PROJECT N. 037033

EXIOPOL

A NEW ENVIRONMENTAL ACCOUNTING FRAMEWORK USING EXTERNALITY DATA AND INPUT-OUTPUT TOOLS FOR POLICY ANALYSIS

CONCEPTUAL FRAMEWORK FOR LINKING IN CONSUMER ACTIVITIES AND POST-CONSUMER WASTE MANAGEMENT AND RECYCLING ACTIVITIES AND RELATED PRODUCT FLOWS

Report of the EXIOPOL project

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Executive Summary

This report describes how consumer activities and post-consumer waste handling are included in the SUT framework of EXIOPOL. Options for how to treat these activities in a more comprehensive way are discussed, with a reasoned choice on how to deal with this subject in EXIOPOL.

Traditional SUTs with environmental extensions do not cover direct emissions from households. Moreover, traditional SUTs treat demand for products and demand for domestic waste treatment services independently, whereas they are obviously coupled. The framework developed covers both subjects together, giving due place to consumer activities with environmental extensions, and linking consumption to the post-consumer waste handling activities. One main choice is not to go deep into consumption theory, where the housing service may for example be described as the combination of a building with furniture and heating. All products purchased are treated independently, allowing for relevant combinations in later applications of the database.

This document sets the stage for the data collection task that will be reported in PDIII.2.c-2.

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1 Introduction

This chapter introduces the scope of the present report, and reviews some of the earlier literature on the same topics.

1.1 Why a special treatment of waste and consumers?

The workpackage of the EXIOPOL project in which this document has been produced deals with consumptive activities and post-consumer waste handling. Admittedly, consumers and waste are two entirely different things. Thus, this report will contain separate discussion on consumers and on waste. But these consumers and waste are also related subjects in some sense. When we divide the activities related to products into three natural parts, production, consumption, and post-consumer waste treatment, it is production for which supply-use and input-output tables were originally designed. Consumption activities and post-consumer waste treatment do not fit entirely in these classical frameworks. So consumption activities and post-consumer waste treatment are two aspects of economic activity that need to be addressed in order to obtain a more comprehensive view of the economy and its resource extractions and emissions. Especially direct emissions by consumers can constitute a substantial part of total emissions, for energy related emissions typically in the order of 20 to 40%. (Tukker et al, 2006; Peters & Hertwich, 2006) This report will discuss the adaptations in the supply & use and input-output frameworks in order to accommodate consumptive activities and coupled post-consumer waste treatment. This report describes only the framework; it does not give the data details. Another deliverable (PDIII.2.c-2) is devoted to the task of collecting those data. It will be produced at a later stage of the EXIOPOL project.

This immediately suggests that the framework developed in this document is less mature than the structure for the industrial part of the EXIOPOL project, and that the data that will be supplied in the deliverable PDIII.2.c-2, will be less certain and complete than those for the industrial part. Industrial IOTs and SUTs have been made for many decades, and their architecture and the guidelines for compiling them have been thoroughly discussed.

What is special about consumer activities and post-consumer waste in the context of SUT and IOT? It is a number of things:

- Industries use products that are made by other industries for intermediate use and they supply products to other industries for final consumption. In contrast, although consumers use products that are made by industries, in most IO model formulations they do not supply anything directly to industry, though of course waste streams are delivered to industry for waste processing. We could also consider the supply of discarded products which households supply as inputs to secondary production or as fuel for electricity or heat production, but these discarded products are not usually considered as production either.
- In some studies consumers are regarded as producers of labor. However, viewing household consumption as necessary inputs for labor does not accurately reflect the range of products consumed. Clearly such a model does not satisfactorily represent societal activities other than industrial production. In social accounting matrices, developed by Stone (1947), the supply of labour by households and the demand for goods is endogenized. Options to include different classes of labour, by education and skill level, and different groups of households are commonly applied in labour economics. Options to extend this analysis to address environmental aspects of consumption have been explored by Duchin (1998).

- Typically, transactions in supply, use, and input-output tables are recorded in monetary units. This presents a challenge for the representation of waste products. For normal products, the monetary flow has the opposite direction as the product flow, be it a good or service. Whenever steel flows from industry 1 to industry 2, money flows from industry 2 to industry 1. For waste this is often not the case. Transactions involving waste are generally recorded in one of two ways. Waste collection and disposal is represented as the purchase of this service by an industry or consumer. Thus, the supplier of waste is not paid for the waste, but rather has to pay in order to get rid of it. In this case the flow of money and of material are in the same direction. In other cases waste materials are used to off-set the production of new materials. In these cases the input of waste material is recorded as a negative value. This treatment is similar to the way in which changes in stocks are represented. Products produced previously are recorded as negative inputs to industries today.

