Resource productivity, environmental tax reform and sustainable growth in Europe

Work package 3

Extending E3ME to include analysis of material flows

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Contents

1 Introduction

This section outlines the case for modelling material flows and illustrates how the current version of E3ME covers this kind of analysis through its input-output framework.

1.1 Why model material flows?

Material flows and sustainable development

The productive use of resource inputs is central to the concept of sustainable development and material flows are central to Eurostat's Production and Consumption sustainable development indicators[1]. This is an area which the E3ME model is unable to address adequately at present, so the inclusion of the indicators defined below would enhance the model's abilities in the area of sustainable development.

At its broadest level, material flow analysis could cover all raw material inputs to the production process and manufactured outputs. Waste, which has a negative economic value, can also be included. However, the scope for modelling material flows is constrained by the limitations in the available data sets (see Chapter 2). In particular, as a bottom-up sectoral model, E3ME requires a highly detailed disaggregation of data and as a time-series econometric model requires a full set of time-series data to estimate model parameters.

1.2 A brief description of E3ME4.2

The most recent version of the E3ME[2] model is version 4.2, which was completed in October 2006. This version of the model covers the EU25 Member States in 2006, plus Norway and Switzerland, and is made up of 42 industrial sectors[3], including 17 manufacturing sectors and three mining sectors.

Model Equations

E3ME comprises of 22 estimated equation sets, covering the components of final demand, the labour market, prices and energy use. The behavioural relationships in each of these equation groups are econometrically estimated for each industry and region separately, although a method of shrinkage is used for estimating long-run relationships in Europe's ten New Member States (that joined the EU in 2004) to cope with the shorter available time series.

Model Data

E3ME's databases include time series data for each of the 42 sectors covering the period 1970-2004 (1993-2004 in the New Members). The cross-section database includes input-output (IO) tables for each of the 27 regions, disaggregated by the 42 products and industries. Due to the available data it is assumed each industry produces a single product.

The input-output coefficients implicitly determine the production process of each of the 42 industries. Although the IO coefficients do change over time to capture the effects of price changes and technological progress, they are typically fitted to a logistic trend line that is treated as exogenous by the model. Consequently IO

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[1] http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1998,47433161,1998_47437045&_dad=portal&_schema=PORTAL

[2] For more detail see http://www.e3me.com/

[3] See Appendix A for the main model classifications

coefficients, and therefore production processes, are typically not allowed to vary in response to specific changes in price, or technological progress. In the input-output tables, inputs are measured in terms of value (euros or constant-price euros) rather than physical units.

