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Citation: Ulli-Beer, S., D. F. Andersen, G. P. Richardson (2004). Using the SD-SWM-model to inform policy making for solid waste management at the local level. Proceedings of the 22nd International Conference of the System Dynamics Society. Oxford, England (July 25-29, 2004).

Using a SD-SWM-model to inform policy making for solid waste management at the local level

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This paper presents a comparative policy analysis drawing on the System Dynamics Solid Waste Management model that is based in a feedback perspective on human behavior and public policy (Ulli-Beer 2003). The model is suited to address the following request: What local policies increase recycling, and help to establish / ensure a solid waste management system that fosters competitive recycling markets?
Subsequently, the model was used as a policy laboratory in which various policy experiments addressing "what-if-questions" under controlled conditions could be conducted. Subsequently the impact and outcome of recycling initiatives and strategies at the local level were analyzed under different scenarios. Various policy experiments illustrated crucial dynamic interactions between flexible preferences and contextual factors (Ulli-Beer et al 2004). Furthermore, policy sensitivity of personal factors could be identified that explains the success or failure of recycling initiatives. The policy experiments show that combinations of interventions altering personal and contextual factors are crucial for policy compliance and for designing robust recycling initiatives especially under uncertain and adverse conditions in the system.

Key words: System dynamics, computer simulation model, citizens' choice and preferences, environmentally relevant behavior, policy compliance, public policy and analysis, recycling initiatives, solid waste management, comparative policy analysis

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[1] The author would like to thank the dissertation-adviser-team Prof R. Kaufmann-Hayoz (member of my dissertation committee, University of Berne,), Prof. M. Schwaninger (Chair of my dissertation committee, University of St. Gallen) and the two co-authors (being important mentors not only but especially during my one year long visit at the System Dynamics Group in Albany). They all contributed significantly to this work in many different ways. Furthermore, I highly appreciate the support from many friends and colleagues who provided valuable comments and encouraged me in the course of this study, especially from Aldo Zagonel, Mohammad Mojtahedzadeh, Rod Mac Donald, Vedat Diker and Susanne Bruppacher. The work was financially supported by the SNF from Switzerland and the Basic Research Funds of the University of St. Gallen, Switzerland. I am greatly indebted to my husband, parents, parents in law and friends who were tacking care of our children, when their mother was preoccupied by this work.

Introduction

Early on Ayres and Kneese (1969) pointed out that externalities associated with disposal of residuals resulting from the consumption and production process is an important class of externalities.

> *"Their economic significance tends to increase as economic development proceeds, and the ability of the ambient environment to receive and assimilate them is an important natural resource of increasing value" (282).*

Furthermore, these authors emphasize that isolated and ad hoc taxes and other restrictions are important but not sufficient for an optimal control of natural resources. What is needed is a more systematic and coherent program of environmental quality management including public investment programs.

However, recent economic studies on solid waste management policies focus on economic instruments offering incentives to either households or producers or to both in order to influence the intrinsic waste content to be disposed of. Based on empirical economic studies Choe and Fraser (1999) conclude that

> *"without explicit incentives, neither the firm nor the household will necessarily undertake costly action to reduce the amount of waste, but explicit incentives such as waste charges might induce households to choose the option to illegal disposal" (235).*

The model from Fullerton and Wu (1998) illustrates that optimal waste management policies depend crucially on households' waste separation behavior including illegal dumping. Policies such as various combinations of environmental taxes on the firm and waste collection charges only lead to the first best optimum if household waste separation behavior is not significant. A waste collection charge gives incentives for both high separation efforts and illegal dumping thus rendering a Pigouvian tax sub-optimal (Fullerton and Kinnaman 1995; Fullerton and Kinnaman 1996). The authors suggest a combination of policies such as a waste collection charge on the household, explicit monitoring of illegal waste disposal and an environmental tax on the firm. Choe and Fraser (1999) further emphasize the role of monitoring costs and the willingness to comply with environmental regulations for an optimal solution. Based on their comprehensive equilibrium model including both firms' and households' behavior the authors conclude that whether it is optimal to eliminate any illegal waste disposal entirely depends on the monitoring costs necessary to induce such extreme compliance. Furthermore they emphasize the interdependent nature of policy instruments at different levels of implementation. "Such an interdependence calls for careful coordination of policies among different regulatory bodies" (243).

Shinkuma (2003) suggests a further economic model and shows that the magnitude of transaction costs associated with recycling subsidies and the price of the recycling good the firm has to pay to the household are crucial to the choice of second best policies.

These recently published examples of economic approaches analyzing solid waste management policies show that theoretically the social optimum could be reached by different regulatory policies and that they are equivalent substitutes. However, in the real economy certain factors prevent such an optimum. Shinkuma (2003) interprets this observation as follows: "The policy direction to follow has its most relevance as an empirical rather than a theoretical question" (79).

The main tenor of these economic studies is: Although economics can give theoretical arguments why a nation wide policy of solid waste management based on economic policy-instruments could be a cost efficient way of internalizing externalities and seeking a social optimum in a perfect world, with competitive markets and rational decision-makers, they may not help addressing more complex phenomena that both are related to implementation issues and a “faulty” reality that is characterized by imperfect information and uncertainty as well as dynamical complexity. Hence, a methodological approach is required that aim at putting the principles to work, of enhancing learning processes which leads to a continuously improved implementation (see also Schwaninger 1997:109). This is what this paper aims at, to illustrate such policy analysis approach.

In this paper a complementary approach to the economic way of policy analysis is described. It is based on a SD-SWM-model. Its conceptualization was guided by a feedback perspective on human behavior and public policy and a concrete real world phenomena observed in a typical Swiss locality. The local authorities are in charge of implementing national wide solid waste management policies based on the polluter pay pays-principle (Ulli-Beer 2003; Ulli-Beer, Richardson et al. 2004). Hence, the model includes structures that may help the decision makers in micro controlling and fine tuning the system performance when implementing economic policies. While economic models aim at describing “optimal solution” and the state of the system in equilibrium the SD-SWM-model focuses on describing the transition process from one equilibrium to another.

Similarly, to the economic concept of willingness to pay, citizens’ preferences are operationalized by data on *acceptable separating time* and *acceptable separating or burning cost.* However, there are some major differences in the overall choice concept of the SD-SWM-model compared to the economic theory of consumer choice. First, the preferences can be influenced by a social norm for separating behavior. Second, the observed separation pattern is not described by a utility function that will be maximized, but rather by simple deliberation processes comparing acceptable costs and real costs in separating but also by comparing real cost and alternative action costs of not separating. Further, the SD-SWM-model choice approach conceptualizes mainly two groups of people with different preference structures – those that may develop intention to separate and those that may not. Finally, the model structure also includes measures of the influence of habits that are actually not part of a choice process. Therefore, this specific SD-choice structure may be seen as an important building block of the overall SD-SWM-model including crucial psychological concepts explaining individual behavior. This is seen as an important precondition for an adequate policy analysis instrument trying both to exclude systematic disciplinary biases and to identify important intervention points also considering changes in personal factors (Stern 2000; Vlek 2000). In sum, the presented choice structure allows policy analysis that take into account economical and psychological processes.

Methods

An integrative systems methodology (Schwaninger 1997; Weber and Schwaninger 2002) was chosen that is especially suitable for investigating complex issues in drawing on concepts of System Dynamics and Cybernetics. A two-step research strategy was pursued. In the first step an overall analysis of environmentally relevant behavior was undertaken and in the second, an in-depth analysis of the specific case was conducted (for the whole study see Ulli-Beer 2004).
The purpose of the first step was to explore and to shape the field of investigation, as well as to identify relevant concepts and to develop frameworks that help to structure the issue. In order to avoid a disciplinary bias no single disciplinary perspective or singly theory approach

was chosen. Instead a consistent research heuristic that is adequate for investigating the complex issue has been developed. The framework "a *Feedback Perspective on Human Behavior and Public Policy"*, (Kaufmann-Hayoz and Gutscher 2001a; Ulli-Beer 2003) was used as a heuristic and substitute of a disciplinary focus. It helped conceptualizing the model in such a way that the main relevant aspects of the multifaceted issues of solid waste management could be integrated (see Figure 1).

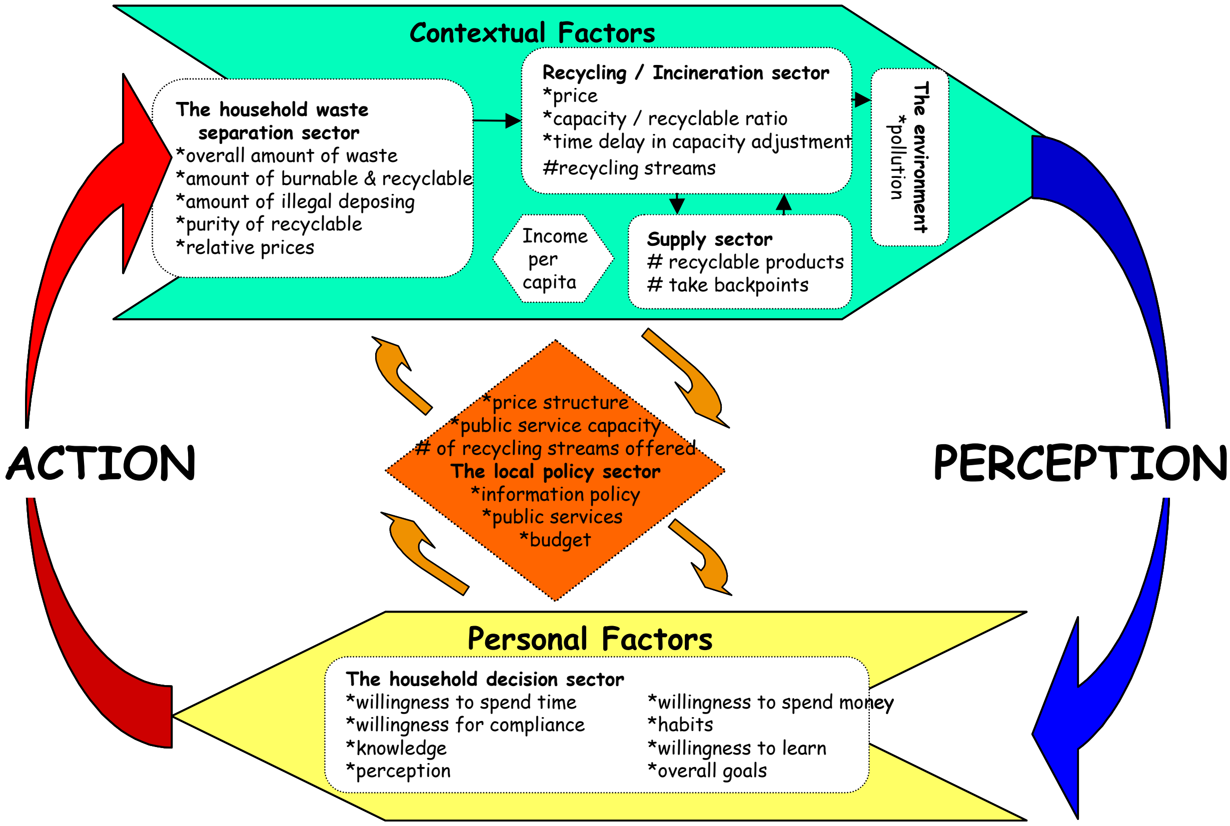


Figure 1: A feedback perspective on citizens' waste separation behavior and solid waste management.

In the main study the computer-assisted theory development method of System Dynamics was applied. The findings and concepts of the preliminary study were adopted to the specific case. It resulted in the SD-SWM-model that served as a virtual policy labor allowing comparative policy analysis.

These introductory comments are followed by a brief overview of the model conceptualization and structure. The main focus of the paper is on the description of the various policy experiment that are reported in the chapter "Using the model as policy-labor". This paper will conclude with a detailed interpretation and discussion of the policy-experiment results – addressing the stated concerns of local authorities that are in charge of implementing solid waste management-policies.

The SD-SWM-model: conceptualization and structure

In the following paragraph a brief overview of the model conceptualization and the dynamic hypothesis will be given as well as basic elements of the model structure are shortly described. A comprehensive discussion can be found in Ulli-Beer (2003) and Ulli-Beer, Richardson, and Anderson (2004).

The problem addressed with the SD-SWM-model are summarized in the following questions: *What local policies increase recycling, and help to establish / ensure a solid waste management system that fosters competitive recycling markets?*
This overarching question was cut up in the following more specific ones:

- *How do you motivate the households to participate in solid waste separation?*
- *How do you recover recyclable material in order to produce competitive secondary raw material?*
- *How do you finance the recovering and disposal activities of local agents?*

These questions and observed changes in variables of interest over time such as the fraction of separate waste or budget variables were guiding the conceptualization of the model.
In order to analyze long-term effects of different local policy interventions a time horizon from 1987 to 2020 was chosen. For the time period 1987 to 2001 there is data available revealing historical patterns of behavior.

