The FORWAST model

IO-based model for life cycle assessment (LCA), mass flow analysis (MFA), waste flow analysis, and substance flow analysis (SFA)

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Jannick H Schmidt, 2.-0 LCA consultants

http://www.lca-net.com/

1 FORWAST

FORWAST is a Specific Targeted Research Project of the 6th European Union Framework Programme. The project duration is from March 2007 to March 2009 (extended to December 2009). More information on the project and its involved partners is available on the project homepage: http://forwast.brgm.fr/

2 Purpose of the FORWAST model

The overall objective of the FORWAST project is to:

1. Provide an inventory of the historically cumulated physical stock of materials in EU27 and to forecast the expected amounts of waste generated, per material category, in the next 25 years.
2. Provide an assessment of the life-cycle wide environmental impacts from different scenarios of waste prevention, recycling and waste treatment in the EU27.

These inventory and assessment results are to be provided as an output of an Leontief-type environmentally extended, quasi-dynamic, physical input-output model covering the EU27, including raw material extraction and processing of imported materials and waste treatment of exported wastes.

The fundamental concept behind the model is that of mass balances ("what comes in must go out"), implying that the resource input (R) minus emissions (B) and stocks changes (ΔS) determines the potential waste amounts ($W=R-B-\Delta S$). To determine *where* and *when* the materials in the resource inputs come out as waste, the material flows are followed through the different activities of the economy which is done in the input-output model, and the point of intersection between stocks additions and waste generation is determined by the lifetime of the material stocks.

The three desired model outputs are:

1) **Stock in technosphere:** Amount of material originally sourced from the environment, and at the beginning of a specified period still in use by a human activity, i.e. not yet released as emissions. The model also allows the Stock in technosphere to be specified by material, by nature of the stock (product type), and by location of the stock (by industry, household or waste treatment activity)
2) **Waste flow:** Material output from a human activity, which is neither part of the main product output for this activity nor an emission
3) **Monetarised environmental impact:** Monetarised indicator of impact from human activities on the environment. The model also allows the environmental impact to be specified by emission, by midpoint impact category, and by other endpoint indicators as well as to be traced back to specific human activities

In addition to the model outputs mentioned above, the model also has other applications:

4) **Hybrid unit IO-model for generic LCA purposes**. Since all activities are based on economical as well as physical mass balances, the model is based on a higher degree of data validation than traditional IO-models.
5) **Substance flow analysis**. The model contains a complete mass flow analysis of the EU27 economy in terms of total dry matter mass disaggregated into 13 different materials. By applying information on product material compositions for any additional material, the model framework enables for detailed substance flow analysis for this material
6) **Modelling of waste management in IO-LCA**. Traditional IO-tables do not distinguish supply of virgin material from supply of e.g. iron scrap for recycling. Neither do traditional IO-tables include several waste treatment activities such as recycling, composting, biogasification, incineration etc. In the FORWAST model products are distinguished from by-products, and such waste treatment activities as mentioned above are included. In addition, the modelling of inputs and outputs of these waste treatment activities is dependant on the type of waste being treated.

3 From data input to model output – in brief

The model with all its balanced tables and the relationships between tables is illustrated in **Figure 1**. From a data collection point of view the starting point of the model is monetary (MSUT) and physical supply and use tables (PSUT). The physical tables are a mirror of the monetary tables, and the two tables are related via price relationships. The physical tables are much less filled than the monetary tables because many products are service products, i.e. they do not have a physical weight. The advantages of having data also in physical units are several:

- Physical data enables for calculating waste generation and stock changes,
- Physical data enables for mass flow analysis (MFA), and if combined with product composition data it also allows for substance flow analysis (SFA),
- Physical units enables for mass balance checks of inputs and outputs for all activities,
- When carrying out an LCA, physical units are often more desirable from a data collection point of view – prices often fluctuate, masses less so.

Analytical input-output table (HIOT)

By combining the monetary and physical supply and use tables, we obtain hybrid unit supply and use tables (HSUT). From the hybrid supply and use tables, it is easy to obtain an IO-table by applying a so-called technology model, i.e. a matrix operation specifying how to deal with by-products. The derived analytical IO-table is a hybrid unit IO-table (HIOT).

