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A Dynamic Model for the Assessment of Plastics Waste Disposal Options

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Abstract

Commissioned by the Swiss Foundation for the Reintegration of Plastic Materials (SSK), a numerical expert model has been developed, which allows to assess plastics waste management strategies by dynamic simulation of time-periods up to 15 years. The tool was conceived to answer questions of the type: What will happen, if up to 200'000 tons of plastics waste per year are taken out of the waste stream, which is incinerated in Swiss Municipal Solid Waste Incineration (MSWI) plants, and fed into thermal recovery or mechanical recyling? Simulations on a regional scale indicate that - under specified conditions – such a diversion of industry plastics waste from the waste stream into MSWI plants makes sense from an ecological as well as from an economic perspective. In view of the increasing amounts of waste and the high costs for additional MSWI plants it hence seems appropriate to intensify the discussion about industry plastics waste disposal options in Switzerland.

1. Goal and Scope

1.1 Complex Systems: Characteristics and Challenges

The purpose of waste management is to ensure the disposal of waste according to law and under consideration of economic, ecological and social conditions. Waste management can be viewed as a system, which consists of a social and a technical dimension and is strongly influenced by the interactions between the key players involved (public and private disposal organisations, authorities, associations, consumers) and the existing logistics and technical infrastructure.

Because of its high functional differentiation, which manifests itself in a great variety of specialised key players, processes, facilities and transportation systems,

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the waste management system shows typical characteristics of highly interrelated, complex systems. Some of these characteristics are (Willke 1996):

- their dynamism, which is due to the interaction between processes with different time-scales and feed-backs, as well as the superposition of effects;
- a great number of possible actions, from which the most adequate has to be chosen in order to ensure the survival of the system;
- the emergence of conflicts about the question, which of the possible actions are to be preferred under the condition of limited resources;
- hardly foreseeable consequences of decisions.

To master the challenges of such complex systems, approaches are needed, which support the (public) discussion about their design and their regulation. In particular, they should

- be able to integrate the key players of the system into a co-operative process (e.g. within the scope of so called private-public-partnerships);
- consider the relevant interrelations and feed-backs in the system;
- allow to reproduce the system behaviour under different boundary conditions;
- allow to assess possible actions with respect to their effects and to their compatibility e.g. with principles of sustainable development.

An approach, which has the potential to come up to these expectations, is the numerical approach of system dynamics, which directs one's attention onto the dynamic aspects of a system (Forrester 1961; Roberts et al. 1983; Sterman 2000).

1.2 Waste Management Strategies: Controversial Discussions

In the actual public discussion about the Swiss Waste Management System, an important topic is the intended extension of Municipal Solid Waste Incineration (MSWI) capacities as a consequence of the increase of municipal solid waste amounts - the latter having been triggered, among others, by the economic recovery of the last few years. Due to its amount (which was estimated to amount to 570'000 tons in 1999 (SAEFL 1999)), its heating value (which exceeds the heating value of typical MSWI waste by a factor of approximately 3) and its potential for recycling and thermal recovery in cement kilns, plastics waste plays a major role in this discussion: A diversion of plastics waste from MSWI plants into cement kilns and material recycling facilities could allow to avoid at least part of the planned investments into additional MSWI capacities. At present, the main part of plastics waste (> 80%) generated in Switzerland is incinerated in MSWI plants. Materials recycling amounts to less than 10%, thermal recovery in cement kilns to less than 5%.

To support and de-emotionalise this discussion, the Swiss Foundation for the Reintegration of Plastics Materials (SSK) has commissioned EMPA and Rytec Inc.,

Münsingen, to develop a numerical model for the assessment of different plastics waste disposal options - based on a system dynamics approach and involving key players of the Swiss Waste Management System.

2. Methods

Starting point for the development of the model was the question: What will happen, if up to 200'000 tons of plastics waste per year are taken out of the waste stream, which is incinerated in Swiss MSWI plants, and fed into thermal recovery or mechanical recyling? The model was built with the software Powersim® Constructor (Powersim Corporation 1996), which supports the development of numerical models according to the system dynamics approach. System dynamic models are systems of non-linear ordinary differential equations, which generate simulation results through numerical integration. To involve the key players into the modelling process, workshops were regularly held with representatives of the Swiss Agency for the Environment, Forests and Landscape (SAEFL), members of plastics associations, operators of disposal and recycling plants, etc.