In short, the postulated dynamic hypothesis can be described as follows.
Since the performance of citizens' separation behavior was low, the localities gave price incentives in form of a garbage bag charge (implemented in 1991). The intended effect was to promote the separation behavior. As a consequence the fraction of separated waste increased and the relative amount of solid waste for burning decreased. The unintended effect was that not only the relative amount of waste disposed for burning decreased, but also the revenue generated from the trash bag charges declined. Therefore, the budget deficit started to increase. A further increase in the price for burnable material had nearly no additional effect on the separation behavior, since the number of recycling streams was held nearly constant. The citizens had no real legal option to avoid higher costs for disposing of burnable material. As an unintended consequence, the quality of the separated material decreased. Citizens started to put burnable material in the recycling streams. However, this effect was only observed and could not be exactly quantified.

The sector diagram (Figure 2) gives an overview of the main sectors of the local SD-solid waste management model and how it is embedded in a wider market system.

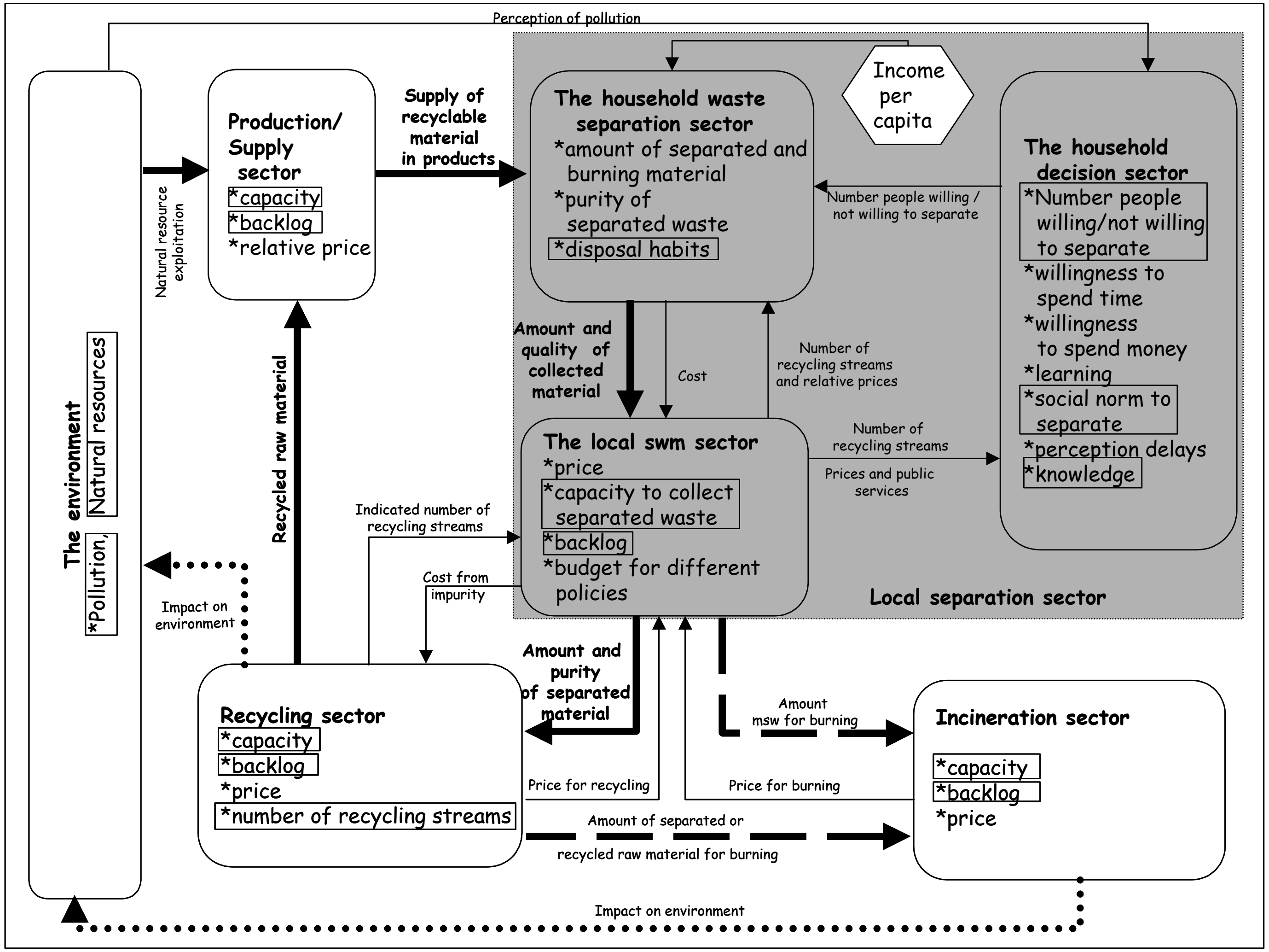


Figure 2: Sector Diagram of the extended SD-SWM-model

Using the model as policy-labor

With the SD-SWM-model two distinct classes of policy-questions could be addressed (see Zagonel, Rohrbaugh et al. 2004 forthcoming):
Firstly, "What might happen if we were to make such and such policy change?" analyzed in back-casting and in forecasting[2] policy-experiments. For example decision maker might ask: "What might happen to the fraction separated material if prepaid taxes on further recyclable products will be implemented?" Secondly, "What might happen if some scenario not under our control were to change dramatically?" In virtual policy experiments such questions were addressed and comparative policy analysis were conducted by using the model as a policy-laboratory. Hence, the behavior pattern resulting from the different policies under similar conditions or under different scenarios could be compared and explained. Furthermore, sensitivity analysis was used to explore the effect of uncertainty in the system.

Before entering in the discussion of the different policy experiments an important characteristic of the model structure will be highlighted. It is crucial for the understanding and interpretation of the simulation-results of the policy experiments.

The main stock and flow structure of the model has similar characteristics as basic epidemic and innovation diffusion models such as the SIR-model or the Bass-model (Sterman 2000): 300ff). The diffusion process is boosted by the second-order reinforcing feedback structures. The exponential growth or decline is limited by first order control loop structures, controlling the overall growth capacity (such as the number of *<people not willing to separate>* and *<people willing to separate>)* hence, resulting in s-shaped growth. An important characteristic of the second order-models is the tipping point. If the diffusion process does not take off a policy initiative is likely to die. The question of whether the policy initiative will succeed is a question about which feedback loops are dominant (Richardson 1995). The recycling initiative will succeed if the positive loops controlling the rates **"getting motivated"** dominates the positive loops controlling the rates **"getting disappointed[3]"** otherwise the initiative will fail. Different policy-interventions have different effects on the two positive feedback loops (see Figure 3). A higher garbage bag charge weakens the loop **"getting disappointed"** whereas an increase in the *<effective nr recycling streams>* increases the *<effect of time cost separating>*. This will weaken the loop **"getting motivated"**. A price for separated material will have the same effect. Furthermore, it is assumed that a prepaid tax could lead to a *<effect of crowding>* resulting in an enforcement of the loop **"getting disappointed"**
The strength of these loops will mainly determine the model behavior. However, in the full-blown model version numerous further loops will control these diffusion-loops and subsequently the model behavior.

[2] The term forecasting refers to the time horizon in the future and indicates that the effect of a policy interventions made in the future will be analyzed. Contrarily, the term back-casting refers to a policy intervention that was made in the past.
[3] Probably, this loop could also be named "getting discouraged" or "demotivated", since different psychological concepts could be used to explain the process that lead people to decide against waste separation. However, in this book this loop will be called uniformly "getting disappointed".

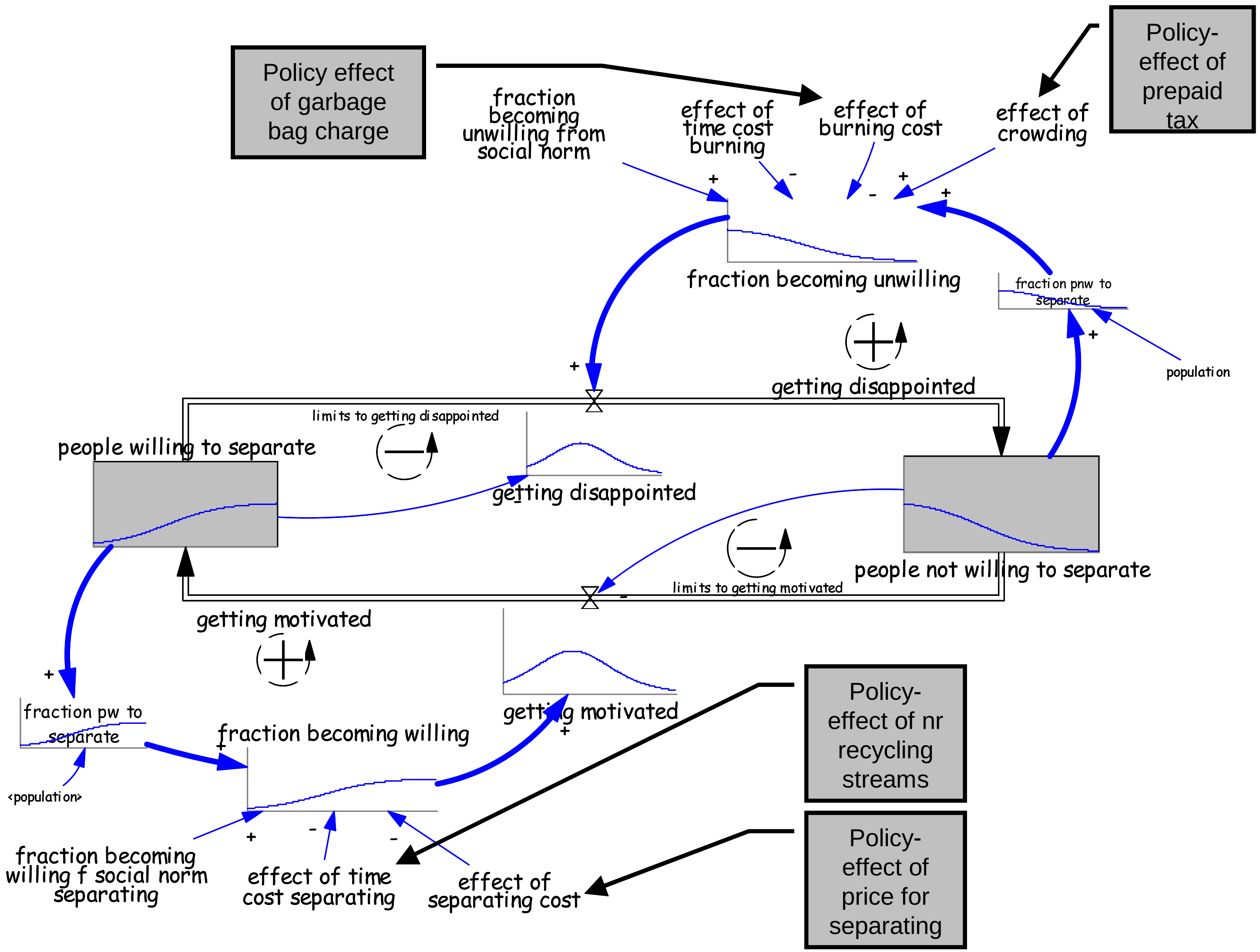
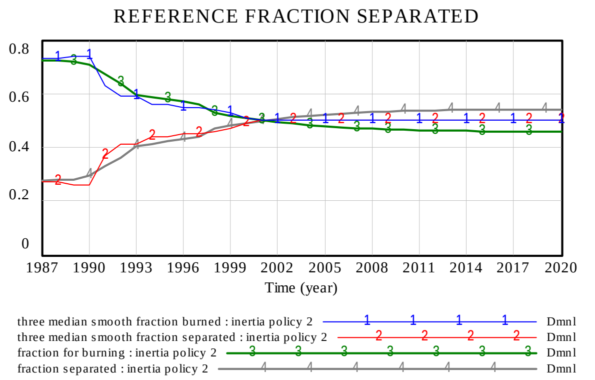


Figure 3: Simplified model structure and policy effects.

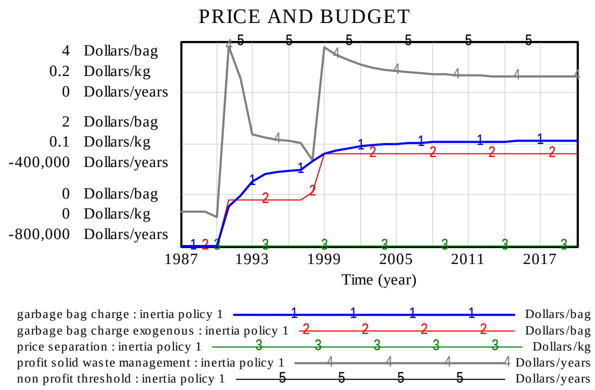
The outcome of the policy-experiment will be measured with the following indicators / variables of interest:

- The simulated values of <*fraction separated*>, <*fraction for burning*> are depicted against the smoothed real data.
- number of the different groups of people willing or not willing to separate, respectively: <*ep willing to separate*>, <*iep willing to separate*>, <*iep not willing to separate*>, <*ep not willing to separat*>
- <*total amount appropriately separated*> and <*total amount inappropriately separated*>. These amounts will be depicted against the <*total amount recyclable material*>.
- <*garbage bag charge*> and <*price for separating*> and the <*profit of solid waste management*>.

