The FORWAST model
An IO-based model for mass flow analysis, waste
flow analysis, and life cycle assessment

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Presentation to the Final workshop of the FORWAST project
Copenhagen, 25th November 2009

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- Calculation of waste generation
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- Life cycle emissions
- Time series to calculate future waste and stocks
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Model outputs

- Waste generation in years 2003-2035
- Accumulated stocks in years 2003-2035
- Environmental impact of EU27 production and consumption
Definitions

- **Definition of waste:**
  - Output of a human activity that remains in the technosphere and cannot directly (i.e. without further processing or emissions) displace another product
  - After processing in a waste treatment (recycling) activity, the recovered waste may displace other products.

- **Definition of stock:**
  - Product that has not yet become waste or emissions

- **Definition of environmental impact:**
  - Included emissions: CO$_2$, CO, N$_2$O, CH$_4$, NO$_x$, NMVOC, SO$_2$
  - CO$_2$-equivalents calculated using IPCC 100 year GWP
  - Resource input (fibre/food) 1 kg C = -3.67 kg CO$_2$
Mass balance approach

- Total material flow in economy

- Detailed material flows in economy (which products and activities)

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Calculation of waste generation

- Inputs of products become products, emissions and waste

\[ W_V + \Delta S = U - D^*U - G_c \]
Calculation of waste generation

- Three types of inputs

Resources  Products  Waste

Supply of products

Emissions

Use of products

Ressource inputs

Use of waste

Emissions

Physical activity

Waste treatment activity
Distinction between waste and stock addition

1 kg waste ($W_v$) + stock addition ($\Delta S$)

0.04 kg waste ($W_v$) +
0.96 kg stock addition ($\Delta S$)
Modelling of waste treatment in the IO-model

Specification of treatment for each waste type ($J$)

Calculated waste output from activity ($W_v$)

102 waste types → 34 waste types
- waste from 58 physical products in SUT
- waste from 44 waste treatment activities

Hybrid units in IO-table:
Waste treatment services are measured in kg treated waste
Model output: Environmental impact

- Monetary supply use
- Physical supply use
- Emissions
  - Hybrid supply use
  - Final demand
    - By-product technology model
      - Hybrid input-output
        - Leontief inverse
          - Life cycle emissions
Time series: calculation of waste and stocks

- Start year: 1903
- Reference year: 2003
- End year: 2035
Model output: Accumulated waste generation

- For each year, e.g. 2003, we have:

\[
\begin{align*}
W_{V,2003,u=1} \\
\Delta S_{2003,u=1} \\
L_{S,2003,u=[1;100]}
\end{align*}
\]
Model output: Accumulated waste generation

- We can calculate waste from $\Delta S_{2003,u=1}$ for the subsequent years:

- $W_{V,2003,u=1}$
- $\Delta S_{2003,u=1}$
- $L_{S,2003,u=[1;100]}$
- $W_{V,2004,u=2}$
- $W_{V,2005,u=3}$
Model output: Accumulated waste generation

- We can do the same for all years, and then sum up the waste for each year originating from several years:

\[
\begin{align*}
\sum W_{V,2003} & = W_{V,2003,u=1} + W_{V,2003,u=2} + W_{V,2003,u=3} \\
\sum W_{V,2004} & = W_{V,2004,u=1} + W_{V,2004,u=2} \\
\sum W_{V,2005} & = W_{V,2005,u=1}
\end{align*}
\]
Model output: Accumulated stocks (S)

- For each year, e.g. 2003, we have:

\[ W_{V,2003,u=1} \]
\[ \Delta S_{2003,u=1} \]
\[ L_{S,2003,u=[1;100]} \]
Model output: Accumulated stocks ($S$)

- We can calculate $\Delta S_{2003,u=2...endyear}$ for the subsequent years:

- $W_{V,2003,u=1}$
- $\Delta S_{2003,u=1}$
- $L_{S,2003,u=[1;100]}$

\[
\begin{align*}
\Delta S_{2003,u=2} &= -W_{V,2003,u=2} \\
\Delta S_{2003,u=3} &= -W_{V,2003,u=3}
\end{align*}
\]
We can do the same for all years, and then sum up the stock changes for each year originating from several years:

\[ \Delta S_{2003,u=1} \]
\[ \Delta S_{2003,u=2} \]
\[ \Delta S_{2004,u=1} \]
\[ \Delta S_{2004,u=2} \]
\[ \Delta S_{2005,u=1} \]

\[ \Sigma = S_{2003} \]
\[ \Sigma = S_{2004} \]
\[ \Sigma = S_{2005} \]
The model

- Self-validating; Mass balance checks (activities and products)
- Overall model outputs (wastes and stocks) are:
  - only affected by uncertainties in resource and emission data
  - all other uncertainties are allocation uncertainties
- State-of-art IO-model
  - Hybrid unit model (easy to use for hybrid LCA)
  - Waste is correctly modelled: Virgin/recycled, and several treatments