Traditional IO-tables for IO-LCA purposes are monetary tables extended with environmental data (emissions which are obtained from NAMEAs). In the FORWAST model this “extension” contains much more information than just emissions. It also includes information on waste generation (and addition to stocks) as well as resource inputs. All data in the extension are based on material balances using the principle:
Supply (supply of products) = Use (use of products + use of waste + resource inputs – supply of waste – additions to stocks – emissions)

Calculation of generation of waste and additions to stocks

For each activity, the following data are collected: Outputs (products and emissions) and inputs (products and resources). The discrepancy between inputs and outputs is then generation of waste plus addition to stocks. By distinguishing between ancilliary inputs, capital equipment and feedstocks, and by applying the life times of products, the ratio between generation of waste and addition to stocks can be derived.

Inclusion of time series to calculate historical and future waste generation and stocks

Balanced supply and use tables are established for a reference year. In order to calculate accumulated stocks and today’s as well as future waste generation, we determine historical/future stock additions and stock degradations (= waste generation) by extrapolating the reference model within the relevant time horizon.

Material specific supply and use tables (MSPSUT)

If the physical supply and use table (PSUT) is supplemented with information on product material composition, material specific supply and use tables (MSPSUT) can be derived. This can be used for calculating the material composition of wastes and for substance flow analysis.

The overall composition and mechanisms in the model are summarised in **Figure 1**. A brief explanation of the tables and abbreviations used in **Figure 1** is presented in section 5.

