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Integration of Waste Supply and Use Data into Regional Footprints: Case Study on the Generation and Use of Waste from Consumption and Production Activities in Brussels

Vanessa Zeller[a,b,*], Edgar Towa[a,b], Marc Degrez[b], Wouter M.J. Achten[a]

[a]*Institute for Environmental Management and Land-use Planning, Université Libre de Bruxelles (ULB), Av. F.D. Roosevelt 50, 1050 Brussels, Belgium*
[b]*4MAT department, Université Libre de Bruxelles (ULB), Av. F.D. Roosevelt 50, 1050 Brussels, Belgium*

* Corresponding author. Tel.: +32-(0)2-650-4333. *E-mail address:* vzeller@ulb.ac.be

Abstract

The development of material flow accounting and environmental impact assessment models to evaluate production and consumption activities is a challenge at the regional level due to the restricted availability of regional data, especially waste data. However, the regional context is often required, for example for the development and evaluation of regional circular economy programs for which waste generation and valorization plays a key role. In this research, we present an approach to develop regional waste supply and use tables based on regional waste statistics and national input-output tables. The results show that this method is well suited to quantify waste generation from households, but it is more difficult to implement for waste generation from urban economic activities where production and waste intensities deviate from the national average. The comparison between regional statistics and calculated waste extensions indicates that regional statistics could underestimate certain waste flows which are important for the circular economy context, such as metal, glass and inert waste. Such uncertainties can be reduced by developing more complete and reliable bottom-up waste data and physical/hybrid tables where full mass balance checks can be carried out. However, the results demonstrate that it is possible to develop a coherent framework at city-regional scale that integrates material/waste flow accounting and impact assessment of production and consumption.

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Keywords: Regional assessment; input-output; waste extensions; waste flow accounting; impact assessment

1. Introduction

The aim of the paper is to present an approach to include waste generation and use into a regional input-output framework to *i*) complete regional impact assessment/footprint by the important parameter of waste generation and to *ii*) increase sector resolution of waste flow accountings. The paper starts with a short introduction on the role of footprints for sustainability analysis and on the emerging importance of analyses at the regional level. After a brief introduction of the case study of Brussels-Capital Region (BCR), we present the input-output (IO) model used in this study and the approach to extend the existing IO-framework with waste flows. In the results section, the results from the waste flow accounting and an example for the quantitative impact assessment of Brussels' waste sector is presented. The paper ends with a discussion of the approach, possible applications and perspectives on further research steps.

1.1. Sustainability assessment of production and consumption

In order to assess environmental impacts from consumption and production activities, for example from regional household consumption or economy-wide production activities, the input-output framework is often used. It is well suited for such an application, as input-output tables (IOTs) provide the necessary

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production-consumption inventory data and the necessary methodological framework, i.e. input-output analysis (IOA) for such large scale assessments [1]. IOTs can be extended by environmental, but also socio-economic data, to carry out (partial) sustainability assessments following the principle of life cycle thinking [2]. Usually, these assessments are more complete in terms of inventory data (no cut-offs), but less exhaustive in terms of environmental data compared to process life cycle assessments (LCAs). Most studies focus on specific indicators such as the carbon, water or land use. In this context the terminology of footprint (carbon, water or land use footprints) is used.

The input-output framework is not only a framework for large scale impact assessment; it can also be used as a framework for material flow analyses (MFA). For this application, the development of hybrid IOTs, where production activities are measured in physical units and service activities in monetary value, is necessary. While the procedure to count for resources and products in physical units is well-known, the physical quantification of waste flows based on IO data is more difficult to implement. This is why a specific waste input-output methodology has been developed.

Although the theoretical foundations of waste input-output models and the development towards material flows accountings have been introduced since more than 10 years [3], [4], to date few databases are available that provide these hybrid tables and physical waste supply and use data. An exception is Exiobase [5–7], a global multi-regional IO database that consists of monetary as well as hybrid tables with waste extensions. Recently, this database was used to analyze the global waste footprint [8]. A limitation of IO-databases is their geographical resolution which is restricted to the national, and in some cases sub-national (e.g. regional) level.

1.2. Regional context

The development of regional[1] inventory data for LCAs or footprints was not a priority for a long time. Today the largest LCA database Ecoinvent does provide inventory data at subnational level for certain processes. With the development of more local impact assessment method and recognition of the planetary boundary approach, the demand for more regional datasets is increasing and currently hybrid and more regionalized datasets are under development (for example [9, 10]). In contrast, in the context of MFA and for applications such as resource or waste management, regional or local datasets are required, because the operational management level is rather the meso-level. However, for both applications, either an impact assessment or material flow analysis, the inventory data must reflect the goal and scope of the study. Thus, in order to study material flows and impacts at the city level, for example in the context of circular economy strategies, regionalized datasets are necessary that can represent specific regional characteristics. Recently, city-centric global multiregional input-output model was developed, but with a restricted focus on the urban carbon footprint [11].