The following base-runs illustrate the model behavior with the actual policies in place, called **inertia policy**[4]: an increase in <*effective nr recycling streams*> and an increasing <*garbage bag charge*>



(A) Line 1 and 2 are three median smoothed real data



(B)

Charts1: Dynamics back-casting policy-experiment "inertia policy":

The simulated <*fraction separated*> and <*fraction for burning*> closely tracks the smoothed real data (see Chart 1 A). There is a clear trend of growth in the <*fraction separated*>. Based on the historical growth trend the model data indicates a further increase in the <*fraction separated*> till it seeks equilibrium that will be slightly higher (54%) than the actual fraction (50%).
A change in the <*effective nr recycling streams*> creates the opportunity for people to separate more material, which has two effects. Firstly, it reduces the <*total amount disposed for burning*> resulting in less revenue. Secondly, it increases the cost for collecting the separated material. These two effects result in budget deficit due to price adaptations delays in the <*garbage bag charge*>. This adaptation delay creates the observed budget deficit in the real world. Chart 1 B illustrates this case in the **inertia policy 1** experiment (garbage bag charge exogenously given). It is simulated with the <*garbage bag charge exogenous*> resulting in a budget deficit between 1993 and 2000, appearing again after 2001 (see the gap between line 4 and 5 <*profit solid waste management*> and <*non-profit threshold*>)[5].

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[4] The model structure allows to simulate the inertia policy either with the garbage bag charge exogenously given or endogenously computed. In the first case, in the **intertia policy 1** the actual garbage bag charge serves as model input. For the second, **the inertia policy 2**, a endogenously computed garbage bag charge leading to a zero budget deficit will be used.

[5] For additional back-casting experiments addressing "what if else"-question see Ulli-Beer (2003).

Forecasting policy-experiments

THE EXPERIMENT SETTING: The base run give evidence that the model structure is able to explain some observed real world dynamics of solid waste management. Building on further model-tests (see Chapter: Summary model testing) enough confidence in the model structure was established. The simulation runs explaining the dynamics of alternative policy-experiments are hypothetical outcomes based on the causal theory. Those postulate behavior patterns and do not predict point values. In the following, one main alternative policy regime with prepaid disposal taxes under different conditions will be described. Each policy-package specifies the design of a policy-experiment, controlling for differences in the external conditions. The influence of the different conditions are analyzed in order to understand the interactions and outcome of different policy-combinations. Figure 4 illustrates those interventions influencing the main loops determining the system behavior.

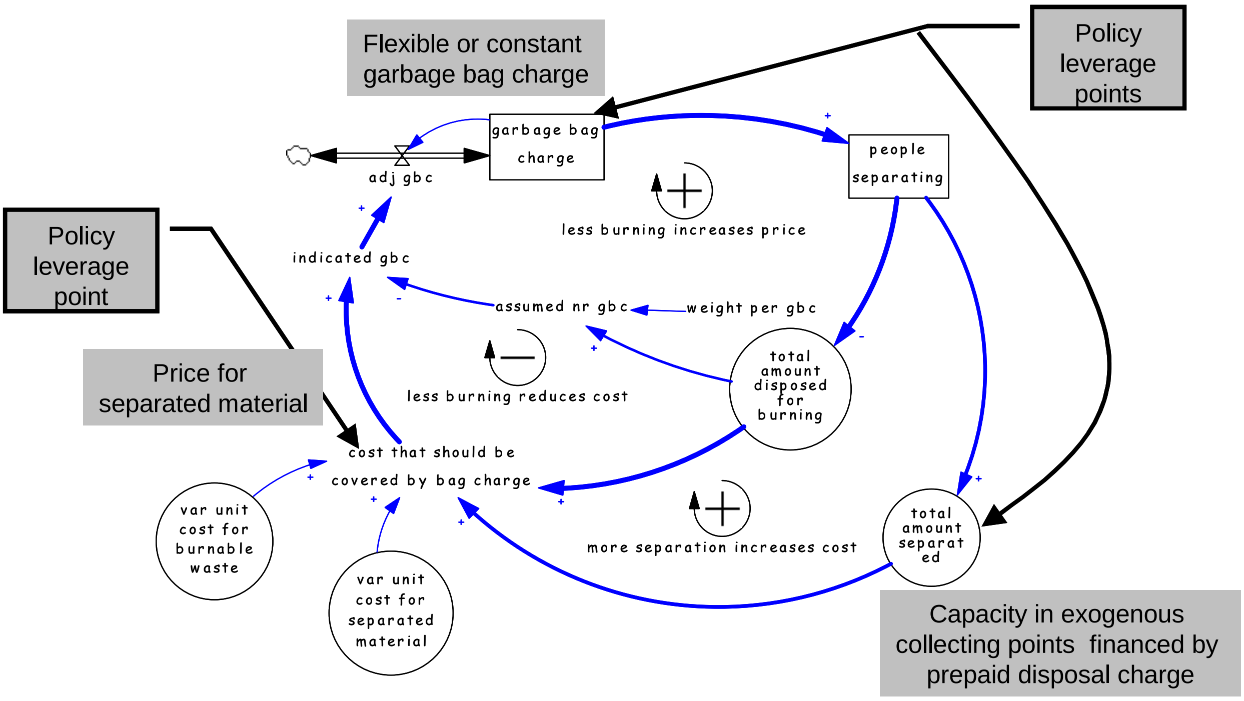


Figure 4: Policy-leverage points in a simplified model structure

Four experiments under a prepaid tax regime will be described. The object of these experiments is to gain a better understanding about policies and conditions that will lead to a robust intended policy outcome.

1. The implementation of prepaid tax without a garbage bag charge for burnable material (**Implement prepaid tax without garbage bag charge**)
2. The implementation of prepaid tax with a flexible garbage bag charge (**Implement prepaid tax with flexible garbage bag charge)**: In this experiment the garbage bag charge will vary since a zero profit/deficit budget is aimed for.
3. The implementation of a prepaid tax with a constant garbage charge (**Implement prepaid tax with constant garbage bag charge**)
4. The implementation of prepaid tax combined with a constant garbage bag charge and a further increase in the number of recycling streams (**Implement prepaid tax with constant GBC and increase number recycling streams**)

The policy-experiment four - in which the <*effective nr recycling streams*> will be increased further after 2004 - are designed in order to test both the effect of an increase in recyclable material on the price development and the effect of an increase in the number of streams on citizens' separation behavior. A further increase of the <*effective nr recycling streams*> from 9 to 14 streams with an decreasing marginal increase in recyclable material is assumed (for a portray of the graphical function, see Appendix).

Table 1 illustrates the design of the four policy-experiments. The active policy-levers (indicated by one) specify the policy bundle for each forecasting experiment.

Names of policy bundles	Policy lever				
	Garbage bag charge exogenous	Garbage bag charge endogenous	Increase in number streams	Prepaid tax	Increase recycling streams further after 2004
Forecasting					
Implement prepaid tax without garbage bag charge	0	0	1	1	0
Implement prepaid tax with flexible garbage bag charge	0	1	1	1	0
Implement prepaid tax with constant garbage bag charge	1	0	1	1	0
Implement prepaid tax with constant GBC and increase number recycling streams	1	0	1	1	1

Table 1: Overview and design of the forecasting policy-experiments[6].

THE EXPERIMENT RESULTS:

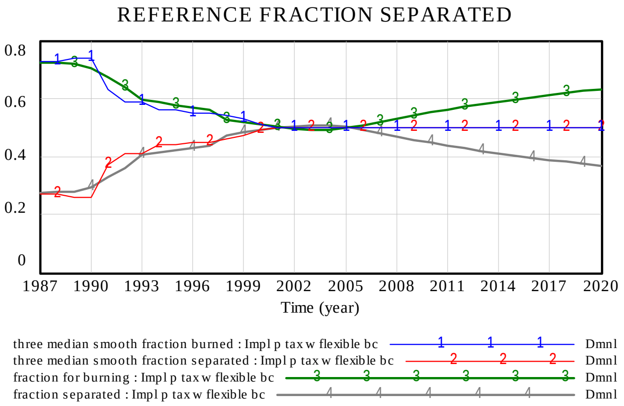
Implement prepaid tax without garbage bag charge

The policy-experiment **implement prepaid tax without garbage bag charge** has mainly an illustrative character in order to understand the feature of a prepaid tax. It showed the consequences of missing financial incentives for citizens of a pure prepaid disposal policy resulting in a strong decline of the fraction separated.

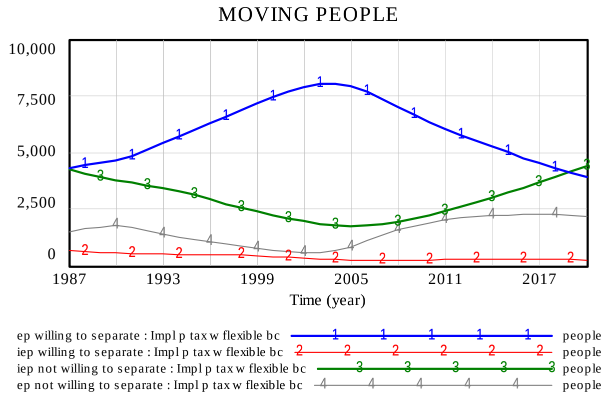
Implement prepaid tax with flexible garbage bag charge

The intended effect of the prepaid tax policy is to disburden the municipality from the raising cost of solid waste management. However, the Charts 2 A-D show both the intended effect of the prepaid tax policy and the unintended consequences. As a result from shifting the separating cost to other actors, the solid waste management cost, and therefore also the <*garbage bag charge*> decline (line 1 in D). The strong decline in the <*garbage bag charge*> results in both less <*ep willing to separate*> - this population drops down to 4138 people (B) - and a decline in the <*fraction separated*>, concluding at 37% (A). A somewhat unexpected result is the strong increase in the <*tot amount inappropriately separated*>. Obviously, due to the remaining cost for burning, the growing number of <*iep not willing to separate*> will continue to put burnable material in the recycling streams in order to save money. However, with this policy-package the municipality will be able to reach a balanced solid waste management budget (D line four.).

[6] The same logic can be found in the forecasting interface of the model (see Appendix).



(A)



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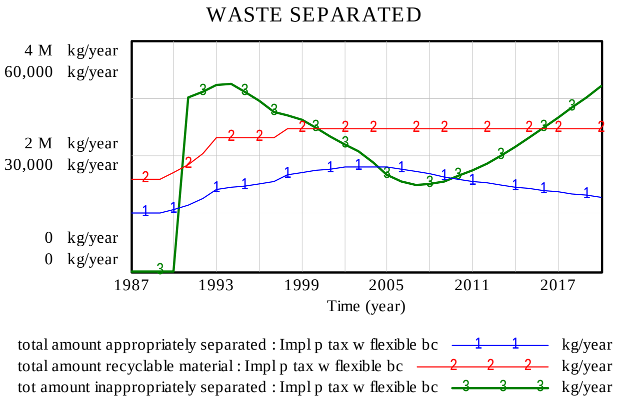

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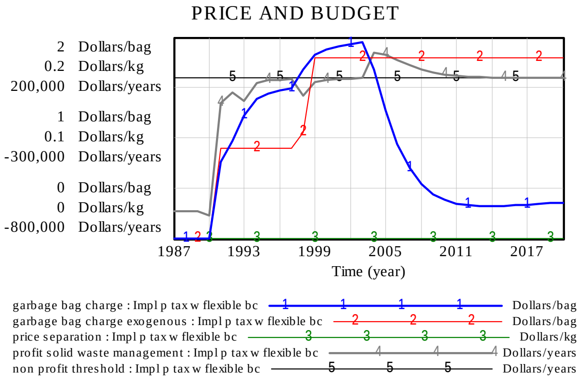
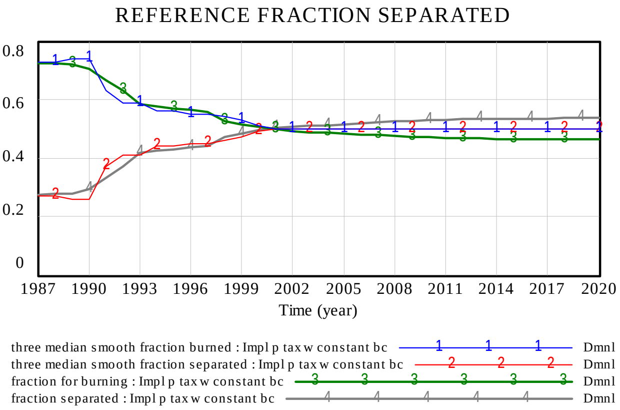


(D)

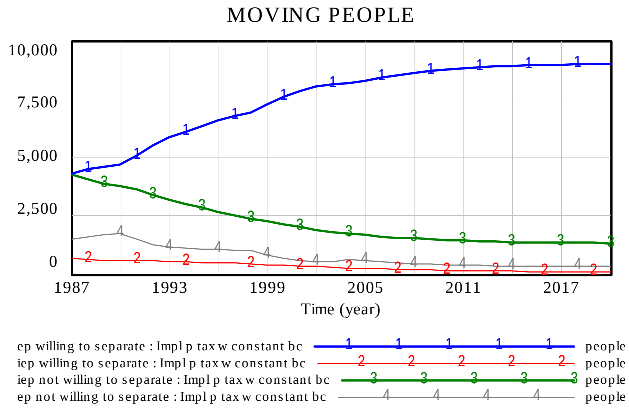
Charts 2 A-D: Dynamics of forecasting policy-experiment “implement prepaid tax with a flexible garbage bag charge”

Implement prepaid tax with constant garbage bag charge

This policy-experiment responds to the observations made in the previous experiments. Obviously, the prepaid tax policy alone has no power to motivate people to separate their waste. Contrarily, countervailing price effects will disappoint them (due to the two reinforcing feedback loops **“getting motivated”** and **“getting disappointed”)**. Therefore, this experiment analyses the effect of a prepaid tax in combination with a constant garbage bag charge offering an effective financial incentive to separate the waste. In the model the real data of the garbage bag charge are used and held constant after 2000 (see D line 2 <*garbage bag charge exogenous*>). Chart 3 A-D exhibits behavior patterns similar to the ones of the **inertia policy** in the back-casting experiments. The <*fraction separated*> seeks equilibrium at 54% (A) and about 9100 people are participating in the recycling initiative (B). The same overshoot and decline pattern in the amount of <*tot amount inappropriately separated*> material can be observed. The two peaks are a result of the implementation of and increase in the <*garbage bag charge exogenous*>) in 1991 and 2000 (C). However, an important difference in the solid waste management budget can be observed. Due to the constant garbage bag charge and the shift of recycling cost to other actors, the solid waste management budget exhibits a profit, seeking equilibrium smoothly at 814’000 CHF/year (see D line four <*profit solid waste management*>).



