Evaluating the sustainability of recycling packaging materials combining LCA and Fuzzy Set Theory

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1. Introduction

There are different recycling systems in Switzerland as in many other countries collecting and recycling different materials mostly packaging like paper, PET, PE or glass bottles as well as metals. But there are a lot of further used materials where a recycling potential exist, like CD, liquid packaging boards (LPG), plastic bags, sheets and foils or coffee capsules. The Swiss retailer association wanted to know which recycling and logistics system (e.g. separate or combined collection) would be the best from an overall point of view.

For some criteria's like ecological performance LCA and for the economic performance LCC can be used. But for a sustainable system other criteria's are also important. For some of these criteria's like satisfaction and acceptance of consumers or communicability there is no quantitative method available. But of course there exists qualitative knowledge. For other criteria like future markets for recycling materials or synergies to existing systems there were qualitative good estimations from experts but no quantitative figures. So the question rose how these different types of information can be used to model and evaluated this complex system in a transparent and comprehensible way.

2. Methods and procedure

For problems like this typically multi-criteria decision analysis (MCDA) is used. Because of the following main reasons we did not used classical MCDA but the fuzzy set theory (FST) see e.g. [2], [4] and [5]. This mathematical framework permits to combine the available quantitative results from LCA and LCC with the qualitative or linguistic expert judgements. Floating transitions typically for environment can be handled and the uncertainty of estimations are taken into account. In FST values like amounts of materials or environmental impacts are described by distributions, so called membership functions,
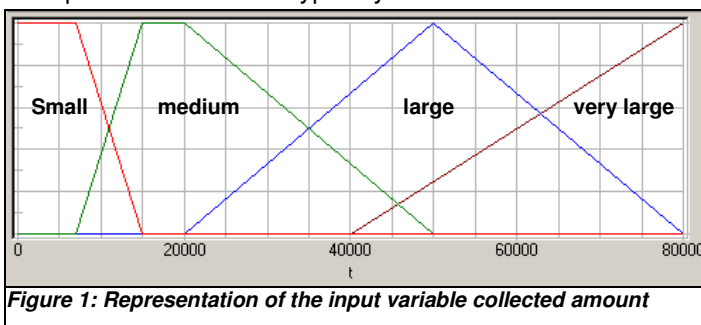

Figure 1: Representation of the input variable collected amount

and not by exact numbers or crisp sets, Figure 1 shows as an example the representation of the input variable *collected amount*. The relations linking the different input variables with the outputs are given by rules from expert judgements represented in matrixes (modus ponens see e.g. [1]). With these two elements a model for the system under study can be build. Together with experts from different fields like logistics, recycling technologies, ecology and economy the model given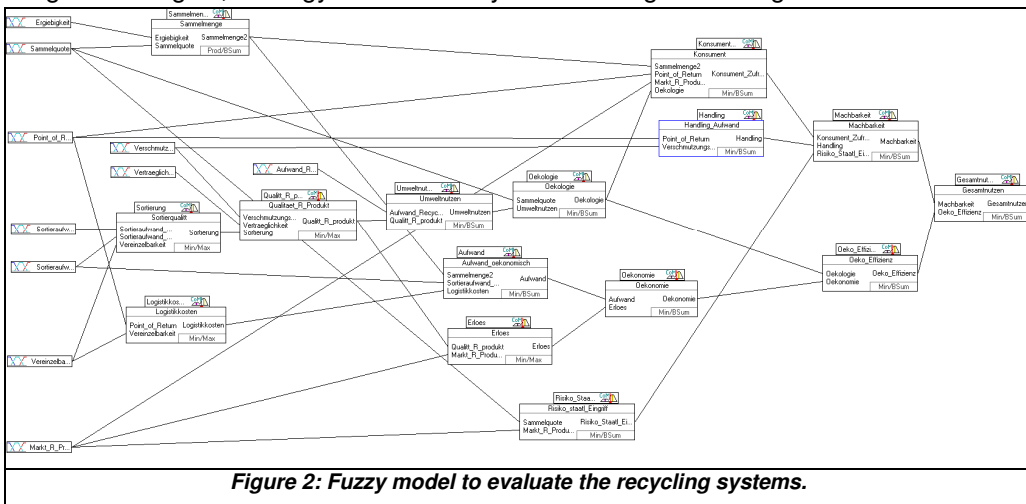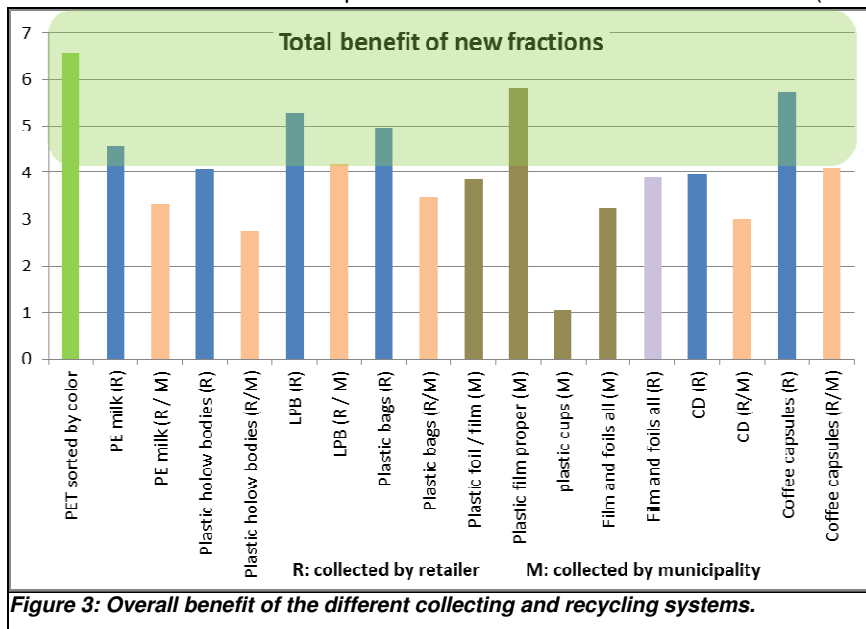 in Figure 2 has been developed [2]. On the left hand side the different influences / characteristics (input variables) are given. The blocks in the middle are the matrixes of the rules containing the expert knowledge concerning the consequences of the different inputs and relations (lines) to the output variables.