- The monetary input-output framework is inappropriate for tracking flows of low-value materials. For example, many metal wastes with essentially no value are used as inputs to secondary production. In some cases products with no value are recycled despite the increased cost when compared with virgin materials for environmental, public-relations, or liability reasons. In other cases the value of a material fluctuates such that at some times the collecting company is paid for disposal and at other times the collecting company pays the value of the recoverable material.

- There are cases, however, where this post-consumer discarded product price is clearly positive. Many metal wastes are in fact valued products. Gold, silver and platinum from jewellery form a substantial input in metals production. Also waste paper of good quality has a positive price with recyclers, with collection systems from households being set up commercially in countries like India and China. It could be argued that such positive value products are to be referred to as normal products, with private households as producers, and not as waste, so that we can keep using the term waste for undesired items. This would be similar to households as employers of household personnel, which is in the system already. Second hand products are another category of discarded products with positive price, which we will leave out of account as forming internal "supply and use" within private households.

- In many countries the inputs to and outputs from municipal waste collection are difficult to distinguish as this service is provided by the government. When this activity is funded through general taxes there is no clear connection between payments and the use of waste collection services or production of waste. Thus separate accounts representing waste in physical units are needed to adequately model the effect of changes in demand for consumer products must somehow make sure that the on post-consumer waste treatment changes accordingly and the availability of secondary materials.

- Of special concern is the issue of combined production. Industries which produce more than one product are a case to consider in the step from SUT to IOT, but not so much in the SUT itself. The treatment of secondary products has been the source of many controversies. It can also show up in waste treatment in two different ways. The first case is that of combined waste treatment. Most waste incinerators, landfills, etc. are not devoted to treating one type of waste, but treat a number of them simultaneously. A municipal waste incinerator burns packaging, newspapers, plastic dishes, and many other discarded waste products together. The second case is that of recycling, where a waste product is absorbed and a useful material or energy is produced. Many incinerators burn plastic waste and coproduce electricity, and many waste facilities are able to recover metals.

- In modelling a changed demand for consumer products, we must somehow make sure that the post-consumer waste treatment services change accordingly.

In the discussion that follows, a distinction must be made between two activities: accounting and modelling, with different requirements.

With respect to accounting, the main concern is that all data that is supposed to be recorded is in fact recorded systematically, and is easily retrievable. The requirements for modelling are more demanding, however. In modelling, we might wish to investigate what happens for example when the exogenously determined demand for cars changes. Through the model, we expect to see changes in car production, steel production, etc. But we would also like to estimate changes in fuel production, in direct emissions, and in disposal of used cars. Thus in setting up a framework for SUT/IOT we must analyze the requirements from an accounting perspective as well as from a modelling perspective.

1.2 What is already present in EXIOPOL?

Although the issues mentioned above are issues of concern, it is also important to mention that several things related to consumers are already part of the standard SUT:

- Waste treatment facilities are part of the normal industrial structure, and as such they are already accounted for in the normal tables. Indeed, Table 1.1 lists the seven industries that have already been included in the industry-part of the EXIOPOL-SUT, and which could be classified as industries dealing with waste.
- Consumers are included in the final demand section of use tables which include use by households, government, and non-profit institutions serving households (NPISH),. See Table 1.2 for the final use types in EXIOPOL.

Table 1.1: The waste-related industries that are in the standard SUT with the EXIOPOL industry classification.

EXIOPOL industry code	industry name
37.1	recycling of metal waste and scrap
37.2	recycling of non-metal waste and scrap
40.11.f	production of electricity nec (including biomass and waste)
90.01	collection of waste
90.02.a	incineration of waste
90.02.b	landfill of waste
90.02.c	sanitation, remediation and similar activities

Table 1.2: The consumption-related information that is in the standard SUT.

EXIOPOL final use code	final use name
y01	Final consumption expenditure by households

y02.a	Final consumption expenditure by non-profit organisations serving households (NPISH)
y02.a	Final consumption expenditure by government
y04	Gross fixed capital formation
y05	Changes in inventories and valuables

1.3 What is not or insufficiently present in EXIOPOL?

For several reasons, however, the inclusion in the standard framework is insufficient. Two main reasons are the following:

- EXIOPOL aims at including environmental extensions. The framework for environmentally extended industry tables is well-known, but the household consumption as a vector in a final demand section generally has only one value in national NAMEA. Thus, all direct consumer-related emissions are combined such that the impacts particular to specific consumption activities such as fuel use in cars, gas combustion for home heating and cooking, or the use of pesticides for gardening cannot be distinguished.
- With emphasis on resource availability and cradle-to-cradle economy, the material flows in the economy are to cover the post consumer flows as well. Without the relevant product-specific linkages this would be impossible.
- Likewise, post-consumption activities are affected. A reduced demand for newspapers will lead to a reduced demand for the post-consumer newspaper disposal.