(A)



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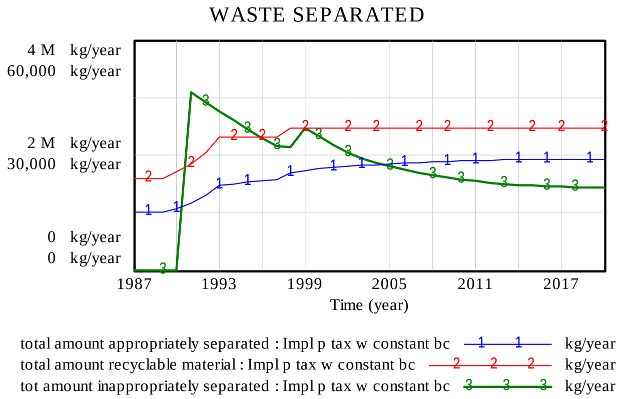

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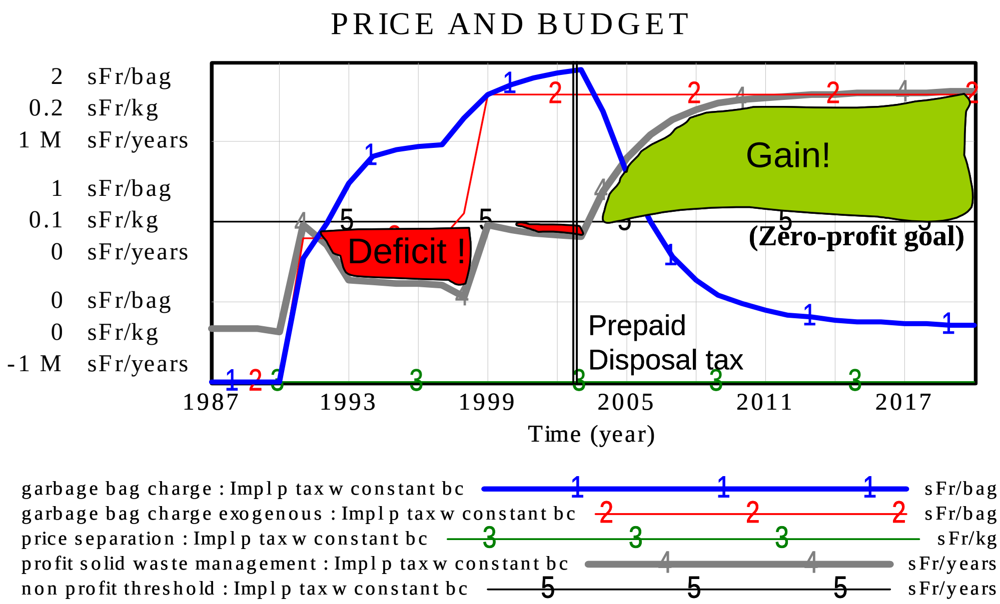


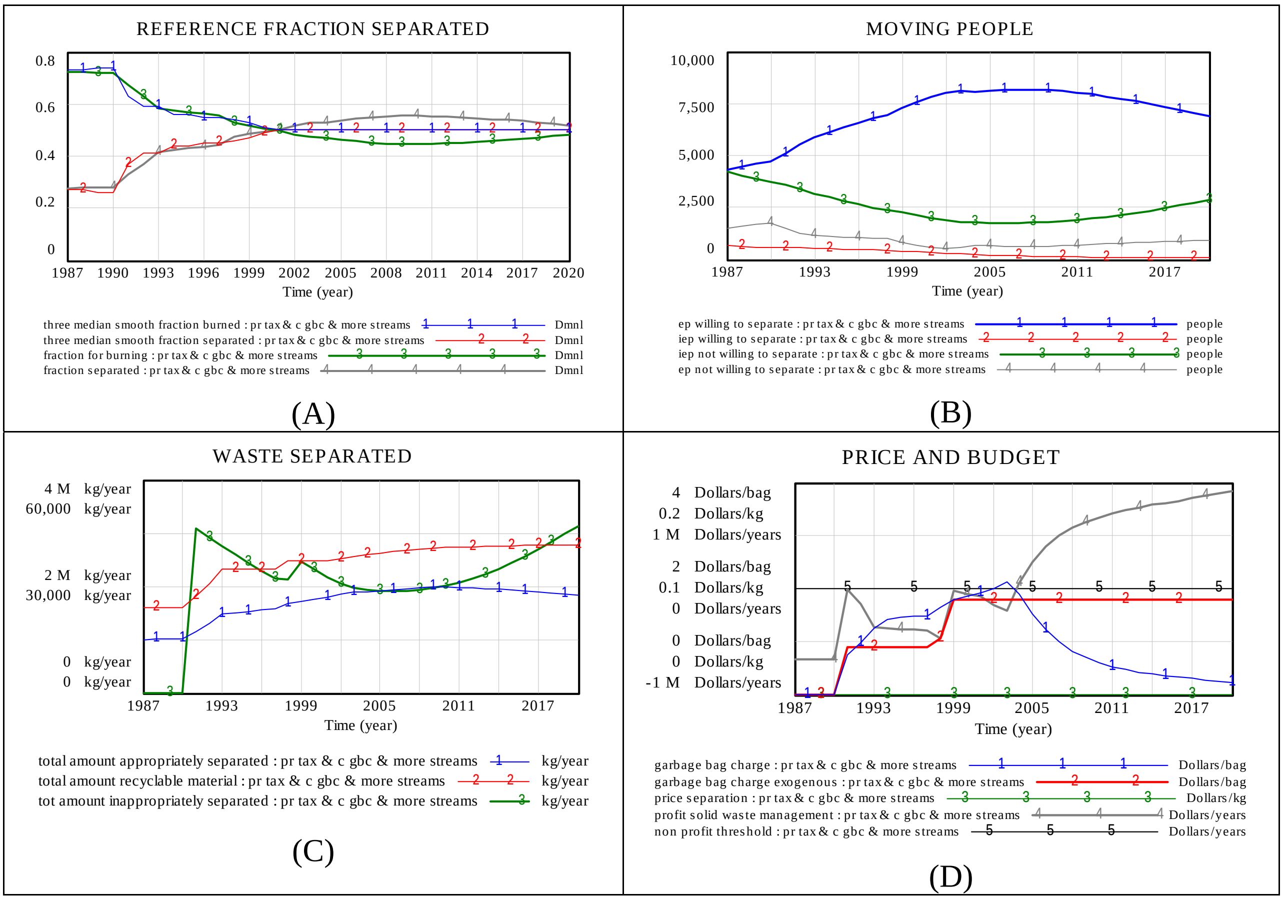
(D)

Charts 3 A-D: Dynamics of forecasting policy-experiment “implement prepaid tax with a constant garbage bag charge” line Nr 2.

Implement prepaid tax with constant garbage bag charge and increase number recycling streams further

In the former experiment the recycling initiative takes off but the actual <*fraction separated*> gets limited mainly because of the limited <*total amount recyclable material*>. One way to increase this amount would be to increase the <*effective nr recycling streams*> further, reflecting a situation in which more and more different material becomes recyclable. In fact, this would imitate a scenario in which the recycling market starts to grow with new recycling technologies entering the recycling market.

Charts 4 A-D illustrate that in the short term, there is a slight improvement in the fraction separated. It peaks with about 55% in 2009 and then decreases, reaching a value of 52% at the end of the simulation horizon (A). The decline in the <*fraction separated*> is caused by the decrease of willing people. This overshoot and decline pattern reflects the capacity limit of citizens to separate. They get overwhelmed from the separating tasks. As the <*effective nr recycling streams*> increases the <*effect of time cost separating*> it weakens the loop **"getting motivated"** resulting in a shift in the loop dominance towards the loop **"getting disappointed"** (B). A further unintended effect can be observed in Chart 4 C. After the "first-worse-before-better" pattern of impurity in the first half of the time horizon, a clear growth in the amount of inappropriately separated material can be observed. In addition, Chart 4 D clearly exhibits a growing profit (gap between line four and five), a further unintended effect of this policy-experiment that has to be considered well in reality.
We can conclude that the efforts to increase the <*total amount recyclable material*> further on, has to be paid by a high price but resulting only in a small increase in the <*total amount appropriately separate*> (C) and in worsening the performance of the recycling initiative in respect to impurity.



Charts 4 A-D: Dynamics of forecasting policy-experiment "implement prepaid tax with constant garbage bag charge and increase in number recycling streams".

Table 2 compares the different price incentives given in the back- and forecasting policy-experiments. Only in the policy-experiment **implement prepaid tax with flexible garbage bag charge** the price is computed endogenously, under the prepaid policy regime. Therefore only in this policy-combination a zero profit budget was accomplished. In the three others forecasting experiments there was either a budget deficit **(implement prepaid tax without garbage bag charge**) or a profit (in the other two cases with constant garbage bag charges).

Garbage bag charge, CHF/bag (Price burning CHF/kg)	1987	1991	2000	2004	2020
Back-casting policy-experiment					
Inertia policy 1	0	0.9	1.8	1.8	1.8
Inertia policy 2	0	0.76	1,87	1,98	2.07
Forecasting policy-experiment					
Implement prepaid tax without garbage bag charge	0	0.76	1.87	0.26	0
Implement prepaid tax with flexible garbage bag charge	0	0.76	1.87	1.68	0.36
Implement prepaid tax with constant garbage bag charge	0	0.9	1.8	1.8	1.8
Implement prepaid tax with constant garbage bag charge and increase in number recycling streams	0	0.9	1.8	1.8	1.8
Prepaid tax (CHF/kg)	0	0	0	0.2	0.2
Price separation (CHF/kg)	0	0	0	0	0

Table 2: Price incentives given in the different prepaid policy-experiments.

Insights from the forecasting experiments

The main observed characteristic of a **prepaid tax policy** is that it tends to reinforce the loop **"getting disappointed"** due to mainly two effects: First, due to the countervailing price effect, and second, due to a crowding effect. In the case of a combination with a garbage bag charge that meets a zero profit goal, the adjusted garbage bag charge may be too low to hinder people getting disappointed to separate. The prepaid tax by itself would give no systematic incentive to generate impurity. Combining it with a garbage bag charge may lead to higher impurity, since more people become unwilling to separate correctly.

Combining a prepaid tax policy with a constant garbage bag charge policy is nearly as effective as the inertia policy 2. Furthermore, this policy-package would result in a profit given a constant solid waste generation. The dynamics of the countervailing price effect of the prepaid tax policy with constant garbage bag charge lead to *a trade off between the policy effectiveness and a zero profit budget*. Whereas an effective policy with flexible garbage bag charges tends to lead to a zero profit budget or a deficit, a sub optimal policy with a lower <*fraction separated*> tends to lead to a profit. This trade-off could make a recycling initiative economically questionable for local authorities.

A further important observation is, that an additional increase in the <*effective nr recycling streams*> would overwhelm the citizens resulting in a lower <*fraction separated*> and higher impurity. The hypothesize crowding effect is not as influential at this point since the pool of <*ep* *willing to separate*> is already nearly depleted due to the dominance of the loop **“getting disappointed”.** The crowding effect underlines this trend.

Table 3 compares the results of the policy-experiments. The values of the variables of interest indicate the overall policy performance at the end of the time horizon. The <*fraction separated*> illustrates that a comparable policy outcome could be reached under both the **inertia policy 2** and the policy-package **implement prepaid tax policy with constant garbage bag charge**. However, the variable <*accumulated cost for local waste management*> illustrates that under the prepaid charge policy the cost of the public solid waste management will be lower. All the policies giving price incentives tend to cause some impurity in the recycling streams unless both waste qualities would be priced. The policy-package **implement prepaid tax with constant garbage bag charge** is effective and results in lower cost. This gives evidence that this policy-package could outperform the actual **inertia policy 2 –** if the cost for municipalities becomes a critical factor.