1.3. Case study of Brussels-Capital Region

Brussels-Capital Region is one of the three administrative regions of Belgium. This city-region can be characterized by

- high population density (7,434 person per km² [12]),
- high share of residential and service sector land use (63% [13]),
- dynamic population and economic development [14], [15],
- comparatively low level of disposable income (17k€ per cap*yr [16]), but high regional GDP [17],
- regional economy dominated by the service and public sector (90% of gross value added [18]) and small share of industrial production (all values refer to 2015).

In comparison to the other Belgian regions and determined by some of the factors described above, Brussels has a significantly lower waste performance than the other regions in terms of material and organic recycling rates [19] with a recycling rate of 27% in 2013 [20]. Turning this environmental challenge into 'business opportunities' is the target of Brussels' circular economy plan [21] which intends to close material cycles, reduce environmental pressure and stimulate local economic activities. Since waste treatment is a key sector in the circular economy model, the program is also strongly linked to the city's waste management plan that determines specific waste prevention and recycling targets and measures [22].

In order to support this transition towards higher performance by identifying most promising solutions, it is necessary to analyze the quantity and characteristics of existing and future waste flows and to determine possible impacts of new circular economy and especially waste treatment/recycling options. Therefore, this research aims to provide a coherent framework for the assessment of material/waste flows and impact assessment at city-regional scale.

2. Data and method

2.1. Environmentally extended multiregional IO-model

For the environmental impact assessment of production and consumption activities from a life cycle perspective, it is crucial to consider the direct (i.e. impacts caused and taking place within the region) as well as the indirect impacts from imported goods and services. Therefore, the developed model considers production activities in Brussels (Br) and trade between Brussels and the two other Belgian regions (Flanders, Fl and Wallonia, Wa), Europe (EU) and non-Europe (see Fig.1). The basic interregional Belgian model/data, provided by [23], represents Belgian production and consumption in 2010. It is coupled with Exiobase data (Exiobase v.2) for the imports (base year 2007). In the model, Brussels' economy is structured into 81 sectors that produce and consume 81 types of products and services. Since the household sector is also represented in these core tables, the final matrix dimension is 82 x 82 products by economic activities (represented as one box, in Fig.1).

[1] In this study the term 'regional' refers to the subnational level.

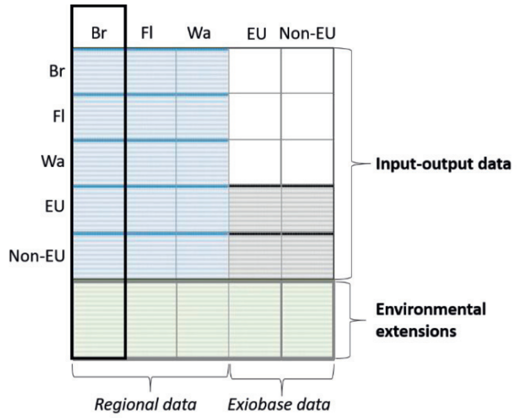

Fig. 1. Structure of the environmentally extended IO model.

For the Belgian regions, the economic model is extended by regional environmental data covering main emission and resource use for these 82 sectors. In the basic version of the model [24], regional (physical) data on waste generation and use was not available. In order to fill this gap, waste supply and use tables were developed for Brussels.

2.2. Development of regional waste extensions

The general idea to include waste generation and use into the regional IO framework is to develop waste supply and use tables as extensions to the economic IO model (see Fig. 2). These extensions are developed by combining regional waste statistical data (bottom-up data collection) and national waste IO data (top-down approach). This approach is chosen, because it is hardly feasible to collect data on all types of waste fractions at high sectorial detail with a 'bottom-up' approach if no statistical monitoring system is in place. But, it is also too uncertain to rely only on national waste input-output data to estimate regional waste generation.