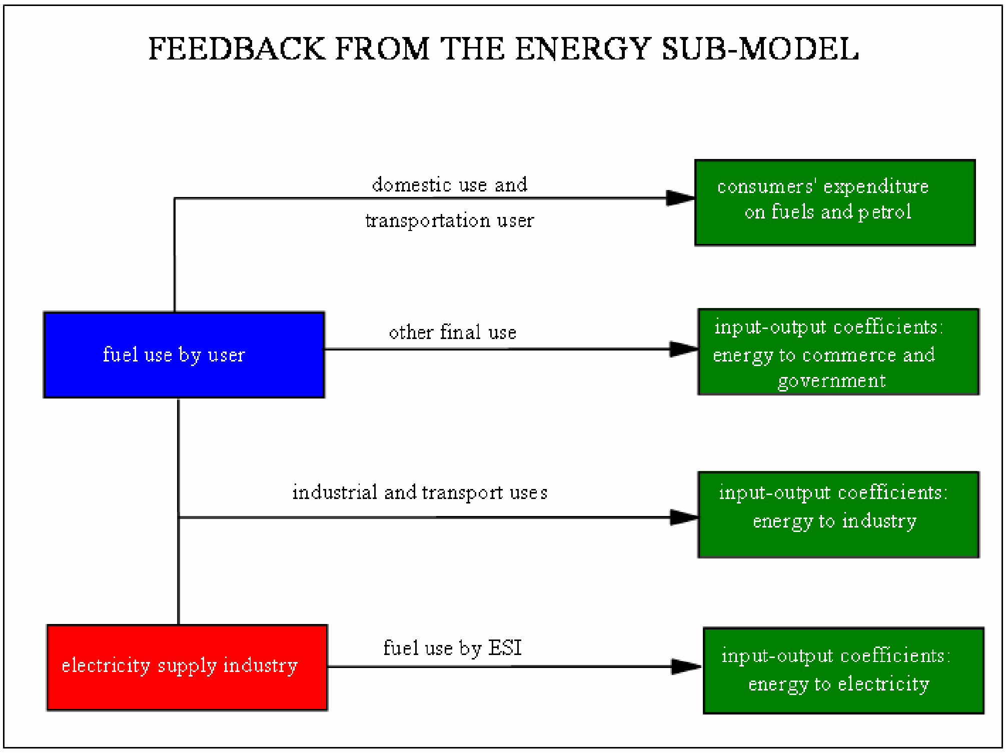
Modelling Energy Demand

The exception to this is the feedback loop from E3ME's energy submodel. E3ME includes five energy equations, for aggregate fuel inputs and the relative shares of hard coal, heavy fuel oil, natural gas and electricity. Each of these equations is econometrically estimated for 19 fuel user groups[4], with the independent variables including activity and price indicators and measures of innovation for each fuel user group. An increase in activity is assumed to increase fuel demand, but increases in price or innovation effects (by the fuel using group) are assumed to reduce energy demand.

Resulting changes in fuel demand are reflected by making relative changes to the IO coefficients (see Figure 1.1). For example if fuel user group 1, power generation, sees a 10% increase in demand for coal in the UK, the IO coefficient for purchases by the electricity industry from the coal industry in the UK would also increase by 10%.

This allows evaluation of a policy that specifically targets energy use, such as a tax on fuel inputs. However, a tax on material inputs, for example water, would lead to higher unit costs and likely loss of output for industries that use water as an input, but the modelling would not allow these industries to adapt their production processes to be less reliant on water as an input.

Figure 1.1



[4] See Appendix A for the main model classifications

1.3 Definitions of Material Flow concepts

Direct Material Consumption

In measuring the demand for material inputs at a national level, the key concept is 'Domestic Material Consumption' (DMC) which is the total resources consumed within (a sector of) the economy. DMC would form the dependent variables in the proposed equations.

Domestic Extraction

DMC can be met by 'Domestic Extraction' (DE) or imports. It is not immediately obvious what the best way to differentiate between these is in E3ME; possibilities include using fixed shares, or relating to the industry values for economic output and imports. Either way this is likely to be a fairly simplistic treatment, but has important implications for transportation requirements.

Direct Material Inputs

Direct Material Inputs (DMI) is defined as DMC + exports. Again, it will be necessary to make assumptions about exports (which make up about 6% of DMI), either using economic data or fixed shares.

2 Data Availability and Requirements

2.1 Definition of the materials

Data issues

The availability of reliable data is the single most important factor when considering the case for model development. This study will look at each of the materials for which there are data available from one or more sources that:

- Are consistent across Europe and use consistent units
- Have annual time series dating from the early 1990s or earlier
- Have reasonable coverage with few or no data points to estimate

As E3ME's energy submodel already estimates demand for twelve fuel types, based on IEA energy balances and energy prices, these are not included in the analysis. This does not mean that they will be included in E3ME, but that the material demands will be calculated from a simple conversion of the results (from energy content to weight) from the energy submodel.

Based on these conditions, Table 2.1 outlines the materials that will be considered, and the industry sectors they are most closely related to.

Table 2.1: How the materials relate to E3ME's industry classification

Material	E3ME industry (number)
Food	Food, Drink and Tobacco (5)
Feed	Agriculture, etc (1)
Forestry	Agriculture, etc (1)
Construction minerals	Non-metallic minerals (13), Basic Metals (14)
Industrial minerals	Chemicals (10), Basic metals (14)
Ores	Non-energy mining (4)
Water	Water Supply (24)
Waste	-

It should be noted that waste is slightly different to the other materials in that it has a negative economic value and the demand is to dispose of waste rather than to use it as part of a production process.

In order to fully model material demands in the context of the wider economy, it is necessary to link these materials to specific industries in E3ME. Preliminary links are shown in Table 2.1 although this will require more careful analysis. For example, Forestry materials are only likely to make up a small part of 'Agriculture, etc', and it is not immediately obvious what proportion of construction minerals come from E3ME sectors 13 and 14.