	Fraction separated (%)	People willing to separate (People)	Accumulated fraction impurity (Dmnl)	Accumulated cost for local waste management (CHF)
Back-casting policy-experiment				
Inertia policy 2	54	9200	0.56	51.5M
Forecasting policy-experiment				
Implement prepaid tax without garbage bag charge	26	1436	0.35	38.4M
Implement prepaid tax with flexible garbage bag charge	37	4138	0.69	37.9M
Implement prepaid tax with constant garbage bag charge	54	9084	0.52	37.6M
Implement prepaid tax with constant garbage bag charge and further increase in number recycling streams	52	6956	0.6	38.1M

Table 3: Comparison of system indicators in the back- and forecasting policy-experiments.

Policy-experiments under different scenarios

In the previous section, different policy-packages were tested in various policy-experiments. It is assumed that actors of the system under focus can decide about these policy-levers. In the following section, four policy-experiments will be tested under different scenarios. Different scenarios are determined through changes in the surroundings that are not initiated by local authorities. Contrarily, the conditions in the surroundings will determine certain conditions of the solid waste management system and action possibilities of the local authorities, as well as the effectiveness of local policies. In the model, changes in exogenous parameters will define different scenarios.

The previous policy-experiments have been conducted under a **base scenario** that is characterized by a **constant solid waste generation** per year and **by well-defined unit cost for recycling and incineration**.

The following Figure 5 portrays the scenario leverage points in the simplified model structure, illustrating the effects on the basic loops.

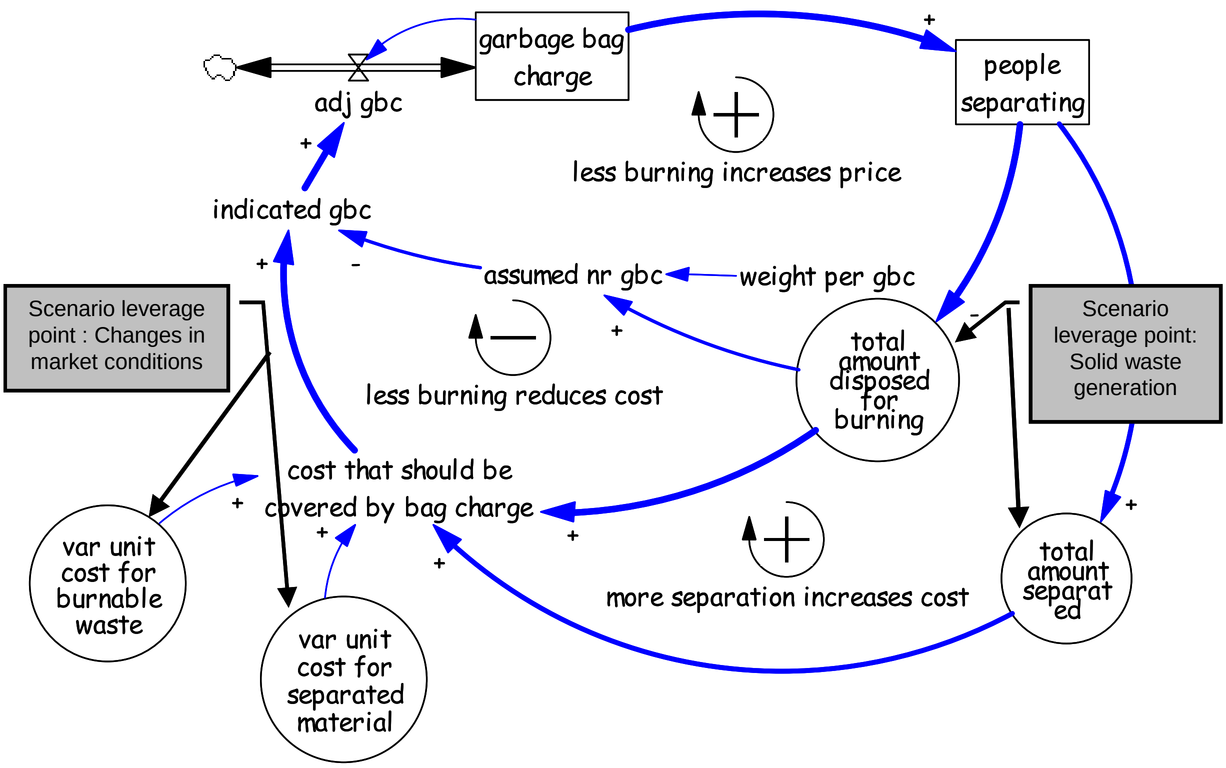


Figure 5: Scenario leverage points influencing main loops.

The scenario leverage point **solid waste generation** reflects both the trend in the overall waste generation and in the <*total amount recyclable material*> (determined by a growing <*effective nr recycling streams*>). The scenario leverage point **changes in market conditions** reflects the effect of market prices in the incineration and recycling industries on the outcome of a local recycling initiative.

THE EXPERIMENT SETTING: In the scenario-experiments two-dimensional changes in the scenario parameters are analyzed, determining either best-case or worst-case conditions. In the model they can be specified in ranges determining for example best-case conditions in the recycling market with lower prices than in the base run or worst-case conditions with higher prices in the recycling market.

The distinction of external conditions in best-case and worst-case scenarios for the recycling initiative constitutes the two dimensions of the further changes in the model assumptions. There are four scenario parameters that can be specified in this way:

- <*incineration cost per unit*>
- <*recycling cost per unit*>
- <*prepaid disposal tax*> (other actors than the local authorities will determine their value)
- <*normal unit cost of one unit of capacity building*> in the collecting points.

For each of these parameters ranges are specified that lead either to a best- or worst-case scenario (see Table 4).

In addition to these two scenario-determined biases, the uncertainty range of policy parameters can bias the conditions for the policy-experiments further. For the best- (worst-) case scenario the parameter ranges are set to the most (least) favorable condition for a recycling initiative. Table 4 lists the parameters and ranges for the best-and worst-case scenarios for a recycling initiative. The current model value is the threshold value for the two cases.

				Best-case scenario (uncertainty range)		Worst-case scenario (uncertainty range)	
	Scenario / Policy-lever	Units	Model value	Minimum value	Maximum value	Minimum value	Maximum value
SP	Incineration cost per unit	CHF/kg	0.23	0.23	0.5	0.1	0.23
SP	Recycling cost per unit	CHF/kg	0.1	0	0.1	0.1	0.5
SP	Prepaid disposal tax 2004	CHF/kg	0.2	0.2	0.5	0.05	0.2
SP	Normal unit cost of one unit of capacity building	CHF/kg	0.14	0.05	0.14	0.14	0.5
PP	Max acceptable separation cost	CHF/(year*person)	150	150	300	50	150
PP	Max acceptable separating time	Hours/week	2	2	3	0.8	2
PP	Max acceptable cost for burning	CHF/(year*person)	180	100	180	180	300
PP	Unit cost for collecting burnable material	CHF/kg	0.1	0.1	0.5	0.05	0.1
PP	Unit cost for collecting separated material	CHF/kg	0.2	0.1	0.2	0.2	0.5
PP	Normal time per stream	Hours/(week*streams)	0.2	0.1	0.2	0.2	0.3

Table 4: Uncertainty ranges for best- and worst-case scenario-experiments (SP = Scenario Parameters; PP = Policy Parameters).

The purpose of this experiment design is to contrast the outcome of different policy-packages under both extreme cases considering the uncertainty in exogenous determined trends and endogenous policy parameters. The experiments are conducted in the sensitivity analysis mode using the multivariate sensitivity test option. Four system indicators measure the outcomes of the experiments:

- the <*fraction separated*>
- the <*garbage bag charge*>, respectively the <*profit solid waste management*>
- The <*accumulated fraction impure material in separated waste*> as an artificial indicator for the policy effectiveness over the time horizon
- The <*accumulated total cost for waste management*> as an artificial indicator for the policy efficiency over the time horizon
-

Table 5 illustrates the design of the eight different scenario-policy-experiments aiming at analyzing the outcome of four policy-packages under either best- or worst-case conditions.

Names of policy-experiments			Best-case scenarios	Worst-case scenarios
Forecasting under different scenarios	Growth waste generation	Further increase in recycling streams after 2004	Uncertainty range biased towards most favourable conditions	Uncertainty range biased towards least favourable conditions
Low price market recycling condition				
Inertia policy 2 best-case scenarios	1	1	1	0
Implement prepaid tax with flexible bag charge best-case scenarios	1	1	1	0
Implement prepaid tax with constant bag charge best-case scenarios	1	1	1	0
Implement price for burning and separated material best-case scenarios	1	1	1	0
High price recycling market condition				
Inertia policy 2 worst-case scenario	1	1	0	1
Implement prepaid tax with flexible bag charge worst-case scenario	1	1	0	1
Implement prepaid tax with constant bag charge worst-case scenario	1	1	0	1
Implement price for burning and separated material worst-case scenario	1	1	0	1

Table 5: The design of the two-dimensional scenario-experiments.

THE EXPERIMENT RESULTS:

Fraction separated under the different scenario-experiments

The confidence bounds in the best-case scenario are in general smaller than those in the worst-case scenario caused by the main characteristic of the model structure, the tipping point and the two borders of attraction (see Charts 5). There exists an upper and a lower limit of <*fraction separated*>: under the best-case-conditions nearly all simulation runs reach equilibrium at the upper limit of the <*fraction separated*>, around 62%. There is a clear dominance in the loop **"getting motivated"**. However under the worst-case conditions in most simulation runs the loop **"getting disappointed"** gets stronger; there is a clear bias in the results towards the lower limit of <*fraction separated*> around 28%. Charts 5 illustrate a typical simulation result in respect to the difference in the confidence bounds for four different policy-packages.

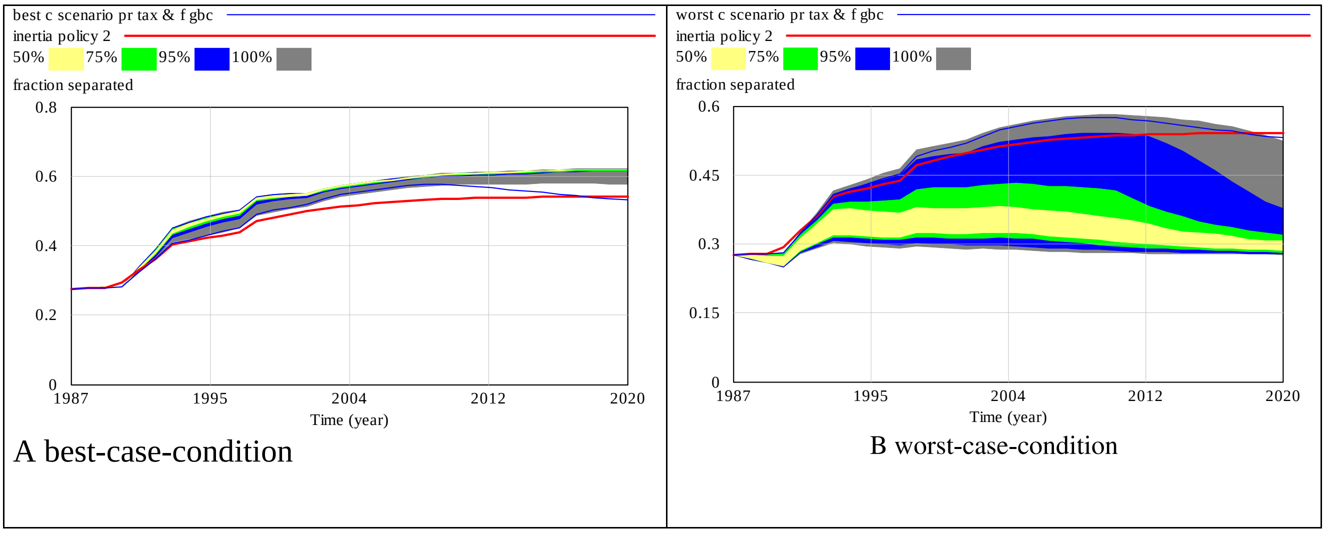


Chart 5: Confidence bounds in the best- und worst-case experiments: Implement prepaid tax with flexible garbage bag charge; <fraction separated>.

Chart 6 depicts the confidence bounds in the simulated <*fraction separated*> at the end of the time horizon. Under a prepaid tax policy regime a smaller confidence bound around the lower border of attraction can be observed in comparison with the **inertia policy** case.