The first step of the approach is the data collection and conversion of datasets into a common data format. The regional waste statistics provide data in a format representing Brussels' current collection system. The waste data is highly aggregated. For example, mixed residual waste is accounted as one fraction. The datasets are provided by different agencies, such as the main collector of municipal solid waste (Regional Agency Brussels-Propreté), Brussels' Environmental Administration for all waste types that need to be registered and a statistical office for certain waste type produced in economic activities [25]. The collected statistical datasets have been analyzed and combined into one dataset [26], so that the total waste quantity for solid, non-hazardous waste generated in Brussels could be estimated. In order to convert the collection-based data into the IO-compatible format, the percentage material fractions (for example 53% organic waste in the mixed residual household waste) taken from bags composition analyses [25, 27, 28] were applied to the initial data. Then, the waste fractions were attributed to households or economic activities following the accounting rules of the system of national accounts [29].

In parallel to the collection of statistical data, the national waste IO data for Belgium was extracted from Exiobase (v.2). These datasets represent material fractions, for example paper, metals, plastics, etc. at high sectorial resolution. These datasets were converted from dry to wet mass based on dry matter content specified in Exiobase datasheets. Then, waste quantities from products produced in previous accounting periods were added, because they are accounted separately in Exiobase 2 and need to be included for the comparison of total waste generated in the specific year. In the following, national waste coefficients $W_{n,coef}$ were calculated by

$$W_{n,coef} = W_n \hat{g}_n^{-1} \quad (1)$$

where W_n is the national (here Belgian) waste extension matrix and $\hat{g}_n^{-1}$ the inverted matrix representing the yearly national industry output (cf. [30] for the calculation of coefficient matrices). The regional waste extensions are then calculated by

$$W_r = W_{n,coef} \hat{g}_r \quad (2)$$

where $\hat{g}_r$ represents the regional (here Brussels') industry output in 2010, specified in Brussels' supply tables. The result of these data treatment steps, called the regionalized waste IO data, is a first theoretical estimation of waste generated in Brussels in 2010.

After these data conversions, data sets provide a compatible format, so that waste statistical and regionalized waste IO data can be compared: Based on statistical data we estimate 2.1 kt of solid, non-hazardous waste generated in 2010 in Brussels, while the theoretical estimation based on IO data shows 3.2 kt. The detailed results are presented in section 3.1 for the household sector and in 3.2 for economic activities. The aim of the comparison is to evaluate the degree of variation between the two datasets in order to (*i*) draw general conclusions whether the theoretical estimation based on IO data can be used as approximation if bottom-up data is not available and (*ii*) whether the chosen approach for this study can be applied to all waste fractions and sources of waste generation. For this study, for which bottom-up data are available, the waste statistical data is used as basic data and the regionalized waste IO data as disaggregation key to align the statistical data to the 81 economic activities and households.

The third step is the calculation of the final waste extension table for Brussels which shows 8 waste categories and 82 sectors. Therefore, the aggregated waste statistical data is allocated over the economic activities. For this procedure, a disaggregation based on weighting factors [31, 32] is applied. The factors are calculated based on the regionalized waste IO data. They represent the contribution of a sector to the total waste generation of a waste category: for example, the hotel and restaurant sector contributes 8% of the food waste from economic activities. The weighting factor is then multiplied by the waste statistical data (for example, the hotel and restaurant sector in the final waste extension table shows 5 kt of food waste). The results are presented in the sector contribution analysis (section 3.3).

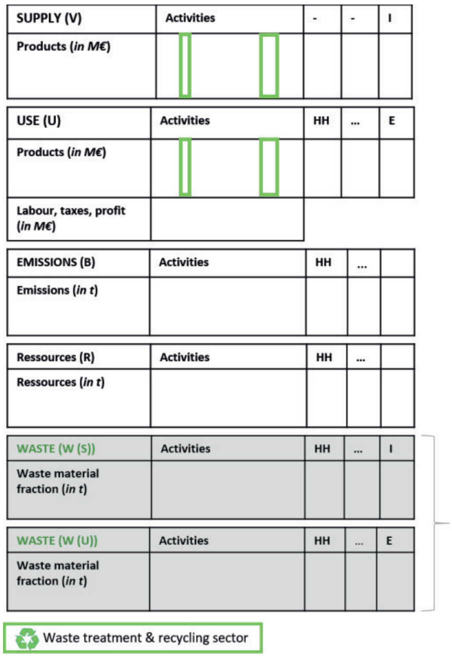

Fig. 2. Structure of supply and use tables with waste extensions (example given for one region, Brussels). HH=Households, I= Imports, E=Exports

2.3. Environmental impact assessment

Based on the input-output model presented in Fig. 1, environmental impacts from Brussels' production and consumption activities can be evaluated. Therefore, the algorithms from environmentally extended input-output analysis (EE-IOA) [33] are applied to the developed tables. The inventory data is calculated by multiplying the environmental extensions by the Leontief inverse and a demand vector. The results of the inventory are then assessed by applying an impact assessment method. In this case study, IMPACT 2002+ (V2.14 / IMPACT 2002+ / Normalization) was chosen.

