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A SD-choice structure for policy compliance: micro behavior explaining aggregated recycling dynamics

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This paper presents a System Dynamics Solid Waste Management model that is based in a feedback perspective on human behavior and public policy (Ulli-Beer 2003). A SD-choice structure is suggested that both highlights the interactions of personal and contextual factors and is suited to explain and forecast the impact and outcome of recycling initiatives and strategies at the local level as well as to explore different scenarios (Ulli-Beer, Andersen et al. 2004). The model structure indicates crucial dynamic interactions between flexible preferences and contextual factors. Furthermore policy sensitivity of personal factors could be identified that explain 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.

Key words: System dynamics choice structure, computer simulation model, choice and preferences, environmentally relevant behavior, policy compliance, recycling initiatives, solid waste management

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Introduction

In the current throw-away-society the challenge of recovering valuable resources and protecting the natural environment is becoming more and more an urgent task for decision makers at the national, regional as well as the local level. Although many industrial societies have a well-organized management of solid waste, growing waste mountains and disposal costs are signs of inappropriate production methods and behavior[2]. One way to alleviate this development is seen in fostering recycling efforts. Thus it is important to understand driving forces that will render recycling initiatives successful in the light of sustainability.

This study integrates knowledge and data from different disciplines and perspectives in order to understand the multidimensional factors and processes leading to observed recycling dynamics. Aggregated human behavior effects on the recovery of natural resources from a macro-perspective are combined with individual behavior theories from a micro-perspective. Understanding both levels may yield significant clarification of environmental problems and provide a more complete basis for policy analysis and design, which is in line with Vlek's (2000) observations.

Thus the focus of interest is not mainly on the micro-process as the end but "lies instead in the act of synthesis, in beginning to show how the micro processes combine to constitute a functioning system" as was suggested by Coleman (1965:91) 40 years ago and is aimed at by Forrester (2003) referring to the SD economic model: „In the system dynamics model that we are discussing, the micro-structure creates macro-behavior".

In sum, this paper describes a SD-choice structure for policy compliance that is suited to address aggregated recycling dynamics.

The investigation was guided by a general dynamic hypothesis suggesting that there exist important dynamics interaction between citizens' choice and preferences as well as public policies affecting the public management processe. This general research focus was applied to the specific problem addressing separation behavior in a typical Swiss locality[3] (Ulli-Beer 2003). In the specific case, separation behavior of citizens and policies influencing the context in which choices are made, are analyzed and modeled in order to gain a better understanding of local solid waste management problems that are also globally relevant (Duggan 2002), (OECD 2000; Ludwig, Hellweg et al. 2003). The case study is thought to be relevant for nearly every local solid waste management system concerned with recovering valuable resources. Furthermore, separation behavior and solid waste management belongs to a specific class of behavior, environmentally significant behavior (Stern 2000). It includes both the kind of behavior that directly or proximally causes environmental change (e.g. separation behavior of citizens) and the kind of behavior that shape the context in which choices are made (e.g. local policies influencing the quality of services and their prices; both having indirectly a crucial impact on the environment by determining the preconditions for citizens' separation behavior).

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[2] http://www.umwelt-schweiz.ch/buwal/eng/medien/umweltbericht/druck/index.html (Swiss Agency for the Environment, Forest and Landscape)

[3] The municipality Ittigen was chosen since it is recognized as taking innovative approaches in their environmental policies. It is located in the agglomeration of Berne (Switzerland) with about 11'000 inhabitants (www.ittigen.ch).

The modeling effort draws upon a broad research program, the Swiss Priority Program "Environment" (SPPE[4]) launched by the Swiss National Science Foundation. Furthermore, the model structure refers to psychological and economical concepts such as planned behavior, decision-making, preferences, incentives, social norms, routine and habits as well as compliance (Ulli-Beer 2004:22-71).

The SD-choice structure described in this paper is relevant for enhancing the understanding of relationships between personal factors (for example preferences) and contextual factors (such as price incentives) influencing policy compliance. Basically two sorts of preconditions for environmentally responsible behavior can be distinguished: contextual preconditions and personal preconditions. **Contextual preconditions** include interpersonal forces, distinctive features of substitutes, existence of different action alternatives and technologies, and design, as well as infrastructures, monetary incentives and costs (including time costs) as well as legal regulations. **Personal preconditions** include forces influencing values, beliefs, attitudes, goals, self-identity, knowledge and skill, as well as general capabilities such as literacy (Foppa and Frey 1985; Foppa 1989; Foppa and Frey 1990; Jaeggi, Tanner et al. 1996; Stern 1999; Stern, Dietz et al. 1999; Tanner 1999; Vatter 2001a; Bruppacher and Ulli-Beer 2001b).