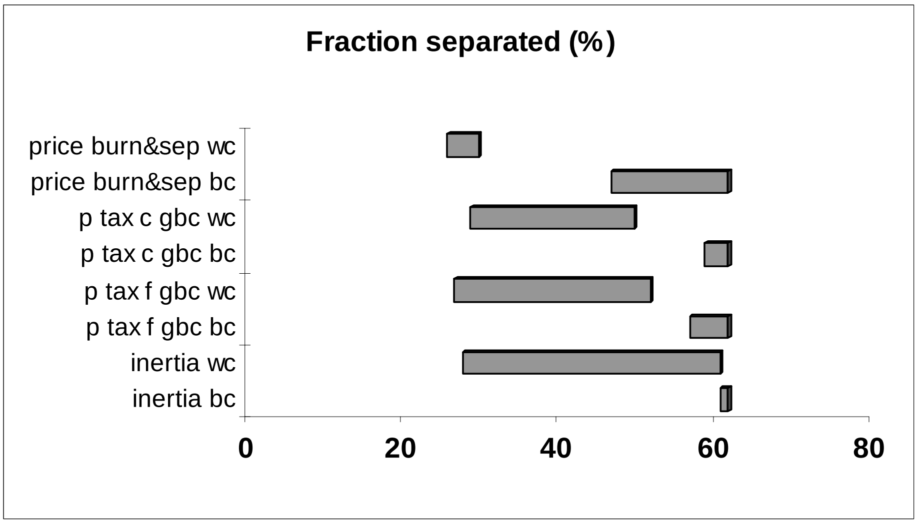


Chart 6: Confidence bounds in the best- and worst-case experiment; <*fraction separated*>.

The wider confidence bounds in the worst-case conditions can be interpreted in the following way. For example, in the **inertia policy** the <*garbage bag charge*> could get high enough to countervail the <*effect of time cost for separating*>. Although the **"getting motivated"** loop will be weakened, the <*garbage bag charge*> would increase enough, weakening the **"getting disappointed"** loop even more. Therefore, the <*fraction separated*> could be high even under worst-case conditions. But probably in such a situation, the <*garbage bag charge*> would be so high that it would not be accepted any more. However, in the prepaid tax regime, under the worst-case conditions, an upper limit may exist that is sub-optimal to the actual possible outcome. Nevertheless, policies changing some conditions may improve the outcome; it means that the system is sensitive.

Garbage bag charge under the different scenario-experiments

The following portrayed simulation results show the confidence bounds of the <*garbage bag charge*> that would ensure a zero <*profit solid waste management*>-budget, with the exception of the policy-experiment-results **implement prepaid tax with constant garbage bag charge.** For this policy-package the development of the budget will be observed. But first, we will focus on the development of the <*garbage bag charge*> in the other policy-experiments.

Chart 7 summarizes the test-results. Under the best-case conditions, the **inertia policy 2** experiments show a clear increase in the <*garbage bag charge*>. However, under worst-case conditions, with a slight decrease in <*garbage bag charge*>. the **"getting disappointed"** loop dominates, and with a strong increase, the **"getting motivated"** loop dominates. Under the best-case conditions for **prepaid tax with flexible garbage bag charge** only a slight increase can be observed. Under the worst-case conditions a sharp decrease towards a price of zero is likely.
The policy-package **implement price for burning and separated material** shows under both condition a likely sharp decrease in the price, concluding in equilibrium on a lower level than the in the base scenario of **inertia policy 2**.

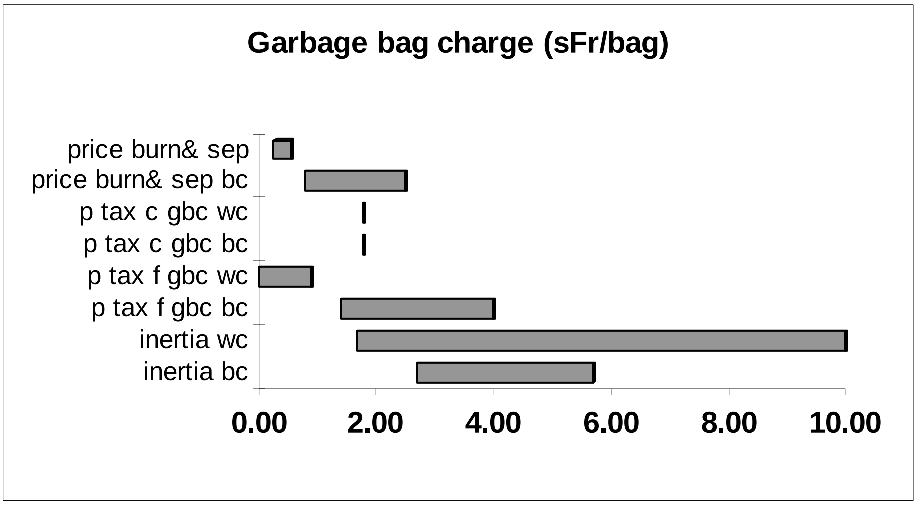


Chart 7: Confidence bounds in the best- and worst-case experiment; <*garbage bag charge*>.

Chart 7 illustrates the confidence bounds of a <*garbage bag charge*> leading to a zero deficit budget (exception in the prepaid tax policy with constant <*garbage bag charge*>). The larger confidence bounds indicate that an 'optimal' <*garbage bag charge*> is sensitive to different uncertainties. However, the chart also illustrates that under a prepaid tax regime the <*garbage bag charge*> would be in a reasonable range whereas in the inertia policy, an unacceptable charge would be indicated.

Chart 8 illustrates the confidence bounds under the policy-package **implement prepaid tax with flexible garbage bag charge**. The (red) line "inertia policy" depicts the <*garbage bag charge*> under the base scenario. Under the best-case conditions the <*garbage bag charge*> tends to be higher contrarely, in the worst-case it will be lower. Probably, in this case we can conclude that the incentives may be too low, resulting in a lower <*fraction separated*>. This development indicates a critical characteristic of the prepaid tax policy and a zero budget deficit-goal. In a worst-case scenario with low incineration cost and high recycling cost an unfavorable price ratio could lead to a failure of the recycling initiative. In this situation a higher <*garbage bag charge*> resulting in a profit would give stronger incentives.

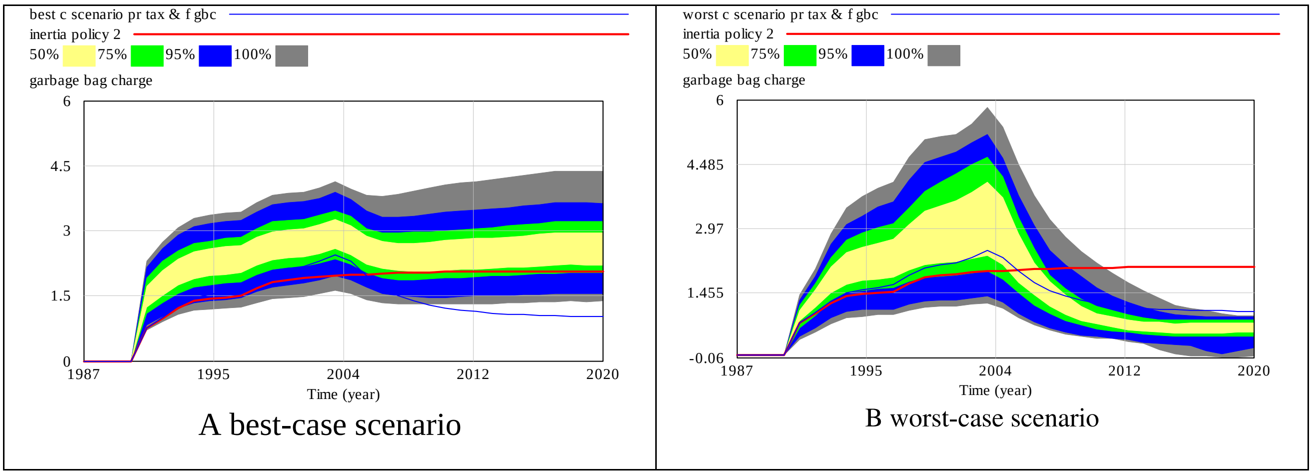


Chart 8: Confidence bounds in the best- and worst-case experiments: implement prepaid tax with flexible garbage bag charge; <garbage bag charge>

The policy-experiment **implement prepaid tax with constant garbage bag charge** gives some insights about the critical path of *<profit solid waste management>* with constant a *<garbage bag charge>*. Chart 9 portrays the development of the *<profit solid waste management>* with a constant *<garbage bag charge>*. Under the best-case scenario the constant *<garbage bag charge>* would lead to a deficit in most cases. This result is in line with the observation made in the previous experiment (see Chart 8 A), indicating the need for a higher charge in order to meet the zero profit goal. However, in the worst-case scenario there would be a profit. This situation could create a paradox for local authorities. On the one hand the best-case condition tends to create a deficit on the other hand the worst-case tends to result in a profit.

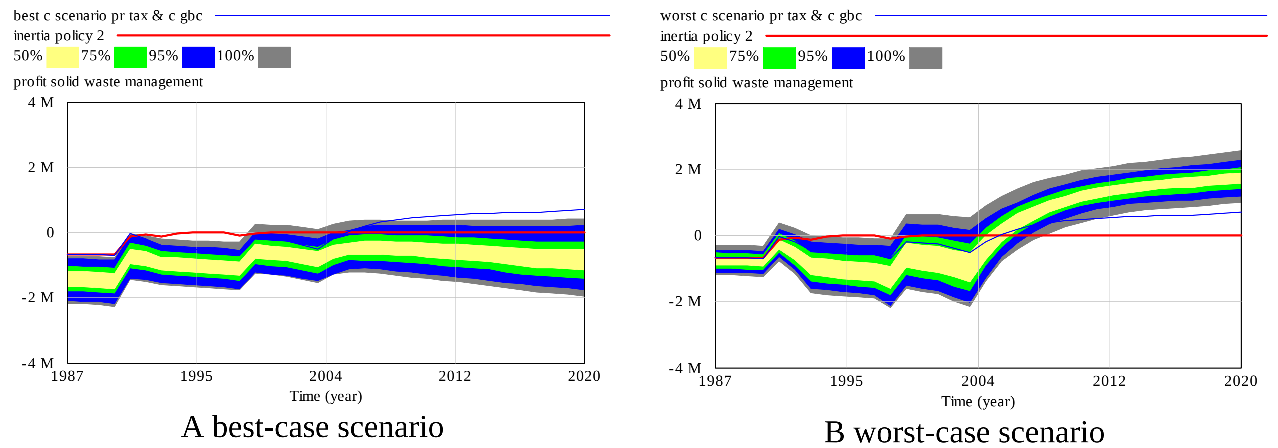


Chart 9: Confidence bounds in the best- and worst-case experiment: implement prepaid tax with constant garbage bag charge; <profit solid waste management>

Accumulated fraction impure material in separated waste under the different scenario-experiments

The performance indicator *<accumulated fraction impure material in separated waste>* computes the overall unintended effect of impurity and is useful for comparing the policy effectiveness of the different experiments. This indicator is a stock with only one inflow; therefore, its value can only grow or reach equilibrium.

Chart 10 illustrate that in the best-case scenarios all policy-packages exhibits low impurity with a narrow confidence bound. However, in the worst-case conditions, there are remarkable differences in the confidence bound range. The policy-package **implement price for burning and separating** has a smaller confidence bound at the lowest level. Contrarily, the **inertia policy** under the worst-case conditions exhibits the widest range including the highest impurity level. Since the impurity is very sensitive to price incentives on burning, the uncertainty in the outcome of the <*accumulated fraction impure material in separated waste*> can be explained by the uncertainty in the <*garbage bag charge*>. Under worst-case condition the **prepaid tax** policy-experiments show slightly smaller confidence bounds.

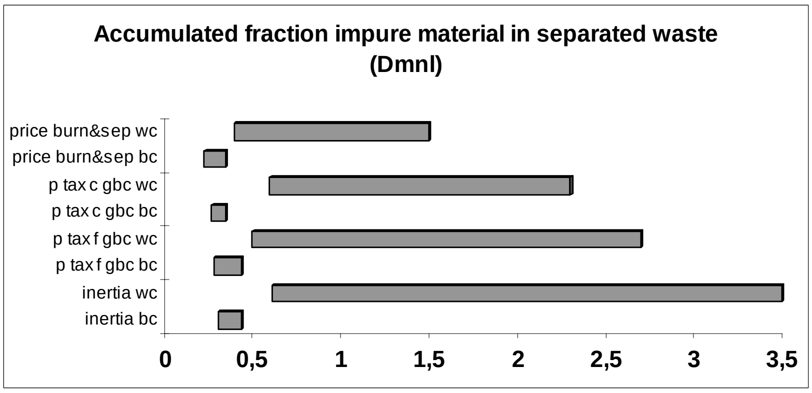


Chart 10: Confidence bounds in the best- and worst-case experiments; <*accumulated fraction impure material in separated waste*>.

The test results can be summarized as follows: Under best-case-conditions the different tested policy-packages are equally effective. However under worst-case conditions there are wider ranges in the confidence bounds, indicating that small changes in the parameters can have a significant effect on the impurity. The policy-packages **implement price for burning and separated material** tends to be more effective in regard to impurity.

Accumulated fraction total cost for waste management under the different scenario-experiments

The indicator <*accumulated fraction total cost for waste management*> has the same characteristics as the <*accumulated fraction impure material in separated waste*>. It can only show an increasing behavior mode.