At the right hand side the output is

Figure 2: Fuzzy model to evaluate the recycling systems.

given as overall benefit regarding different aspects like ecology, economy and feasibility as well as consumer acceptance of the system. This indicator can be seen as a sustainability index of the system because it includes the ecologic, social and economic dimension. In order to display and compare the results of the different systems and scenarios the fuzzy distributions are transformed into figures using algorithm given by the FST, see Figure 3.

3. Results and discussion

The model described in chapter 2 was used to calculate the overall (ecological, economic and social) benefit of various materials like LPG or PE bottles and sheets for different scenarios. Furthermore the model was also used to calculate different scenarios concerning collection and logistics. Figure 3 shows the results for possible new collecting fractions and collecting systems. The diagram shows that the overall benefit can be very different. There are fractions with a high benefit like PE hollow bodies, LPG and clean PE sheets with a high benefit if they will be collected by the logistic system of the retailers. If they are collected by the municipality the benefit is lower. There are also other fractions like CD with a lower benefit because of the low amount.

Figure 3: Overall benefit of the different collecting and recycling systems.

4. Conclusions

The result of this study was twofold. First of all it gave a good decision base for the retailers as well as for the municipalities and national administration to their policy of sustainable, future collection and recycling systems. Second it could be shown that this methodological approach is not only useful but very powerful for decision support of complex systems. The important advantages of this method are:

- representation of qualitative expert knowledge with linguistic terms
- bringing together in a mathematically exact way quantitative and qualitative data and knowledge from different fields like ecology, economy and societal as well as technical aspects
- nonlinear relations can be handled and FST makes the interpolation
- floating transitions which are typical for environment can be handled
- Fuzzy logic can deal with more than one 'right' judgement typical for human reasoning
- doing all this in a transparent way.

So we gained the experience that for complex decisions FST will be one of the efficient ways for decision making according to the statement of Lofti Zadeh: "In almost every case you can built the same product without FST, but fuzzy is faster and cheaper."

5. References

[1] Salski A. (edit.). 1996. Fuzzy Logic in Ecological Modelling. Ecological Modelling 85, Elsevier, Amsterdam
[2] Schelker R., Geisselhardt P., Dinkel F. 2011. Die Zukunft der Separatsammlung von Altwertstoffen in der Schweiz, REDILO GmbH, Basel, Switzerland.
[3] Zadeh L. A. 1964. Fuzzy Sets. In: Information and Control, Vol. 8: 338 – 353.
[4] Zadeh L. A. 1973. The Concept of a Linguistic Variable and its Application to Approximate Reasoning, Memorandum ERL-M 411, Berkley.
[5] Zimmermann H. J. 1991. Fuzzy Set Theory and its Application, 2nd ed., Kluwer, Dortrecht.