Thus, it is obvious that a comprehensive picture of the environmental extensions of economic activities requires an expansion beyond the standard SUT- or IOT-framework, both from an accounting and from a modelling perspective.

1.4 Other approaches to including consumers and waste

A precursor of the EXIOPOL project was the EIPRO project (Tukker et al., 2006). In this project, no SUT was used but direct IO-data were used. But the IO-structure was different from the classical one in a sense that is of interest in the present discussion. The EIPRO-framework relied on a division of activities in three main categories: production, consumption and post-consumer waste treatment. The production block was a 478 by 478 system of industry-by-industry data. Next to that, a consumer block of 478 by 478 was constructed. This block contains information on how different products are used in combination. For instance, the final demand for electricity has been distributed among the various electrical appliances, such as computers, vacuum cleaners and lamp bulbs. Next, a "use" matrix of such products has been made. In this, a vector defines the "recipe" for combining lamp bulbs and electricity in the activity of lighting. A third set of blocks is devoted to the waste treatment of each of the products purchased, with zero waste flows for products used up in consumptive activities like gasoline. For this, 9 waste processing sectors have been taken out of the industry by industry table and formed into a separate block. They cover post-consumer waste processing as well as industrial waste processing. Finally, environmental extensions have been added to the production, to the consumer activities and to the waste treatment. See Figure 1.1 for an overview. Figure 1.2 shows the mathematical structure.

There are several reasons why the EXIOPOL framework has to go beyond the EIPRO approach. First of all, the EIPRO model is IO-based, it is not a SUT. Breaking it up to SUT level is necessary. Secondly, the coverage of waste processing as a separate block deviates from standard SUTS and IOTs. In line with the EIPRO approach, but adapted in these two respects, we will fill in the consumption and post-consumer waste in EXIOPOL.

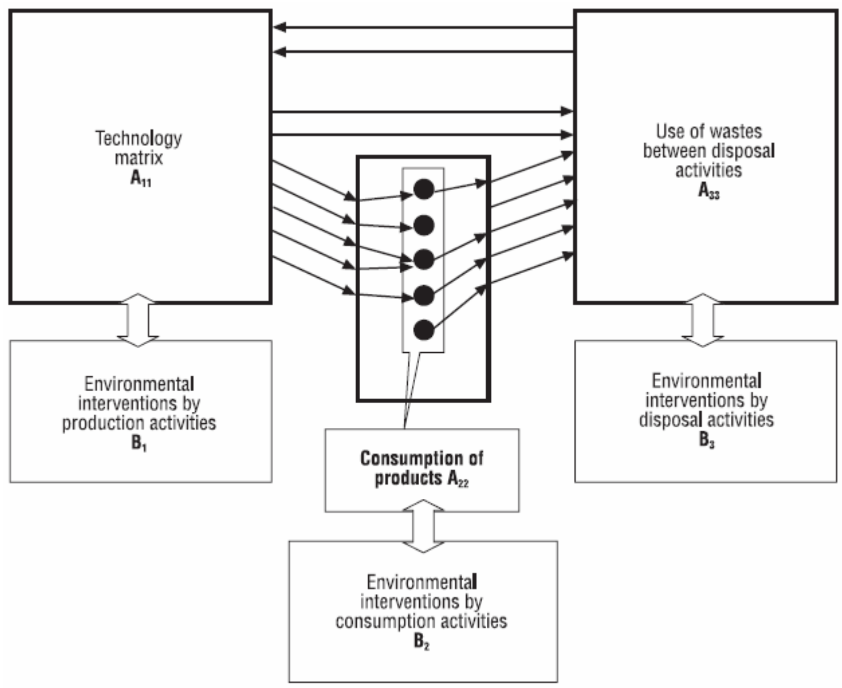

Figure 1.1: Overview of the architecture of the EIPRO model (Tukker et al., 2006, p.57).

$$m = \begin{pmatrix} B_1 & B_2 & B_3 \end{pmatrix} \left(I - \begin{pmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{pmatrix} \right)^{-1} \begin{pmatrix} k_1 \\ k_2 \\ k_3 \end{pmatrix}$$

Figure 1.2: Overall mathematical structure of the EIPRO model (Tukker et al., 2006, p.58).

Another development in the present context is the waste input-output approach by Nakamura and co-workers (Nakamura, 1999; Nakamura & Kondo, 2006, Nakamura et al., 2007). It is based on incorporating the mass balance principle in a physical IO-setup. It is a scientific challenge for the future to modify this framework in a way that it fits monetary SUTs. This is not possible in EXIOPOL.

Kagawa (2005) presents an IO-framework that incorporates waste as well as consumption. It does so in an interesting way that endogenizes consumptive activities. For the EXIOPOL context, this is an interesting development, but the focus is on the database, and on the connection with existing models. Endogenized modelling steps should not be part of the database. This may be an option for later applications.