In order to demonstrate how the waste flow accounting can be combined with the environmental impact assessment, Brussels' waste sector is analyzed. The waste sector consists of five subclasses: recycling, incineration, biological waste treatment (composting and biogasification), waste water treatment and landfilling, but biogasification and landfilling are not present in Brussels and waste water treatment is not in the focus of this study. The demand vector represents the economic output of Brussels' incineration, recycling and composting sector in 2010. In terms of economic contribution and amount of treated waste, incineration is the most relevant waste treatment activity located in Brussels. Impacts from waste collection as well as all other upstream impacts and impacts from the final waste services demanded by the sectors (for example landfill of incineration residues) are also included.

3. Results and discussion

3.1. Comparison of waste generated by households

First, it has to be mentioned that waste generated by households as accounted in IOT differs from the category 'household waste' as defined in the list of waste established by Commission Decision 2000/532/EC. In the latter, inert waste such as concrete, bricks, tiles etc. are not included, whereas in IO all types of waste generated by households are considered.

The comparison of waste from households (see Table 1) shows higher results for the waste IO data than for the statistical waste data for most waste categories. This is an expected result, taking into account that waste IO data represents a theoretical estimation (balancing item) based on national waste coefficients from 2007 and that the statistical data is based on measurements of registered waste only, not covering unregistered waste. Furthermore, the bag composition analyses and additional data used to decompose multi-material products (for example bulky waste) do not allow to disaggregate all waste types into the different material fractions. The remaining composites such complex packaging, fine particles or street cleaning residues are accounted in the category 'other (composites)'.

The variation in the quantitative most important waste fractions (organic and inert waste) is relatively low, therefore, the total variation is only 9.7%. However, a very high variation occurs in the category metal waste. One explanation for the deviation is that a significant share of metal waste from households is not appearing in the waste statistical data, because parts of the metal scraps are collected by not registered collectors. However, the estimation of metal waste from households based on IO-data seems also very high compared to other waste fractions such as organic waste.

Table 1. Comparison of waste from households (Brussels 2010).

Waste material fraction	Waste statistical data (kt)	Waste IO-data (kt)	Difference (%)
Glass	24	30	23.8%
Inert	178	183	2.8%
Organic (Food waste)	100	92	-7.3%
Metals	26	136	419.9%
Paper & cardboard	64	77	20.2%
Plastic	40	28	-29.0%
Textile	10	12	16.8%
Wood	15	18	18.5%
Other (composites)	38	-	-
Total	495	544	9.7%

3.2. Comparison of waste from economic activities

The comparison of statistical and IO data for waste from economic activities is presented in Table 2. The results show similar differences as seen before. For most datasets, the theoretical estimation of waste IO data is higher than the regional statistical data, especially for metals and glass waste.

Again, for these waste streams, the waste statistical data could represent an underestimation of waste flows. But also, the IO-based estimation can be biased if the national waste intensities deviate from the regional ones. This is the case if *i)* the economic output indicated in Brussels' supply table is higher than the real production (head quarter problem) or if *ii)* the composition of a specific sector in Brussels deviates from the average national composition. The first problem can be reduced by comparing regional production data with the data from supply tables. This was done in detail for the food manufacturing sector with the result that regional food waste intensity was reduced to 66% of the national intensity. The second problem can be treated by increasing the sector detail with disaggregation approaches. This was implemented for the energy, construction products and waste sector.

Table 2. Comparison of waste from economic activities (Brussels 2010).

Waste material fraction	Waste stat. data (kt)	Waste IO-data (kt)	Difference (%)
Glass	14	92	533.0%
Inert	1024	1514	47.8%
Metals	162	320	97,8%
Organic (Food waste)	61	60	-0.5%
Paper & cardboard	128	166	29.7%
Plastic	65	72	10.4%
Textile	13	5	-61.9%
Wood	49	37	-24.5%
Other (composites)	45	-	-
Total	1561	2266	45.2%

3.3. Sector contribution analysis

The sector contribution analysis is based on the disaggregated waste statistical data (Table 1 and 2). It reveals the contribution of each economic activity and the household sector to the generation of a certain waste fraction. For readability reasons the results for the 81 economic activities are aggregated into 12 classes (see Figure 3). For most waste fractions, households constitute the main contributing sector. For inert, metal and wood waste the construction sector holds the most important share. Administrations and the education sector are also important sources of inert, metals and paper waste generation. The combination of information about total quantities and sources of waste generation supports the development of alternative waste treatment scenarios. For example, organic waste, currently mainly incinerated, shows a high valorization potential by combining the three most contributing sectors (households, food manufacturing & canteens from health and social sector).

