity to mobilize different research projects around the same boundary objects. These factors can obviously not be easily replicated in all contexts, although certain aspects of it – such as the role of bridging actors or other forms of intermediation – are increasingly the object of conscious supporting efforts to stimulate collaboration in sustainability transitions (Kivimaa 2014).

The specific boundary objects that emerged in our case were joined scenarios, a common database, and shared terminology; we think that these boundary objects could also be useful for other interdisciplinary research on urban metabolism as they clearly facilitated knowledge transfer and the communication of results across teams. Importantly, these boundary objects have not been defined by an ex-ante research strategy or an interdisciplinary theoretical framework; once the teams decided to work together, the boundary objects have emerged rather spontaneously as necessary tools for cooperation. This suggests that theoretical integration across disciplines and epistemologies is not the only way for improving the interdisciplinary cooperation on urban metabolism: once a community of practice emerges (for whatever reasons), it can create boundary objects through the practice of working together.

We close this article with tentatively stated lessons we learned about the benefits (and limits) of the interdisciplinary approach to the transitioning of urban metabolism. The key benefit for us of building interdisciplinary boundary objects is that they potentially allow to grasp urban metabolism as a socio-ecological co-production. The terminologies we defined to categorize types of actors or different biowaste treatment options were informed by knowledge from a relativist epistemological stance that is commonly absent in standard representations of urban metabolism. For example, the life-cycle analysis of compost stations of the same throughput is probably similar if these are used by a local community or a meso-scale commercial operator like Les Achimistes or Compost In Situ[8]. The underlying spatial and socio-political considerations are, however, quite different between a community-based and commercial experience. Similarly, important distinctions were included in the analysis of biochemical cycles, for example by introducing distinct categories for peri-urban and rural agriculture. On the whole, the transition scenarios that could be formulated thanks to such interdisciplinary terminology and a corresponding database provide arguably a richer description of urban metabolism that takes into account a large number of social, political and cultural considerations which in turn allows to assess important but often absent issues such as the social acceptability of different flow management alternatives, operational risk and local political momentum.

But we also experienced limitations to our approach. These pertain mainly to the loop-sided relationship between, on the one hand, the powerful tools developed by quantitative approaches — for instance Sankey diagrams and Stan software[9] — and the more fuzzy and indeterminate tools that are available to depict conceptions of urban metabolism socio-ecological co-production, on the other hand. Similar to the well-known disproportionate influence of the architect's mastery of powerful images in debates about building projects (Loureiro, 2015), we experienced that the representations we formed on urban metabolism constantly went back to the standard reductionist forms of Sankey diagrams and quantitative tables. For example, when faced with the task of summarizing a complex and systemic scenario blending local, meso-scale and regional approaches to biowaste treatment, the consortium opted for a simplistic summary in form of a table of estimated flows, which meant that important spatial and socio-political arguments were to some extent crowded out. A first step in overcoming this limitation is to be fully aware of the disproportionate emphasis in urban metabolism on the heuristic tools of quantitative flow analysis. This should be followed up by more efforts to develop other heuristic tools able to represent socio-ecological complexity of urban metabolism in order to blend insights from material flow analysis with other crucial pieces of knowledge, in particular spatial and socio-political dimensions of urban metabolism.

[8] See the project websites: http://alchimistes.co/ and https://compostinsitu.fr/

[9] A Sankey diagram depicts flows of any kind, where the width of each flow pictured is based on its quantity. STAN (short for subSTance flow ANalysis) is a freeware developed by the Technische universität Wien that helps to perform material flow analysis according to the Austrian standard ÖNorm S 2096 (Material flow analysis - Application in waste management).

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