2.2 Data sources and availability

Mineral Materials

The primary data source for the six agricultural and mineral materials is a data set produced by EUROSTAT / IFF 2004[5]. This is a comprehensive set of annual time

[5] Economy-wide Material Flow Accounts and Indicators of Resource Use for the EU-15: 1970-2001; Helga Weisz, Christof Amann, Nina Eisenmenger, Fridolin Krausmann; Institute for Social Ecology, Faculty for Interdisciplinary Studies (IFF), Klagenfurt University, Vienna

series for each of the EU-15 member states covering the period 1990-2001. It is due to be updated in mid-2007 to include the expanded EU-25 (as of 2006) and include data up to 2005. Units are thousands of tonnes and the coverage is 100%. This would be sufficient to estimate a set of equations for use in E3ME except that there is no sectoral disaggregation. While this may not necessarily present a challenge for materials that are related to specific sectors (eg Construction minerals), other materials, such as industrial minerals, will require some manipulation to be useful in the context of E3ME.

These spreadsheets contain data for domestic extraction, imports, exports, direct material inputs (DMI) and domestic material consumption so it is simple to obtain both data for consumption, and estimates for trade.

Water Demand and Waste Production

The Eurostat Environment and Energy branch of statistics holds series for water consumption and waste production. The series for water consumption are very detailed, and include separate categories for agriculture, construction, households and eight manufacturing groups. The time period is 1970-2003 and units are millions of cubic metres. Unfortunately the matrices of data tend to be sparsely populated and for all regions would require some work to obtain series that was suitable for analysis. Although there are other aggregate series which could be used to help fill out the data matrices, for some regions, such as France, a fixed share ratio would be required for most sectors as there are not enough data points to estimate a meaningful equation. This would only be a marginal improvement on the current treatment.

The data for waste (split by hazardous and non-hazardous) cover the period 1995-2002, but have much better coverage and would require less filling. Units are thousands of tonnes and there is a very detailed sectoral disaggregation. It is unlikely that it will be possible to estimate a full set of equations for waste production (for example there is no obvious price variable) so the short time series may represent less of a problem.

2.3 Defining the sectors for the analysis

Getting the most from the data

In E3ME's energy submodel the 19 fuel user groups are defined largely in line with the IEA data in order to minimise processing requirements. The fuel user groups are consistent for all the fuels.

Given the wide disaggregation of the Eurostat data, and the fact that the sectoral data would be estimated for the agricultural and mineral inputs in any case, the data do not place much constraint on the choice of sectors, although the choice of materials does (eg construction materials would largely be inputs to construction). Therefore in most cases the two most important factors in determining the sectoral breakdown are user-requirements, and ease of fit with the rest of the model (ie a simple conversion back to the 42 industry sectors).

Table 2.2 illustrates an initial suggestion of the sectors that could be included, based on the materials outlined in Table 2.1. These are described as the 'Material Users' below.

Table 2.2: Suggested material users, their main inputs and links in E3ME		
Material User	**Likely to consume**	**E3ME Industry links[6]**
Agriculture	Feed, Water Produce Waste	1
Mining	Produce waste	2-4
Energy	Fuels (from fuel submodel)	9, 22-23
Food, Drink and Tobacco	Water	5
Wood and Paper	Forestry	7
Chemicals and Plastics	Industrial minerals	10-12
Non-metallic Minerals	Industrial minerals	13
Metals Industry	Industrial minerals Ore	14-15
Engineering and Transport Equipment	Industrial minerals	16, 19-20
Other Industry	Industrial minerals	6, 8, 9, 17-18, 21
Construction	Construction minerals Produce waste	25
Services	Water, Produce waste	26-41
Households	Water, Produce waste	
Unallocated	-	42

2.4 Required processing

Disaggregating and estimating missing data

The data processing can be split into two stages: completing the aggregate data and filling out the sectoral data. For the agricultural and mineral materials the totals are already complete so this step is only required for waste and water. This is more of a problem for water where the matrices are sparsely populated but fortunately there are several supplementary time series, such as abstraction statistics or gross output of the water supply industry (which is already processed for the E3ME databanks) that could be used to fill out the gaps.

The second stage for filling out the sectoral data is more complex but in most cases, for waste and water, there is enough information to construct a full set of data, even if this involves some assumptions about differing growth rates between sectors. The agricultural and industrial inputs, however, cause more of a problem as currently there is no available information at all to allocate the totals to sectors. It would be possible to use IO tables to allocate shares but, while this may give an indication of the relative importance of each sector, it only creates the shares for a single year. This could be combined with some of the economic data from E3ME's databanks to create time sectoral series (constrained to be consistent with the total) but it is not obvious how accurate the results of this process would be.

[6] See Appendix A for a full list of sectors.

3 Model Requirements

3.1 Experience of modelling material flows at CE

UK modelling

This is an area which has previously been given relatively little coverage at CE with the main focus being on waste at the UK (MDM-E3 model) level and local (REEIO model) level.