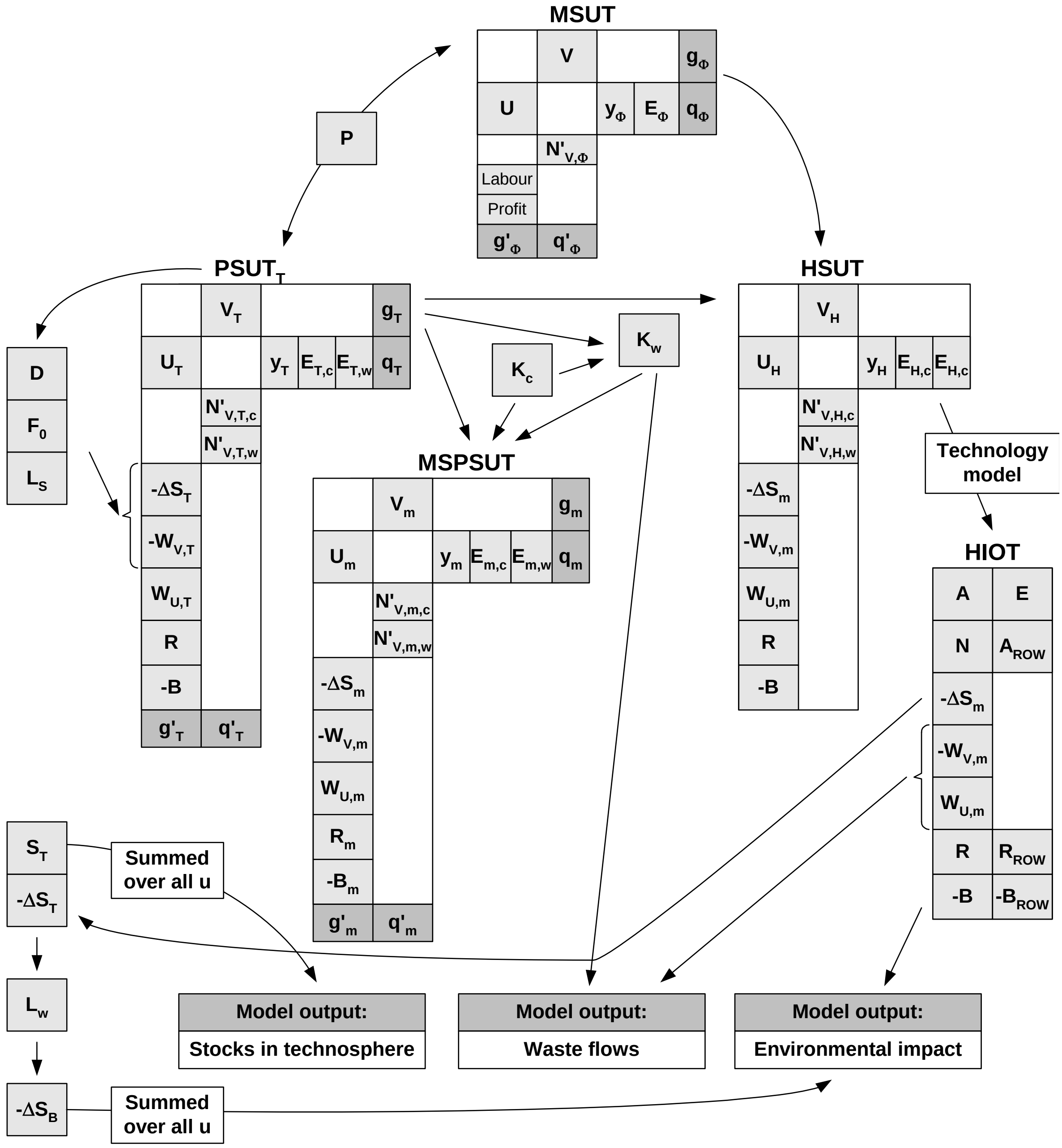

Figure 1: Model overview. **g** and **q** tables in dark grey boxes represent totals.

The matrices represented by light grey boxes in **Figure 1** are explained further in a technical model description to be published on the FORWAST project home page: http://forwast.brgm.fr/

4 FORWAST and data coverage

Monetary and physical supply and use tables are established for all EU27 countries. This is based on in-depths data collection for four countries (France, Germany, Austria and Denmark) and less in-depth data collection for the remaining EU27 countries. The experiences (emission factors, disaggregation factors) from the four in-depths data mining countries are used to fill the gaps where data can not be collected for the other countries.

Time series are applied for total EU27 MSUT and PSUT 30-100 years back in time and 30 years into the future.

The model operates with 13 different materials which sum up to the total mass of the products:

1. Al (Aluminium)
2. BI (Fibre carbon)
3. BO (Food carbon, including tobacco)
4. CC (Coal carbon)
5. CH (Crude oil and natural gas carbon)
6. CO (Carbonate carbon)
7. Cu (Copper)
8. Fe (Iron)
9. ME (Metals, n.e.c.)
10. MI (Minerals and other balancing element, n.e.c., including nitrogen and hydrogen)
11. O (Oxygen in oxidised products)
12. SO (Clay and soil)
13. ST (Sand, gravel and stone)

The model includes nine different scenarios for analysis of future generation of waste and environmental impacts. The scenarios represent 3 different waste management strategies and 3 different developments in global economy.

5 List of tables and abbreviations used in Figure 1

Matrices representing flows:

V	Supply table
U	Use table
ΔS	Stock addition
W_V	Supply of waste
W_U	Use of waste
R	Resources
B	Emissions
ΔS_B	Emissions from degradation of stocks not in use (e.g. waste in landfills)
y	Final use
E	Export
N	Import

Matrices representing transfer coefficients:

P	Price table, determines relationship between monetary and physical tables
K_c	Product material composition
K_w	Waste material composition
D	Product transfer matrix: Specification of how much of the used products that become supply of products (ancillary/raw material)
F	Resource transfer: Specification of how much of the input of resource that become supply of products
L_S	Stock degradation (based on product life time)
L_W	Waste degradation (when does waste become emissions)

Subscripts to matrices mentioned above:

V	The table concerns supply
U	The table concerns use
c	The table concerns products
w	The table concerns waste
ROW	The table concerns 'rest of world', i.e. not the EU27 which is covered by the core data collection
T	Total of all materials
m	Specific material (m)
H	Hybrid units
u	Age of stock