2 The framework for consumptive activities and post-consumer waste handling

This chapter describes the most central features that the database should cover , also for creating room for more detailed consumption analysis with add-on tools. We start by discussing the consumptive activities for which post-consumer waste and emissions are to be added.

2.1 Consumer products with an important post-consumer waste part

Related to post-consumer waste, we may make within the list of products a distinction into several classes:

- Many products are bought by consumers and then need post-consumer waste-processing, either explicitly as discarded products (such as “Printed matter and recorded media” and “Motor vehicles, trailers and semi-trailers”) or implicitly in a transformed way (such as “Paddy rice” and “Beverages”) going into kitchen waste and sewer.
- Some products are consumed without post-consumer waste-processing. These are services, such as hotel and restaurant services, non-material products, such as “Electricity by gas”, and material products which end up in the atmosphere, such as “Motor spirit (gasoline)”.
- Some products are not bought by consumers, and thereby are not important from a post-consumption waste perspective. These are mainly industrial intermediate products, such as “Aluminium ores and concentrates”.

Only for the first class we need to specify the waste treatment. Positively stated, it covers all goods purchased by final consumers. Table 2.1 gives a proposed list of products for which this is the case. In this table, it has been assumed that consumers do not purchase products from primary sectors, such as agriculture and mining, and that purchases from tertiary sectors (services) do not end up in post-consumer waste. Within this list we see issues of solid waste production which occurs both within the interindustry transactions and related to final demand. We create a general waste account for both interindustry and consumer activities, integrated in the interindustry table.

Table 2.1: List of products for which waste treatment data need to be added to the SUTs.

product code	product name
p01.d	Vegetables, fruit, nuts
p15.a	Products of meat cattle
p15.b	Products of meat pigs
p15.c	Products of meat poultry
p15.d	Meat products nec
p15.e	products of Vegetable oils and fats

product code	product name
p15.f	Dairy products
p15.g	Processed rice
p15.h	Sugar
p15.i	Food products nec
p15.j	Beverages
p15.k	Fish products
p16	Tobacco products (16)
p17	Textiles (17)
p18	Wearing apparel; furs (18)
p19	Leather and leather products (19)
p20	Wood and products of wood and cork (except furniture); articles of straw and plaiting materials (20)
p21	Pulp, paper and paper products (21)
p22	Printed matter and recorded media (22)
p24	Chemicals, chemical products and man-made fibres (24)
p25	Rubber and plastic products (25)
p26.a	Glass and glass products
p26.b	Ceramic goods
p26.c	Bricks, tiles and construction products, in baked clay
p26.d	Cement, lime and plaster
p26.e	Other non-metallic mineral products
p27.a	Basic iron and steel and of ferro-alloys and first products thereof
p27.41	Precious metals
p27.42	Aluminium and aluminium products
p27.43	Lead, zinc and tin and products thereof
p27.44	Copper products
p27.45	Other non-ferrous metal products
p27.5	Foundry work services
p28	Fabricated metal products, except machinery and equipment (28)
p29	Machinery and equipment n.e.c. (29)
p30	Office machinery and computers (30)
p31	Electrical machinery and apparatus n.e.c. (31)
p32	Radio, television and communication equipment and apparatus (32)
p33	Medical, precision and optical instruments, watches and clocks (33)
p34	Motor vehicles, trailers and semi-trailers (34)

product code	product name
p35	Other transport equipment (35)
p36	Furniture; other manufactured goods n.e.c. (36)
p45	Construction work (45)
p50.a	Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessories
p52	Retail trade services, except of motor vehicles and motorcycles; repair services of personal and household goods (52)
p72	Computer and related services (72)

In specifying the post-consumer waste treatment of consumer products, a physical relation should form the basis. For instance, if 1 million Euro is spent on TV sets, the corresponding physical amount of TVs defines the waste service needed. This then translates back into a monetary waste treatment. See Figure 2.1.

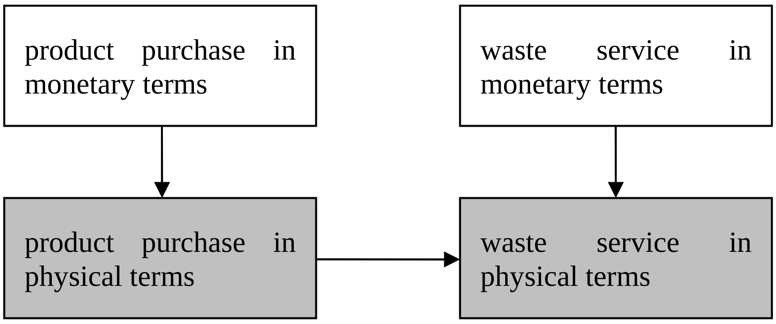

Figure 2.1: The relation between purchase of consumer products and purchase of post-consumer waste treatment services proceeds through physical background data (shaded boxes). Only the monetary entries (white boxes) end up in the SUT, with the physical data in the environmental extensions.