The MDM waste submodel was designed to assess the impact of the landfill tax in the UK and included six sources of waste. Waste generation is defined as a function of activity and technical progress, and five methods of disposal are included in the model.

REEIO estimates industrial waste using fixed shares in relation to intermediate inputs, modelled through input-output flows. Household waste is estimated on a per capita basis and added to industrial waste to give a measure of the total.

European modelling

At the European level, some off-model work has been done for the Matisse[7] project (DG Research) taking a set of economic results from E3ME model runs and using fixed shares to translate these into imported and domestically extracted materials.

3.2 New equations and specifications

Introducing new equations

E3ME comprises of 22 sets of equations covering the components of final demand, prices, the labour market and energy use. The five equations for energy use make up a top-down submodel of fuel demands with one aggregate equation and individual equations for the four main fuel types (hard coal, heavy fuel oil, natural gas and electricity). While the energy submodel provides a template for setting up equations for material demands, it would not be appropriate to have an equation for aggregate material inputs as in general the materials are not interchangeable. For example gas and electricity can often be substituted for one another but this is not the case for water and construction minerals.

Basic specification

Therefore a submodel of material inputs would comprise of up to seven[8] new equations, with one equation for each material. Similarly to the current fuel equations, the independent variables could include an activity indicator, a price level and a measure of innovation. Equations 3.1 and 3.2 illustrate this for each material user, i (see Section 2.2), and each region, j, using the standard ECM methodology employed in E3ME's stochastic equations.

Equation 3.1: Long-run specification

$$LN(MU_{i,j}) = \alpha_1 + \beta_1 * LN(MURY_{i,j}) + \beta_2 * LN(PMUR_{i,j}) + \beta_3 * LN(YRMU_{i,j}) + ECM_{i,j}$$

Equation 3.2: Short-run specification

$$DLN(MU_{i,j}) = \alpha_2 + \beta_4 * DLN(MURY_{i,j}) + \beta_5 * DLN(PMUR_{i,j}) + \beta_6 * DLN(YRMU_{i,j})$$
$$+ \beta_7 * DLN(MU(-1)_{i,j}) + \beta_8 * ECM(-1)_{i,j} + \varepsilon_{i,j}$$

where:

[7] http://www.matisse-project.net/projectcomm/

[8] It is not clear how an equation for waste could be set up in the absence of a price variable.

- MU = Material demand
- MURY = Activity indicator
- PMUR = Price of material relative to other inputs
- YRMU = Measure of Innovation
- ECM is the error in the long-run specification
- LN indicates logs, DLN log-differences, (-1) lagged terms and alpha and beta are estimated coefficients.

We would expect the activity indicator to have a positive effect on material demand and the prices to have a negative effect. Innovation should also have a negative effect on material demand as it is assumed to boost resource efficiency.

Following the template of the energy demand equations, the activity indicator would be defined as sectoral gross output converted into the material users classification. The price variable would be determined by prices of the sector that produces the material (eg Water supply for water) so, unless sector-specific price data are available (which seems unlikely), would be the same across the material using groups. This is the treatment used in the energy submodel. Finally, any measure of innovation will be determined by levels of investment and R&D, again converted from the 42-sector industrial classification to the material using groups.

Other than the dependent variable, all of included variables are already present in the E3ME model, so do not require further data processing.

3.3 Links with the rest of the model

As described in Section 3.2, sectoral gross output and investment/R&D in each sector will affect the material demands of each material using group, and price changes will affect the demand for each material. However, just as important is how changes in material demands feed back to the wider economy through the industries that produce the materials (see Table 2.1).

Input-output relationships

With the exception of water (and waste), the materials defined in Section 2.1 are almost exclusively inputs to the production processes of various industries and so are part of intermediate, rather than final, demand. In E3ME intermediate demands are determined by input-output relationships and it is the coefficients in the input output table that adjust to reflect changes in demand. The relationship is fairly straight-forward with a 10% increase in demand for a particular material leading to roughly a 10% increase in IO coefficients, although in some cases it would be necessary to apply a correction for heterogeneous output in a given industry (eg forestry makes up only a small part of the agriculture industry).

The same principal can be applied to consumer demand for water, with a direct link between household material demand for water and consumption of water, although the situation is complicated by the fact that in the E3ME consumers' expenditure classification demand for water forms only a small part of the 'Gross rent and water' category.

3.4 Possible further model extensions

Transporting material goods

The proposed new equations would allow the E3ME model to be used to evaluate policy aimed at promoting sustainable consumption patterns in terms of material inputs. Model results would include domestic and imported materials required for production by each of the defined sectors.