Under consideration of the results of the project 'Dynamics of Waste Treatment' (Widmer et al. 1998), EcoSolver IP-SSK was conceived as a model, which allows to simulate the ecological and economic effects of possible future developments (scenarios) in *regional* waste management systems for time-periods up to 15 years. EcoSolver IP-SSK consists of an input layer, the model construction layer and an output layer (see figure 1).

On the *input layer*, input parameters are fixed according to the defined scenario. These are, among others, the expected development of the waste streams in the disposal system considered, the amounts of thermally recovered or recycled plastics waste and the transportation distances.

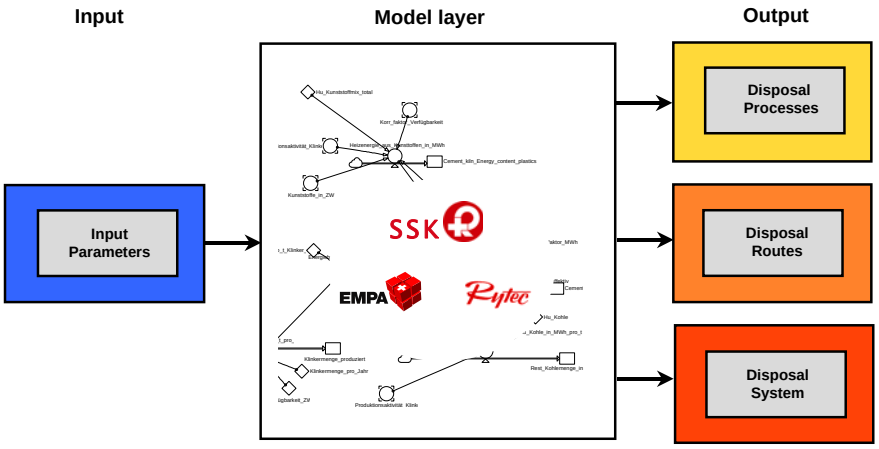

Figure 1: Structure of EcoSolver IP-SSK

The *model construction layer* includes the core model and additional modules for the ecological and economic assessment of the disposal system looked at. In *the core model*, the transportation-, collection-, sorting- and treatment-processes related to the disposal routes considered (incineration in MSWI plants, thermal recovery in cement kilns and mechanical recycling) are represented. As a database, indicators (specific energy consumption, specific emissions of e.g. CO_2, NOx, Cd, Hg, COD, etc.) for processes and systems typically found in Switzerland have been used. Central element of the core model is the incineration process in MSWI plants, which has been modelled in detail.

The *ecological assessment* of the disposal system is based on the problem-oriented CML-method employed in Life-Cycle Impact Assessment (LCIA), and the 'basket of products' - principle, which allows a fair comparison of scenarios with different outputs (Fleischer 1994; Förster and Ishikawa 1999; SAEFL 1998). In addition to the impact assessment categories (abiotic resource depletion, global warming, ozone layer depletion, etc.), environmental indicators are calculated in order to consider important environmental aspects which are not addressed by the CML-method (amount of waste materials, heavy metal distribution into different compartments, etc.; see figure 2). For the calculation of the inventories and the impact assessment categories, published (average) data have been used (SAEFL 1998a, 1998b);

The *economic assessment* is based on process-specific, economic indicators. For the time being, it is limited to single processes and disposal routes. An approach, which is also based on the 'basket of products'-principle and allows the assessment of the entire system, has been developed (Förster and Ishikawa, 1999).

The *output layer*, finally, shows the results of a simulation on three levels:

- the processes (e.g. the incineration process in an MSWI plant);
- the disposal routes (i.e. the sum of the disposal processes for each disposal option);
- the entire disposal system considered.

In view of an assessment of the simulation results, the output of the simulation of a scenario has to be compared to the output of a corresponding reference scenario.

3. Results and Conclusions

To demonstrate the functionality of EcoSolver IP-SSK, scenarios have been defined, which describe thermal recovery and recycling of plastics waste in a model region of 207'000 inhabitants around a MSWI plant with different capacities (Wäger and Gilgen 2000). As MSWI plants differ from each other in technology and operation

conditions, simulation results are specific for the model region looked at. In the reference scenarios, all the waste is incinerated in an MSWI plant.

The scenario presented assumes that the equivalent of each 50'000 tons of industry plastics waste per year on a national scale is diverted into a cement kiln (mixed plastics) and a mechanical recycling plant (polyethylene, polypropylene, polystyrene) in the years 10-15 of the simulation period (see figure 3). On a national scale, such a diversion of 100'000 tons of industry plastics waste per year would set free the capacities of more than two medium-size MSWI plants. Additional boundary conditions of the scenario are, among others:

- in the year 10 of the simulation period the capacity of the MSWI plant is renewed;
- plastics waste, which is thermally recovered in the cement kiln complies with the standards of the SAEFL (1998c);
- there is a market for secondary plastics material.