2.2 Products that are used together in a fixed proportion

Industries use products to make new products. One of the basic assumptions of the IO-model is that technologies scale in a linear way. In other words, in order to increase output by a factor 2, all inputs must be increased by a factor 2. Thus, an increased demand for cars leads to an increased demand of steel, electricity, tires, etc. Environmental satellites are added to industries, not to products: it is the process of transforming economic inputs into outputs that takes effort, extracts resources, and emits pollutants.

Of course this linearity holds only within limits. The assumption implies that there is no (dis-)economy of scale. Moreover, it tacitly assumes that prices do not change. The assumed underlying ratio of input and output coefficients is a technical one, referring to how many tonnes of steel are needed to make a car. If steel or car prices change, one may assume for simplification that only the monetary coefficients will change, leaving the underlying physical ratios more or less unchanged. Only when technologies change (e.g., getting more energy-efficient) or products change (e.g., their composition changes) will the physical basis for these fixed coefficients change.

Consumer activities in this respect resemble industrial activities. Consumers use products often in fixed proportions. To drive thousand kilometres, a certain (fractional) amount of cars is needed as cars last only for a finite number of time and kilometres and so is a certain amount of gasoline. The resemblance can be extended to the environmental satellite: a certain amount of CO_2 and other pollutants are emitted per monetary or physical unit of car driving.

The problem in defining household production functions as columns in a SUT is that there is a tremendous flexibility in defining the level of aggregation and in assigning products to activities. For instance, the use of cars and gasoline can be assigned to an activity “car driving”. But it can also be defined to a higher-level activity “transportation”, which combines various transport-related activities, including the garage and the car cleaning apparatus. Moreover, one may choose to assign part of the car driving to other activities, such as “shopping”, “work”, “sport activities”, and so on. Research models which include these production functions, including physical inputs and time, have been applied for academic analysis (Spreng, 1993; Jalas, 2001) However, there is a paucity of statistical data of comparable quality as the SUTs used in the project, and cross-national efforts to harmonize this data are lacking.

In EXIOPOL household production functions will not be incorporated in this extended sense. Users of the EXIOPOL system may freely combine and aggregate demand vectors for different types of products. They also may split them up over different consumptive activities, like the water for drinking and food and for car cleaning. This latter option will require a substantial amount of additional work in applications.

2.3 Consumptive activities with direct emissions and resource extractions

Consumer products have no direct emissions rather it is the activity of consuming a product that has emissions. For instance, a boiler has no emissions, but using the boiler by burning the gas to operate it does have emissions. Likewise, a car hardly has emissions in standing, but using car and gasoline together produces emissions. Of course the upstream productive activities have their resource extractions and emissions as well. The use of a refrigerator has upstream emissions only, both for the production of the refrigerator and the electricity, whereas the use of a car has both direct and upstream emissions. In other words, in a SUT- or IOT-framework, we have to take care to include both the direct emissions into account by the activity of using products, and the upstream part covered by the industry supply tables. In principle, the same holds for resource extractions. However, here the situation is simpler, as there are hardly any consumer-related activities that extract resources from the environment. There are two exceptions:

- Some consumer activities extract biotic resources from the environment (sport fishing, hunting, etc.).
- Some consumer activities occupy space and thus extract the resource land (housing, sports, etc.).

Of course, if oxygen is defined as a resource, consumptive activities require a substantial amount, as it constitutes one of the largest inflows from the environment. Most products have upstream emissions, with the street singer and the fortune teller as exceptions. Only a few have emissions during use. In most cases, it is a combination of using several products that has the emissions. For instance, it is the combination of using cars and gasoline that emits, and it is the combination of using cooking equipment, gas and food ingredients that emits as well. Thus, in adding information on emissions of consumptive activities, we have to rethink where to place such information. Take the example of using cars and gasoline. Are we to add emission data:

- to the car (which has an exhaust pipe from which the emissions are released);
- to the gasoline (which is, in a chemical sense, the origin of the emissions);
- to the activity of car driving?

The latter is the most pure solution, but it needs the largest revision of the SUT-framework, as products (like cars and gasoline) are already in this framework, but consumer activities (like car driving) are not yet. In EXIOPOL, we propose to follow the same logic as we did when coupling post-consumer waste to consumer products: emissions are coupled to the product that is physically most connected to these emissions. Thus, emissions of car driving are assigned to the gasoline, not to the car, and emissions from cooking are assigned to the gas, not to the cooking equipment. This operation simplifies the EXIOPOL efforts. At the same time it creates open the option to develop a more elaborate web of related consumptive activities. As there is not common way of specifying interrelated consumptive activities, this simplification at the same time leaves open all options based on consumption theory. These may range from the simple EIPRO type of combinations to the more elaborate consumption theory where food involves not only the food and preparation but also parts of the house like the kitchen and the kitchen and eating utensils.