As a result of outsourcing the task of collecting separated material to the retailers, Chart 11 illustrates, that the policy-packages under the **prepaid tax** regime tends to reduce the cost for the municipal solid waste management. Under the **inertia policy** the costs are highly sensitive to the uncertainty in the parameters. High prices in the recycling market would strongly increase the overall management cost. In this situation the localities would perceive recycling as economically unreasonable.

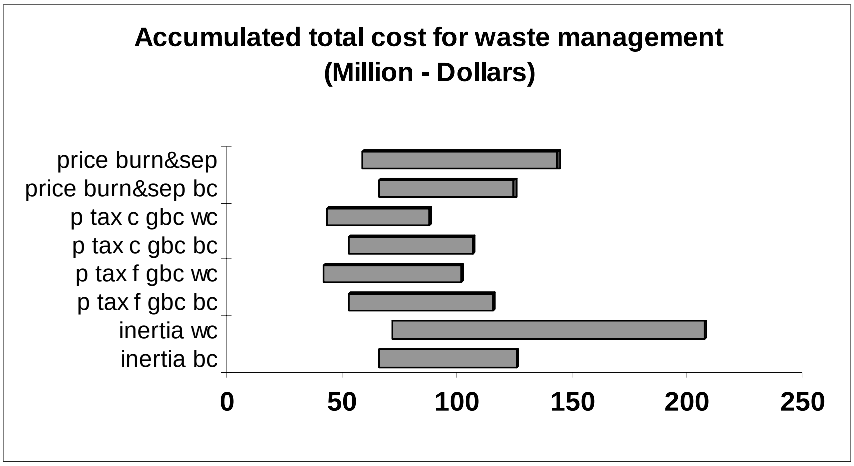


Chart 11: Confidence bounds in the best- and worst-case experiments <*accumulated total cost for waste management*>.

Insights from the policy-experiments under different scenarios

The results of the policy-experiments under different scenario highlight some important differences compared with the base scenario back-casting and forecasting policy-experiments. The growth in <*solid waste generation per capita*> and the further increase in <*effective nr recycling streams*> seem to enforce the dynamics that lead to the two main side effects. Firstly, the impurity starts to grow again after the "first-worse-before-better" pattern observed in the first half of the time horizon. Secondly, the <*garbage bag charge*> steadily increases due to the higher <*total amount separated*>. Both effects boost the <*costs that should be covered by bag charge*> further.
One important insight is that the <*garbage bag charge*> seeks equilibrium only towards the end of the time horizon. This observation implies that authorities would need to adjust the <*garbage bag charge*> further on. This may raise new questions related to social and political acceptance.

However, under the **inertia policy 2** the <*fraction separated*> would seek equilibrium at a slightly higher level (61% compared to 54% in the base scenario). This result is surprising because we could expect that people could get overwhelmed from the separation task induced by the <*increasing nr recycling streams*>. Indeed, the loop **"getting motivated"** will be weakened by this effect. Conversely, the increasing <*garbage bag charge*> will weaken the loop **"getting disappointed".** As long as the former loop is dominating the **"getting disappointed"** loop, the recycling initiative will succeed.

The various scenario-experiments give an idea of the competing forces acting on these two loops and highlight the ranges of possible policy-outcomes.
If the system were biased towards a favorable situation, both a garbage bag regime and a prepaid tax regime would lead to an optimal outcome with high certainty. Given such a situation, the difference between the **inertia policy** and a **prepaid tax regime** in respect to the <*fraction separated*> and the <*accumulated fraction impure material in separated waste*> is small. Both regimes will be nearly equally efficient. The main goal of the prepaid tax regime could be reached, that is to disburden the municipalities from the high cost. However, uncertainty in the system could raise some issues that have to be considered, especially when we have to expect disadvantageous conditions. Worse conditions strengthen those loops that drive the dynamics towards the lower border of attraction, resulting in a failure of the recycling initiative. In all experiments under worst-case conditions we can observe that the <*fraction separated*> converge toward the lower limit. But the large confidence bounds give evidence that little changes in the uncertain parameters may have a significant effect on the outcome.

At this point some main characteristics of the prepaid tax experiments will be addressed. Under the worst-case scenario only a sub optimal outcome could be reached. There are no endogenous dynamics that try to compensate for bad conditions such as low prices for burning or a low willingness to spend time on separating. Contrarily, the prepaid tax decreases the <*cost that should be covered by bag charge*>, resulting in a lower charge and enforcing the loop **"getting disappointed".** A low <*max acceptable separating time*> weakens the loop **"getting motivated".** Therefore, the pool willing people will be depleted even faster.
The dynamics in the budget of solid waste management highlight a further critical point of a prepaid tax regime. The countervailing price effect of a flexible <*garbage bag charge*> was already addressed earlier. The zero budget deficit goal would enforce the effect of an unfavorable price ratio determined by the market conditions in the recycling or the incineration industry, respectively. Lower burning prices result in lower <*garbage bag charge*>. As a consequence, the loop **"getting disappointed"** will be enforced. Furthermore, this would also decrease the overall solid waste management budget, indicating that this policy strategy is economically efficient. **There would be a trade off between an economically efficient strategy and an effective strategy**. Since the local authorities do not feel anymore responsible for an effective outcome of this recycling initiative -

this task will be delegated to the retailer to some degree - they are not urged anymore to improve the situation.

This trade off is accented even more in the case with a too low constant <*garbage bag charge*>. Under a worst-case scenario, the policy **implement prepaid tax with low constant garbage bag charge** would lead to a profit in solid waste management and to a decrease in the <*fraction separated*>. In the case of an increase in the number of recycling streams citizens get overwhelmed, which will shut down the fraction getting motivated. In this case the <*garbage bag charge*> cannot counteract the depletion of the pool <*ep willing to separate*>.

Summary model testing

Testing the model was an integral part of the modeling process, including structure assessment and behavior reproduction tests. In addition the model structure is based on theoretically and empirically well-founded assumptions that generate a plausible behavior and show a good fit to the data. The model passed three extreme conditions tests showing that the model exhibits a robust behavior even under extreme parameter and policy variations. The behavior mode sensitivity of three influential and uncertain parameters were analyzed in both in an univariate and a multivariate mode.
These tests showed that the model tends to exhibit behavior mode sensitivity due to the tipping point. This observation implies that uncertainty in parameters could result in different model output and inconsistent policy implications. However, the range of the uncertainty in the parameter can be confined to those values that would produce the reference mode behavior. Due to the strong bounds of attractions the remaining uncertainty in the parameters exhibits no further model behavior sensitivity leading to robust policy implications.
However, the tipping point in the model is an important insight that has to be taken into account for policy recommendations under different scenarios. It determines the failure or success of a recycling initiative and knowledge about the critical system parameters is decisive.

Discussion and Conclusions

This section addresses the specific observed real world concerns in local solid waste management that were guiding the model conceptualization and discusses the findings in relation to the leading questions.
What local policies increase recycling and help to establish / ensure a solid waste management that fosters competitive recycling markets?

How do you motivate the households to participate in solid waste separation?
How do you recover recyclable material to produce competitive secondary raw material?
How do you finance the recovering and disposal activities of local agents?

For each question, specific policy implications will be discussed in a separate section.
The section begins with an explanation of the observed phenomena and concludes in some subsequent remarks on policy implications stressing the role of monitoring the right parameters and the importance of a profound system understanding.

What caused the problems?

The causal structure of the model and the dynamics explain what caused the observed problems referring to the **recurring deficit**, the **observed impurity** in recycling streams and the **growing costs** of solid waste management. Furthermore, it gives a plausible explanation of the observed development of the **<*fraction separated*>** and about limiting factors of growth and decay. From these insights we can derive some general policy implications.

To begin with, the **recurrent deficit** will be addressed. The main assumption of economic theory underlying a garbage bag policy is that equilibrium exists that would lead to a social optimum and would be in line with a “polluter pays principle”. However, the model shows that reality differs from this theory in two distinct ways. On the one hand, internal dynamics (caused by price incentives and implicit cross-subsidies) would require raising the bag charge continuously. This effect is well explained in the economic literature (e.g. see Weimann 1991:148, or Atkinson and Lewis 1974). On the other hand, changing external conditions such as changes in unit costs or the fraction of recyclable material give evidence that an equilibrium price has to be adjusted to those changes. Delays and limitations in the price adjustment process will result in a deficit. We can conclude that the observed deficit is a logical consequence of the structure of the system and not one of mismanagement of solid waste at the local level.

This is one important insight. But an even more significant implication of the policy experiments relates to the management of dynamically complex systems. The insights from the forecasting-experiments and the policy experiments under different scenarios indicate that having the right management model may be essential to interpret the overall solid waste management-performance.

Secondly, the observed **dynamics in impurity** is a consequence of an initial policy resistance and adjustments delay in personal factors such as <*acceptable time for separating*> and <*acceptable unit cost for burning*>. However, it would alleviate overtime (ceteris paribus). The observed dynamics come from the diffusion process explaining the number of people willing to separate. It results in a “first-worse-before-better” dynamic pattern. However, according to the test results the impurity problem would be mainly solved if the whole population would be willing to separate.

In order to avoid the harmful side effect of policy resistance, policy interventions aiming to build up altruistic norms and intrinsic motivations to separate are suggested. For these interventions, policy instruments such as communication instruments and collaborative agreements influencing personal factors might be effective. They would increase the willingness to invest time in separation behavior. Some empirical experiments presented in the literature demonstrate the range of their effectiveness (i.e. Hopper and Carl-Niesen 1991, Guagnano, Stern et al. 1995).

Thirdly, the **growing cost** is mainly a consequence of a successful recycling initiative but also of impurity and growth in solid waste generation. Policies reducing the impurity problem would slow down the cost growth. The dynamic hypothesis **“trap / chance recycling market”** suggests that offering different recycling streams and motivating people to separate waste is a cost effective approach over the long run. Therefore, local investments in the separation capacities of citizens could be worthwhile.

Finally, the model illustrates that the <*fraction separated*> depends on the number of <*ep willing to separate*> and on the <*effective nr recycling streams*> determining the overall fraction of recyclable material. If there was already a certain <*perceived social norm separating*> in a community, the effect of an increase in the <*effective nr recycling streams*> would increase the amount of separated material. Conversely, in a community with a low <*perceived social norm separating*>, an increase in the <*effective nr recycling streams*> can overwhelm the people, resulting in even less appropriately separated material. The effect of an increase in the <*effective nr recycling streams*> depends not only on the <*perceived social norm separating*>, but also on the overall *willingness to invest time in separation*. The upper limit indicates a maximal capacity to separate. This interpretation of the observed tipping point in the model behavior suggests that in the long run a successful separation-strategy has to be sensitive to the <*effective nr recycling streams*> that are offered. The important information is the *potential capacity of the citizens to separate* but also the *potential capacity to separate in the recycling sector*. The latter will depend on the market development and the former on the <*perceived social norm separating*> and the maximal willingness to invest time in separation activities.

By now the model helped to structure and explain the observed management issues. Having a clear picture of the perceived problems is a first step. Based on this understanding and on the results of the policy-experiments crucial policy implications will be discussed. Furthermore some recommendations will be given addressing the "real world concerns".

How do you motivate the households to participate in solid waste separation?

Some interesting policy implications can be drawn from the model-experiments, which are related to the question *"How do you motivate the households to participate in waste separation?"*
The various policy-experiments give evidence that under best-case conditions all the discussed policy-packages would be successful in motivating the people to separate. However, a good public policy should also be robust under worst-case conditions. Under worst-case conditions, the analyzed policy-packages exhibit different ranges of confidence bounds in the outcome of separation behavior. These indicate both more or less robust policy-outcomes and policy sensitivity to changes in the parameters. The sensitivity analysis demonstrates that the two parameters <*max acceptable separating time*> and <*normal time per stream*> are critical policy parameters influencing the loop **"getting motivated".** They seem to be important leverage points.
Yet, the analyzed policy-packages with garbage bag charges mainly intervened on the loop **"getting disappointed".** Since the <*garbage bag charge*> has a higher elasticity in the inertia policy, this policy-package seems to counteract some worst-case conditions like "***high*** <recycling cost per unit>" or a *"**lower** <max acceptable separating time>"*.

However, the demonstrated countervailing effect of sensitive garbage bag charges will be limited in the real world by acceptance problems and delays in price adjustment processes. Therefore, other policies would be needed to compensate or correct bad conditions in the system. On the one hand public policies should be able to compensate "bad" recycling-market-conditions (exogenously determined conditions) on the other hand they should have the "power" to correct "bad" conditions within the system, particularly a ***low*** <*max acceptable separating time*> or a ***high*** <*normal time per stream*> (partly endogenously determined conditions). The demonstrated limitations and unintended side-effects of the economic instrument, as well as the identified leverage points give evidence that a robust policy should combine policy interventions acting on both loops **"getting motivated"** and **"getting disappointed"**. This insight is especially meaningful for a policy strategy working with prepaid taxes. The policy-experiments showed that one main weakness of this policy is the lack of power to motivate people to participate in separating. The dynamics of countervailing price effects lead to a trade off between the policy efficiency and a zero profit budget goal. Whereas an effective policy tends to lead to a deficit, policy failure tends to lead to a profit. This trade-off could make a recycling initiative economically questionable and lead to wrong decision based on a wrong navigation model.
Different case studies and field experiments based on psychological theories addressed the question how to motivate people to participate in recycling initiative in detail, for example see (Hopper and Carl-Niesen 1991; Dinan 1993; Reno, Cialdini et al. 1993; Guagnano, Stern et al. 1995; Terry, Hogg et al. 1999). They give evidence that communication- and diffusion instruments combined with service and infrastructure instruments are effective.