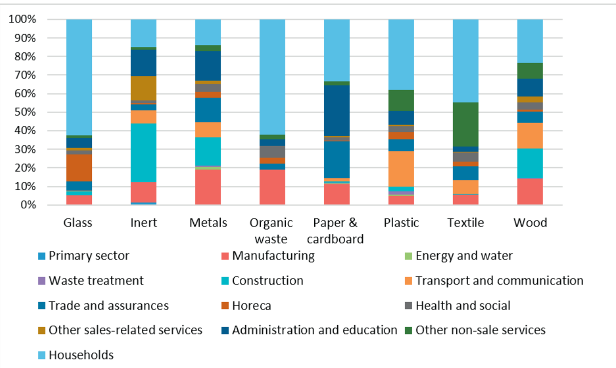

Fig. 3. Contribution of sectors to Brussels' waste generation.

3.4. Environmental impact assessment

Fig. 4 shows the environmental impacts for the total output of Brussels' waste sector in 2010, presented as normalized endpoint impacts (normalization factors from IMPACT 2002+ (V2.14). The contribution of subsectors to an impact category is determined by the economic output and the specific environmental profile. Waste incineration is the most important subsector (67-77%), followed by the recycling sector (20-32%) and biological waste treatment (1-3%).

The normalized results for the total sector output show that climate change and human health impacts are the most important impacts. Climate change is mostly determined by CO_2 emissions related to electricity use, final waste treatment and direct sector emissions. Human health impacts are mostly related to NOx, SO_2 and particulates resulting from the electricity use, transport and direct emissions.

When comparing this EE-IOA with process-LCAs, we find that the environmental data (emissions and resources) and the impact assessment are in general more complete in process-LCA. Thus, for a municipality interested in environmental decision support between different waste treatment options, process-LCA has advantages. The advantage to use the input-output framework is the possibility to extend easily the scope of the assessment on other products and services. Thus, with the IO approach changes in regional production and consumption, the effect on waste generation and environmental impacts from waste treatment can be studied in one model based on regional inventory data.

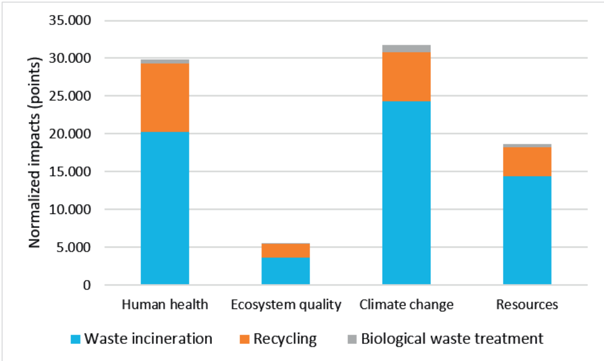

Fig. 4. Normalized environmental impacts from Brussels' waste sector.

4. Conclusions

This research has shown that it is possible to build a coherent framework for material/waste flow accounting and impact assessment at city-regional scale.

We have to recognize that the development of such a framework was possible due to access to regional input-output data and other data that is available due to the specific status of Brussels as city-region. This research also showed the difficulties to generate consistent, complete and detailed regional waste data. The confrontation of bottom-up and top-down data revealed the high uncertainties inherent in both types of data. The fact that certain waste fractions do hardly match while others do match seems to indicate that the regional waste statistical data are incomplete for certain waste fractions. This is the case for metals, glass and inert waste. Additional efforts are needed to validate statistical and input-output data. The theoretical estimations can be improved by conducting complete mass balances between resource and products inputs, and waste and emissions output, which means to develop regional hybrid datasets. However, even improved theoretical estimations have to be cross-checked with measured waste statistical and production data whenever possible.

The used approach to allocate waste data over economic activities based on coefficients is an efficient approach to improve sector detail. The increased sector detail is necessary when practical solutions, for example specific prevention, collection and treatment measures are developed. But also from a methodological point of view it is helpful to have an increased sector detail, for example to develop projections models that can consider economic projections for specific sectors.

This article has dealt only with a small dataset development for Brussels. When seeing the complete multi-regional IO-model and possible applications much more developments are needed, first of all the development of waste datasets for the other regions. At the moment, the upstream environmental impacts and waste generation can be analyzed, but for the complete impact assessment the downstream treatment of waste is equally relevant. This is especially the case for an urban region like Brussels, where a large share of waste treatment and valorization takes place outside the city's boundaries.

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