Simulation results show that a diversion of industry plastics waste from MSWI plants into cement kilns and mechanical recycling is ecologically beneficial, if impact categories according to CML are considered:

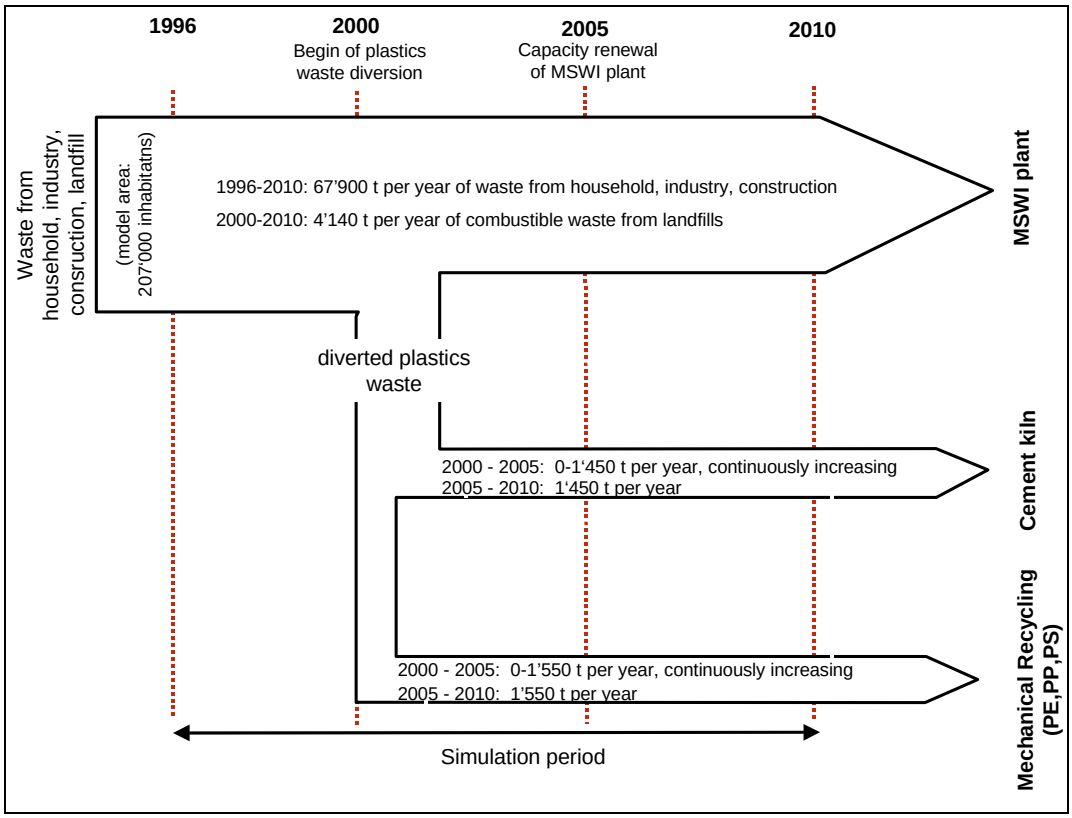

Figure 3: Scenario simulated with EcoSolver IP-SSK

The environmental impact of the scenario decreases for all categories when compared to the reference scenario, in which the plastics waste is not diverted but incinerated in an MSWI (see figure 4). This is i.a. due to a lower consumption of non-renewable energy and less CO_2-emissions than in the reference-scenario.