However, this information must be distinguished from the emissions that are connected to the production of, say, gasoline. There are hence two ways of structuring a straight EEIO calculation.

One option is to use the following structure:

$$f = \left[B_i (I - A)^{-1} + B_h\right] y$$

In this case, we distinguish between the direct industry emissions (i) and the direct household emissions (h).

The other option is to add additional columns/rows for each of the activities/products causing direct emissions. Hence, the “purchase and use by households” would be for this new row and cause both direct and indirect emissions, while the purchase of gasoline by another country would be for the output of the refinery industry and would not cause the direct emissions in the producing country. This implies that there are two different lines for gasoline, one for purchases by households and one for purchases by industry (domestic or abroad).

We favor the second option because it includes consumer activities in an embryonic form in the tables, and because it provides a more consistent and clean-cut way of identifying the country of emissions. It would in any case provide a significant step forward from the present ad-hoc inclusion of household direct emissions in Multi-Regional Input-Output models.

Table 2.2: List of products for which consumptive activities lead to direct emissions or resource extraction or to waste processing.

product type code	product type synonym	product type name
p01.i	C_CATL	Cattle
p05	C_FISH	Fish and other fishing products; services incidental of fishing (05)
p10	C_COAL	Coal and lignite; peat (10)
p14.3	C_CHMF	Chemical and fertilizer minerals, salt and other mining and quarrying products n.e.c.
p16	C_TOBC	Tobacco products (16)
p23.1	C_COKE	Coke oven products
p23.20.a	C_GSLN	Motor spirit (gasoline)
p23.20.b	C_KERO	Kerosene, including kerosene type jet fuel
p23.20.c	C_GSOL	Gas oils
p23.20.d	C_OFUL	Fuel oils n.e.c.
p23.20.e	C_PGAS	Petroleum gases and other gaseous hydrocarbons, except natural gas
p23.20.f	C_OPET	Other petroleum products
p24	C_CHEM	Chemicals, chemical products and man-made fibres (24)
p71	C_MARE	Renting services of machinery and equipment without operator and of personal and household goods (71)

2.4 Structure of the SUT

In the scope document (Tukker & Heijungs, 2008), a product-by-industry format of 131 industries and 131 products was chosen as the structure and harmonized classification of the country SUTs. Traditionally, the use table has a number of adjacent column vectors for final demand. It is now our task to present the revised SUT structure in which consumers and waste fit.

There are several options for accounting frameworks including emissions and waste from consumption activities. Each has advantages and disadvantages. As a general rule, accounting frameworks which support complex modeling activities require more data storage space and are more complicated for unsophisticated users to maneuver. On the other hand, more simplistic accounting frameworks require more effort by the user to obtain specific results for complex systems.

The first option is illustrated in Figure 2.2. It presents a SUT with environmental extensions, and with the consumer part added.