The logical next step is to consider the transport requirements to get the demanded materials to relevant material user in each country. Most of the defined materials have high freight transport costs, both in economic and external terms, for example through road congestion and atmospheric emissions (water transported through pipes is perhaps an exception). Generally these costs will be even higher when the materials are imported so the distinction between DMC and Domestic Extraction is important. Freight transport itself is a large consumer of energy and four separate transport sectors are defined in E3ME’s fuel user classification. Detailed transport data would be required for a full analysis but this is also an important feature of sustainable consumption.

4 Conclusions

4.1 Material flows analysis would fit well into the E3ME model

Material flows and sustainable development

This paper aimed to answer the question of whether the E3ME model could be extended to incorporate the modelling of basic material flows, and outlines the main data and modelling requirements to do this.

It is clear that in the field of sustainable development this would be a desirable enhancement to the model. The additional capabilities would complement those of the energy submodel, which already calculates energy flows by 19 fuel user groups.

4.2 Suitable data are available but will require some processing

Sectoral time series

The key consideration is the availability of suitable time-series data with appropriate sectoral disaggregation. Time-series data for eight materials (including waste) are available. For most of the industrial materials there is a full and complete set of data available for the EU15 (and EU25 from mid-2007) but this data set has no sectoral disaggregation. For water and waste, there are time series with a good sectoral disaggregation available but the data coverage is often poor.

This means that some data processing will be necessary, to allocate the demands for industrial materials to sectors (sometimes a trivial process) and to estimate missing data points in the series for water demand and waste production.

It would be necessary to define the sectoral disaggregation at a fairly stage. However, both the available data and the E3ME model are fairly flexible in this respect, so this is more likely to be determined by user requirements.

No other new data would be required.

4.3 Model development can be based on the energy submodel

New equations with input-output feedback

The proposed development is to create one new equation for each material, making a total of seven. The proposed dependent variable is Domestic Material Consumption (DMC). It is unlikely that it would be possible to create an equation for waste production.

The new equations would follow the specification of the energy demand equations, with material demand a function of industry output, prices and innovation effects. Unlike the fuel submodel, however, it would not be appropriate to have an equation for aggregate material demand.

The results of the new equations can be fed back to the rest of the model through changing input-output coefficients. Again this follows the approach used in the fuel submodel.

The translation between DMC and Direct Material Inputs (DMI), which has implications for the transport of raw materials would be fairly simplistic, most likely based on a combination of fixed shares and economic variables.

Appendix A – Model classifications

R Regions

1	Belgium	(BE)
2	Denmark	(DK)
3	Germany	(DE)
4	Greece	(EL)
5	Spain	(ES)
6	France	(FR)
7	Ireland	(IE)
8	Italy	(IT)
9	Luxembourg	(LX)
10	Netherlands	(NL)
11	Austria	(AT)
12	Portugal	(PT)
13	Finland	(FI)
14	Sweden	(SW)
15	UK	(UK)
16	Czech Rep.	(CZ)
17	Estonia	(EN)
18	Cyprus	(CY)
19	Latvia	(LV)
20	Lithuania	(LT)
21	Hungary	(HU)
22	Malta	(MT)
23	Poland	(PL)
24	Slovenia	(SI)
25	Slovakia	(SK)
26	Norway	(NO)
27	Switzerland	(CH)

Q, Y Products, Industries
1 Agriculture etc
2 Coal
3 Oil & Gas etc
4 Other Mining
5 Food, Drink & Tobacco
6 Textiles, Clothing & Leather
7 Wood & Paper
8 Printing & Publishing
9 Manufactured Fuels
10 Pharmaceuticals
11 Chemicals nes
12 Rubber & Plastics
13 Non-Metallic Mineral Products
14 Basic Metals
15 Metal Goods
16 Mech. Engineering
17 Electronics
18 Electrical Engineering & Instruments
19 Motor Vehicles
20 Other Transport Equipment
21 Manufacturing nes
22 Electricity
23 Gas Supply
24 Water Supply
25 Construction
26 Distribution
27 Retailing
28 Hotels & Catering
29 Land Transport etc
30 Water Transport
31 Air Transport
32 Communications
33 Banking & Finance
34 Insurance
35 Computing Services
36 Prof. Services
37 Other Business Services
38 Public Administration & Defence
39 Education
40 Health & Social Work
41 Miscellaneous Services
42 Unallocated