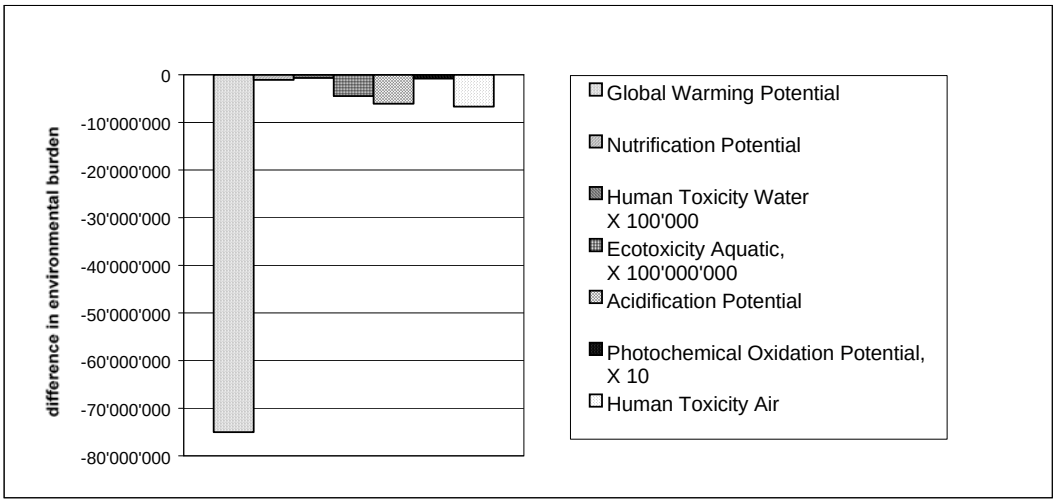

Figure 4: Environmental burden difference between each the scenario and the reference scenario (negative values stand for a lower environmental burden of the scenario, compared to the reference scenario)

From an economic point of view, the diversion of plastics waste has some beneficial effects with regard to the alternative disposal routes (thermal recovery in cement kilns and mechanical recycling). Disposal in the MSWI plant, on the other side, is negatively affected by a diversion of plastics waste, if the MSWI plant does not adapt its oven capacity or compensates the reduction of waste input by waste import from other regions (see figure 5).

Altogether, simulation results are plausible with respect to the effects caused by a diversion of plastics waste. They indicate that – under the conditions specified - a diversion of industry plastics waste from the waste stream into MSWI plants makes sense from an ecological and an economic point of view. In view of the increasing amounts of waste and the costs for additional MSWI plants it seems appropriate to intensify the discussion about this waste disposal option - under consideration of possible changes in boundary conditions (e.g. market prices for secondary raw materials) and regional characteristics of waste management systems (e.g. logistics systems and transportation distances).

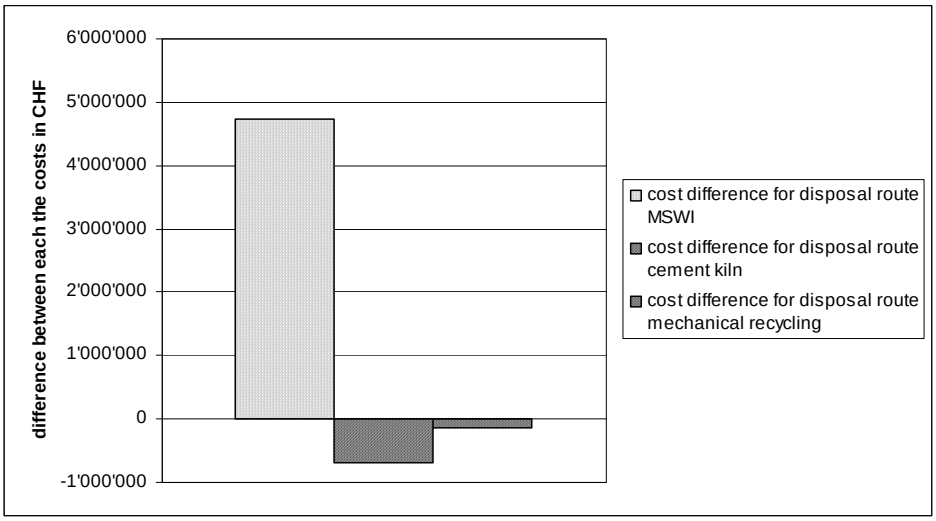

Figure 5: Cost difference between each the scenario and the reference scenario (negative values stand for lower costs of the scenario, compared to the reference scenario)

4. Recommendations and Outlook

With ongoing differentiation and increasing interdependencies in the modern (information) society, approaches which support the public discussion about its design and regulation will gain in importance. In this context, computer-based simulation tools can play a major role, as they allow to visualise and discuss the effects of intended actions before they are implemented – with often serious, irreversible consequences.

Necessary prerequisites for the application of such tools will, among others, be their functionality, their validity, their transparency, their user-friendliness and, last but not least, the ability of the responsible operator to involve the relevant key players into the modelling and simulation process. Possibilities and limits of numerical simulation tools to support decision-making processes still have to be explored. The future will show, how much they can contribute to master the ecological, economic and social challenges of our society.

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