How do you recover recyclable material in order to recover competitive secondary raw material?

One important lesson learnt is that market prices form the recycling industry and the purity of the separated material are crucial variables in the system. In order to recover secondary raw material,

the present strategy in the real world "offering different recycling streams and investing in citizens' separation behavior" is seen as a cost efficient strategy.
Therefore in the model, the recovery-strategy "offering for every recyclable material a separate recycling stream" was tested in a variety of different policy-experiments. With this local recovery-strategy the recycling industry would get a relative pure material that was already sorted out by the citizens. On the other hand, the recycling industry would charge the localities cheaper prices for processing. However, some factors exist that would limit the effectiveness of this strategy.

Limits to growth in <*fraction separated*>
In this paragraph the observed upper limit of the <*fraction separated*> *will be addressed*. The experiment results illustrate that there exists an aggregated *maximal propensity to separate* - measured with the <*fraction separated*> - that depends on different factors and the state of the system:

- The maximal number of people that could become willing to separate: In the model it is assumed that there exists a small fraction in the population that would show policy resistance under each situation.
- The separation habits of willing people: How much can willing people effectively separate?
- The inherent fraction recyclable material in waste: How much material could be recovered theoretically, given the existing recycling technologies and the composition of "waste"? In the model, the <*effective nr recycling streams*> determines this fraction.

Knowing that the observed propensity to separate is a highly aggregated indicator including different factors is important for public-policy-making.
Firstly, any changes in the mentioned factors will also change the maximal propensity to separate. Secondly, a lower observed propensity could be caused by any of those factors. Thirdly, having a better understanding of factors determining the propensity to separate helps to assess the *compliance gap*. The difference between the <*total amount recyclable material*> and <*total amount appropriately separated*> is called compliance gap. The experiments showed that there would always be a compliance gap due to the maximal propensity to separate.

Distinguishing these two measures helps to assess the effectiveness of a local policy initiative. The reference value would be the maximal propensity since the <*actual recyclable material per person*> would be a theoretical value that does not take into account the limits of people to separate. We can conclude, firstly, that policies aiming to improve the propensity to separate would minimize the compliance gap but, secondly, policy makers have also to be aware of how far they can push it, since the three identified factors (number of people willing to separate, separation habits, and the inertia fraction recyclable material in waste) will limit the maximal propensity to separate.

In addition, the different policy-experiments illustrate that the effectiveness of the recovery-strategy "offering for every recyclable material a separate recycling stream" will also be limited by two main factors; firstly, by the <*acceptable time for separating*> and, secondly, by decreasing marginal return of an additional recycling stream, represented in the <*multiplier for recyclable material from effective nr recycling streams*>. Once the maximal effectiveness of the recovery-strategy will be reached, another strategy has to be used in order to push the effectiveness of the recycling initiative further. One possible way could be to design additional streams in such a way that compound material could be easily recovered. Such a strategy must be both aligned with the development in the recycling industry and convenient for the citizens.
An **advanced warning indicator** signifying that the limit will be reached would be a decrease in compliance. This measurement would compare the marginal growth in recyclable material per stream and the marginal growth in the propensity to separate. If the increase of an additional

recycling stream increases the compliance gap means that some people will be overwhelmed by this additional task. Over time overwhelmed people would enforce the loop **“getting disappointed”**.

Seeking the upper border of attraction

Until now we have discussed in detail factors that limit the propensity to separate by tracing the dynamics of the policy-experiments back to the model structure. As discussed above, the first important intervention strategy would be to apply motivational and diffusion techniques that are based on psychological and socio-psychological theories. Those techniques aim at gaining more citizens to participate in the recycling program, resulting in an improved separation outcome. However, the theory in the model suggests that separation behavior is seen as a routine behavior that is based on established habits, or everybody’s automatic behavior-patterns. Therefore, the intervention strategy applicable in this case would be to improve separation habits. As the former intervention strategy aims at motivating people, the latter intervention would aim at breaking frozen disposal-behavior (Lewin 1958) and to initiate the development and establishment of more adequate habits. For example Dahlstrand and Biel (1997) emphasize the need of service and infrastructure instruments, as well as communication instruments.

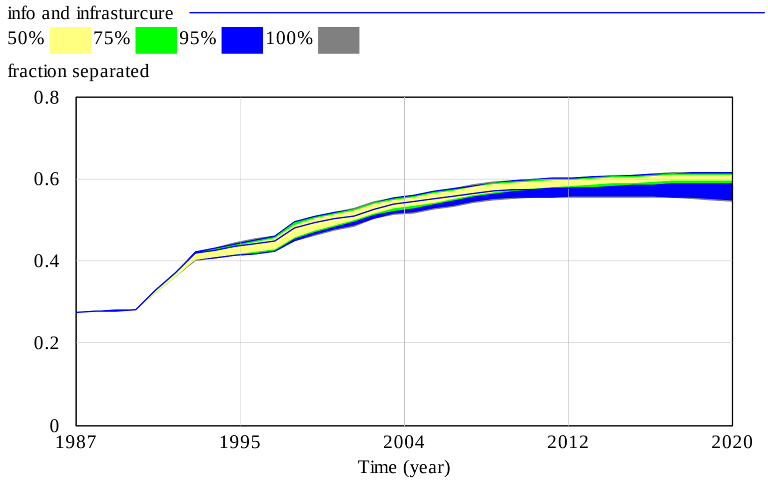
These theoretical considerations and the test results of the scenario-experiments suggest that in order to design a robust recycling strategy, additional policy instruments such as “communication and diffusion instruments” and “service and infrastructure instruments” should be used. Especially for the case of a prepaid tax policy those additional policy instruments would compensate its drawback.

In the SD-SWM-model these interventions would act on the leverage points <*normal time per stream*> and <*max acceptable separating time*>. In order to test the effectiveness of the proposed policy intervention with the help of the model, an additional policy-experiment will be designed. It is reported in this chapter, because this additional policy-experiment should help test the derived implications. Furthermore it illustrates, how the model can be used in the application context in order to assess arguments about policy robustness and to test hypotheses – thus helping master complex dynamic issues and to strengthen those arguments with explicit models (see also Schwaninger 2003a).

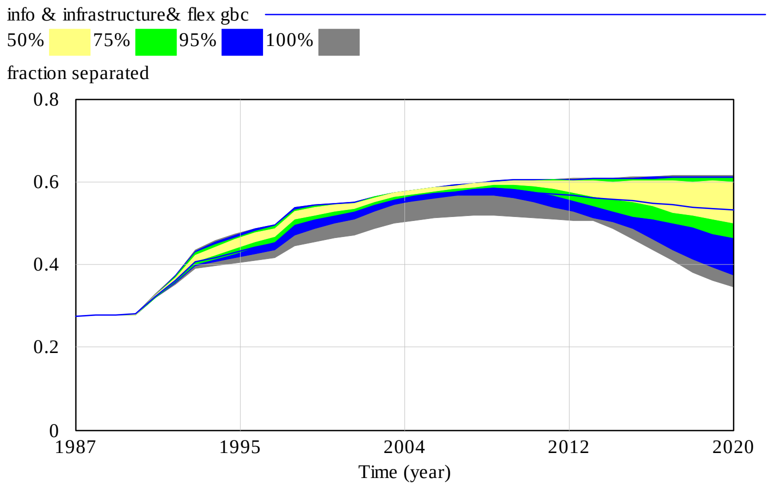
For the policy-experiment **complement prepaid tax with communication, service and infrastructure instruments** the same setting was mainly applied as in the worst-case scenario-experiment **implement prepaid tax with *constant* garbage bag charge** and implement **prepaid tax with *flexible* garbage bag charge**. However, for the parameters <*max acceptable separating time*> and <*normal time per stream*> the settings for the best-case scenario were chosen.

The outcome of this policy-test is depicted in Chart 12 A-B. In the experiment with a *constant* garbage bag charge, the test result shows a very robust policy outcome (A). The <*fraction separated*> would seek equilibrium at the maximal propensity to separate nearly for all parameter combinations. This indicates that additional policy interventions at the local level could turn the prepaid tax system in a robust strategy. In the experiment with a *flexible* garbage bag charge (B) the policy outcome is less robust. This suggests that more elaborate policy interventions are necessary causing stronger parameter changes in the desired direction. However, both test results illustrate that the suggested policy intervention creates a more robust outcome under a prepaid tax regime.

Based on these test results and theoretical reflections the following concrete measures are seen as important: offering information and opportunities to separate in different contexts such as public places and working places. Those would demonstrate separation behavior and would illustrate how citizens could organize their household in order to facilitate their separation behavior resulting in new habits. A second interesting observation derived from the model structure is that public policy tools that aim at improving separation habits would also reinforce the loop "getting motivated". This postulated hypothesis is in line with Hopper and Carl-Niesen (1991) statement: " It is possible that block leaders influenced behavior directly through a process of behavior modeling and imitation, suggesting the continued but expanded use. ... Indeed, it is also possible that behavioral change, shaped by modeling and imitation, preceded and then facilitated changes in recycling attitudes"(217). It would offer a promising opportunity for further empirical policy research based on psychological theories.



(A)



(B)

Chart 12 A-B: Testing leverage point <max acceptable separating time> and <normal time per stream>.

How do you finance the recovering and disposal activities?

In the previous paragraphs the importance of well-designed policies for a successful recycling initiative were discussed. Now some economic consideration will be addressed. In the policy-experiments three different unit-pricing-systems were tested that should help both to cover the cost and to promote separation behavior: **a garbage bag charge policy**, **a prepaid tax for recyclable material with a garbage bag charge** and thirdly **unit prices** for both waste qualities. The economic theory tells us that those approaches would support a social optimum under well-defined steady state conditions. However, the experiments demonstrated that in reality, internal dynamics – caused by adjustment delays, nonlinear acceptance variables or exogenous changes - raises more questions than only transaction cost and implementation issues. The System Dynamics model gives an idea about the price- and cost-dynamics in the transition phase. A successful recycling initiative with garbage bag charges tends to generate a deficit due to the discussed internal dynamics. In the inertia policy and the prepaid tax experiments, "profit" is not a reliable indicator for the success of a recycling initiative. However, the scenario-experiments show that a **prepaid tax policy with a garbage bag charge** tends to decrease the cost of the municipal solid waste management budget. A further advantage of this policy is, that the <*garbage bag charge*> would stay within an acceptable

range. The main difficulty would be to determine both the “right” value of the prepaid tax and of the garbage bag charge. The simulation runs suggest keeping the garbage bag charge at the “inertia policy” level or to increase it slightly. Additional investments in communication, and service and infrastructure policies could either be covered by a surplus of the garbage bag charge revenue or a general “waste management tax”, since the cost of those policies do not depend on any quantities of the different waste qualities.
Alternatively, unit pricing for separated and burning material could be considered as an efficient financing system. However, the simulation run indicates that as long as the prices for separated material would be higher than for burning, the price incentives would counteract the overarching goal to promote waste-separation behavior. In addition, setting the right price for each recycling stream and collecting the money would raise further issues, such as efficient administration and implementation. The implementation cost of such a policy could be prohibitive.

Concluding remarks on policy implications

The various interactions between policy effectiveness and economic efficiency turns solid waste management into a complex task for local actors. Finding the right prices that cover the costs and give the right incentives is particularly difficult due to countervailing price effects on waste-separation behavior. Not only the budget goal has to be controlled but also the policy outcome. Under a prepaid tax regime this task is getting even more challenging since more actors with different goals will be involved. Therefore, the challenge of solid waste management is not only to find the right policies but also to find the right information that guides a solid waste management system fostering competitive recycling markets. This raises the question: “Who will collect the required data and coordinate the information flow between the different stakeholders?”

The SD-SWM-model gives evidence that knowledge about the following system parameters and variables is important:

- How much time have citizens to invest in order to fulfill the waste separation task?
- How much time are citizens willing to invest into separation behaviors?
- What is the maximal propensity to separate that can be reached under the given situation?
- What is the minimal compliance gap?
- How profitable is the recycling industry? Where could further investments be made in sorting capacities?
- What is the ratio of unit cost of material that is put for burning and recycling?
- What is the ratio of unit cost of secondary raw material and virgin resources?

Local authorities have to be aware that the task they are dealing with is more than only to manage the waste but also to induce behavior change in the overall system. This is a crucial endeavor that calls for a profound understanding of the dynamics in the system and for cooperation between the different stakeholders. However, the policy-experiments give evidence that local authorities can make a difference even under worst-case situations but only to a certain limit. Furthermore having the right monitoring and controlling system may be crucial.
For scholars this suggests that developing such a sophisticated solid waste navigation model that helps both to assess the actual state of a development or “diffusion” process, as well as to account for the performance on different levels of managements (operative, strategical as well as normative) would represents a significant opportunity to improve management and policy practice.

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