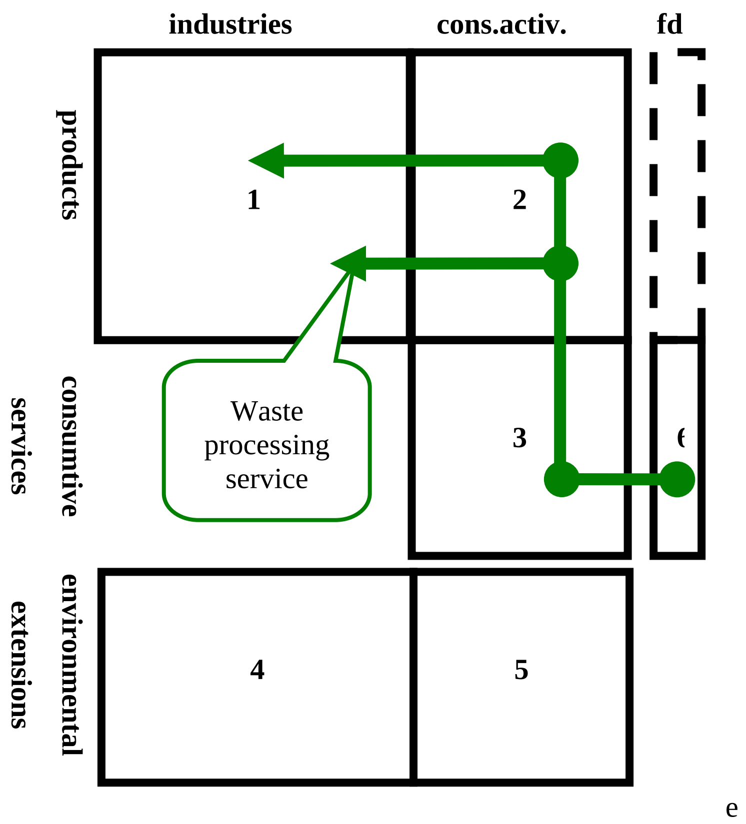

Figure 2.2: Architecture of the EXIOPOL SUT. The final demand (fd) is specified for a consumptive service (e.g. the row "cooling"). This is provided by a consumptive activity (e.g. the column "consumption of refrigerators"). This consumptive activity is connected to a product row (e.g. "refrigerators") and a waste treatment service row (e.g., "electrical equipment waste treatment service"). Finally, these two are provided by two sector columns (e.g. "refrigerator production" and "electrical equipment waste treatment"). Notice that in this example, the electricity to run the refrigerator is not included in the consumptive process, as we have chosen not to specify such more detailed household production functions at this stage of the project.

The elements are the following:

- Top left (1) is the product-by-industry block of supply and use of products by industries. This is the 131 by 131 system as specified by Tukker & Heijungs (2008).
- Block 2 is a table with the rows denoting products and the columns denoting consumption activities. An example of such a consumption activity is "use of electrical equipment". It is represented as a column vector, with input coefficients (use data) for electrical equipment and for waste treatment of this equipment. Note: the electricity to run this equipment is not included in this vector, it is specified as a separate product.
- Underneath is block 3. It is a table with the rows denoting the consumptive services and the columns denoting consumption activities. It only contains supply data, not

use data. As an example, the column that represents the consumption activity “use of electrical equipment” has here a number in the row that represents the consumption service “electrical equipment service”. Block 3 has less than 131 rows and columns. Waste-related activities and services (there are seven of these; see Table 1.1) have been removed, and so have products and their supplying sectors for which there is no consumptive demand (such as uranium).

- Block 4 is the familiar environmental satellite of block 1. It contains the industrial emissions and resource extractions.
- Block 5 is the environmental satellite of blocks 2 and 3. It contains the direct emissions from consumption activities. For instance, the consumption activity “use of gasoline” has emissions at certain rows. Note that a consumption activity like “use of a car” has no emissions in this block, it is covered under gasoline, and neither has a consumption activity like “use of electrical equipment”, as electricity use does not emit any of the emissions considered in EXIOPOL.
- Block 6 is a final consumption vector (or a number of such vectors, e.g., for households, government, etc.). It is constructed from the original final demand vector for the different products as specified by the statistical offices (the dashed block in the figure), but with the waste processing activities added to the products that create the waste, and with the zeros removed for products for which there is no final demand.

This structure is repeated for every country. Consumers have no direct relations to imports and exports. The benefit of this structure is that it allows the specification of consumption activities with specific product recipes. However, a drawback is that environmental extensions are defined in terms of consumption activities rather than products, making it difficult to distinguish the contribution of different products to the overall emission or waste. For example, the consumer activity “cooking” might involve a number of food products as well as gas and some purchase of cooking utensils. The waste produced by this activity would include the combination of the waste contribution of each of these products. The effect of shifting to different foods on waste generation could not be easily distinguished. Having the most disaggregated version first, that is each product purchased treated separately, only including its waste management, solves this problem in a practical way. More complex production functions are a composition using these basic building blocks.

The second option starts from a slightly simplified architecture, which can be constructed by adding columns to the final demand to represent the consumption of single products. The figure in this case would look like the one presented in Figure 2.2 but with the blocks marked 3 and 6 removed. The consumption activities would then be mapped directly to products and involve the consumption of only a single product. These activities would be recorded in block 2, including the waste processing services. Just as in the first option, emissions associated with the consumption of products would be recorded in block 5. The number of consumption activities, columns in block 2, would be determined by the number of products with use phase emissions or post-consumer waste. If we assume that each of the 46 products identified in **Table 2.1** can only be consumed in one way, block 2 would have dimensions roughly 2,100 consumption activity/consumer country combinations by 6,000 product/producer country combinations. The remaining 85 products/services which do not create use phase emissions or post-consumer waste could be accounted for in a single column for each country. Block 5, environmental extensions for consumption activities would then have dimensions of number of environmental extensions by 2,100 consumption activity/consumer country combinations. If it is determined that there are multiple ways in which a product could be consumed which yield different emissions or waste, columns could be added to block 2 and 5 to account for these differences. The benefit of accounting according to option 2 is that model users are not locked into a specified recipe for consumption activities. Rather the user can select their consumption recipe and create the appropriate final demand vector using the products already included in the EXIOPOL framework. The data storage requirement and amount of data needed for this option are more modest than that of option 1 but as we will see still greater than that of option 3. Drawbacks of option 2 include its large data and computer memory requirements as well as the risk of users forgetting inputs to consumption activities which would have been included in the option 1 accounting framework.

The third option is perhaps the simplest approach, which assumes a single consumption activity for each product and which represents emissions and waste related to final demand for products as a matrix with dimensions of 131 products by the number of environmental interventions. Technical benefits of this option include a relatively low data requirement, a simple accounting matrix, and the smallest computer memory use for data storage of the options presented here. In addition this method is easy to explain to policy-makers or unsophisticated model users.

The main drawback to this method is that it doesn't allow the user to distinguish between ways in which the products are consumed. If there are multiple consumption activities involving a single product with different emissions or wastes they cannot be distinguished. If the consumption of products differs across countries it would be possible to represent these differences by extending the matrix to dimensions of roughly 6000 product/country combinations by the number of impacts categories. Options 1 and 2 can "accidentally" be reduced to this most simple data set, allowing for later additions of more complex consumption functions.

This seems a most practical option for EXIOPOL. In this way, we cano have the best of two worlds: simplicity and flexibility. On the one hand the framework allows for adding further detail in applications, adding whatever combinations are relevant in the analysis. In the EXIOPOL database however, the structure is filled in in the most simplistic way possible. There are two types of consumptive activity:

- of products that require a post-consumption waste processing, such as refrigerators and cars; these require two entries in block 2, namely the product and the waste service;
- of products that end up in the environment, such as gasoline and pesticides; these require one entry in block 2, namely of the product, and one ore more in block 5, namely of the emissions.

In this way we couple the waste and emission aspect of a consumed product to that product without fixing the household production functions, the recipes, thus giving full freedom to modeling such household specifications by the IO-practitioner.

3 Data collection

After the design of the framework comes the implementation. This includes at least two aspects:

- adaptation of the relational database structure;
- collection of data to insert in the newly established blocks.

This section briefly indicates some main choices with respect to data collection strategies.

As the method developed is new, and the data gathering procedures hence as well, we plan a case study which we will use to demonstrate the consumers and waste capabilities of the database. Data gathering and case study are not part of the current deliverable.

3.1 Direct emissions from combustion of different fuel types

We might be able to obtain these data directly from TNO/Wuppertal if they have already collected as part of their data gathering activities.

3.2 Mass flows

Using trade statistics (ComTrade or U.S. Trade Data) we could estimate prices for each product included in EXIOPOL. The increased detail available in trade data would allow some representation of the possible range of price (money/mass) values for the different products. Coupling this with estimates of dissipation allows us to estimate the mass of different types of waste.

3.3 Lifetimes

Waste generation depends on the lifetime of products. Perhaps MFA literature includes useful data on the lifetimes of products.

3.4 Treatment methods

Tracking the fate of waste in different countries requires data about the fate of post-consumer waste in each country.

List of references

Duchin, F. (1998) *Structural Economics: Measuring Changes in Technology, Lifestyles, and the Environment*. Washington DC: Island Press

Jalas, M. (2002) A time use perspective on the materials intensity of consumption. *Ecol. Econ 41*, 109-123.

Jalas, M. (2005) The Everyday Life-Context of Increasing Energy Demands: Time Use Survey Data in a Decomposition Analysis. *J. Ind. Ecol.* 9 (1-2), 129-146.

Kagawa, S. (2005) Inter-industry analysis, consumption structure, and the household waste production structure. *Economic Systems Research* 17:4, 409-423

Lancaster, K.J. (1990) *Modern consumer theory*. Cheltenham: Edward Elgar

Nakamura, S. (1999) An interindustry approach to analyzing economic and environmental effects of the recycling of waste. *Ecological Economics* 28, 133-145

Nakamura, S.; K. Nakajima, Y. Kondo, T. Nagasaka (2007) The Waste Input-Output Approach to Materials Flow Analysis: Concepts and Application to Base Metals. *Journal of Industrial Ecology* 11:4, 50-63

Nakamura, S.; Kondo, Y. (2006) A waste input-output life-cycle cost analysis of the recycling of end-of-life electrical home appliances. *Ecological Economics* 57, 494-506

Peters, P.; Hertwich, E.G. (2006) The Importance of Imports for Household Environmental Impacts. *Journal of Industrial Ecology* 10:3, 89-109

Spreng, D. (1993) Possibilities for substitution between energy, time and information. *Energy Policy* 21, 13-23

Tukker, A., G. Huppes, J. Guinée, R. Heijungs, A. de Koning, L. van Oers, S. Suh, T. Geerken, M. van Holderbeke, B. Jansen & P. Nielsen (2006) *Environmental impact of products (EIPRO). Analysis of the life cycle environmental impacts related to the total final consumption of the EU25.* EU Report No 22284EN (ISBN 92-79-02361-6, European Commission, Joint Research Centre, Institute for Prospective Technological Studies, Seville.