The contextual preconditions are influenced by situational, restrictive variables and the personal preconditions are influenced by cognitive, evaluative variables. Both variable complexes influence intention-related variables guiding actions. "Preconditions for environmentally responsible behavior" seems to be a relative concept, being evaluated subjectively: in other words there may be a trade-off between the impact of constraints on behavior and environmental concerns or social norms. Higher environmental concerns depreciate the perception of constraints and obstacles, where as lower concerns tend to reinforce action constraints. Furthermore, high environmental concerns seem to increase the effort and the willingness to spend time and costs on environmentally sound behavior. Similarly, social support seems to increase the effort and the willingness to spend more time and costs on environmentally sound behavior in order to overcome hurdles. However, often habits dominate observed behavior patterns of people and deactivate deliberation processes. Unfreezing such habits may be a tedious and time-consuming process.

Similarly, to economic concept of willingness to pay, citizens' preferences are operationalized with 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 an utility function that will be maximized, but rather by simple deliberation processes comparing acceptable costs and real costs in separating and 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.

[4] http://www.snf.ch/SPP_Umwelt/overview.html

By focusing on interactions between various variables drawing on different disciplines in order to explain environmentally relevant behavior, this computer assisted theory development approach tries to exploit some of the research opportunities on human-environmental interactions identified by Stern (2000). The understanding of those interactions and processes are important for the design of effective policies not only in the realm of solid waste management (Vlek 2000). Indeed, the specific SD-SWM-model can be generalized for many recycling initiatives all over the world. It may serve as a decision support system that help both enhancing discussions about solid waste management strategies among different stakeholders and finding effective policy-packages that aim at increasing the quality and quantity of separated waste. In sum, it informs environmental policy formation and decision-making by offering a SD-model that helps to structure policy decision problems, that Vlek (2000) also identified as an important future research line.

Methods

An integrative systems methodology (Schwaninger 1997; Weber and Schwaninger 2002) was chosen that is especially suitable for investigating complex issues drawing on concepts of System Dynamics and Cybernetics. A two-step research strategy was pursued. First, an overall analysis of environmentally relevant behavior was undertaken in the preliminary study and second, an in-depth analysis of the specific case was pursued in the main study. The following chart (Figure 1) highlights the two research blocks of this study and gives an overview of the applied research methods.

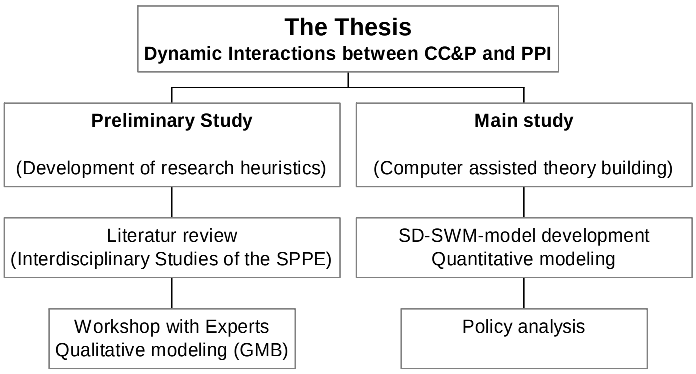


Figure 1: Structure and methods of the study (CC&P and PPI: Citizens Choice and Preferences and Public Policy Initiatives) (Ulli-Beer 2004).

The purpose of the preliminary study was to explore and to shape the field of investigation. Relevant concepts were identified and frameworks were developed 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 addressed (see Figure 2). 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 could be used for policy analysis addressing "What-if"-question (Zagonel, Rohrbaugh et al. 2004 forthcoming) about solid waste management policies (Ulli-Beer, Andersen and Richardson 2004).

The paper is organized in four sections: First, the theoretical and political background as well as the chosen research approach was briefly sketched in the introduction and method part. Second, the model is described comprehensively beginning with a short overview of the model conceptualization advancing to a full description of the model structure and closing with a presentation of the model behavior including a base run description as well as a summary of the model tests results One sensitivity test is highlighted in order to illustrate policy sensitivity of the personal factor *willingness to invest time in waste separation behavior* in the main section. Third, an outlook on using the model as a policy-laboratory is given describing two different streams of policy-experiments and summarizing the main insights of those policy-tests. Finally, the essay concludes with a reflection on how the modeling approach was adequate for addressing the research interest in interaction between personal and contextual factors explaining policy compliance and observed recycling dynamics.

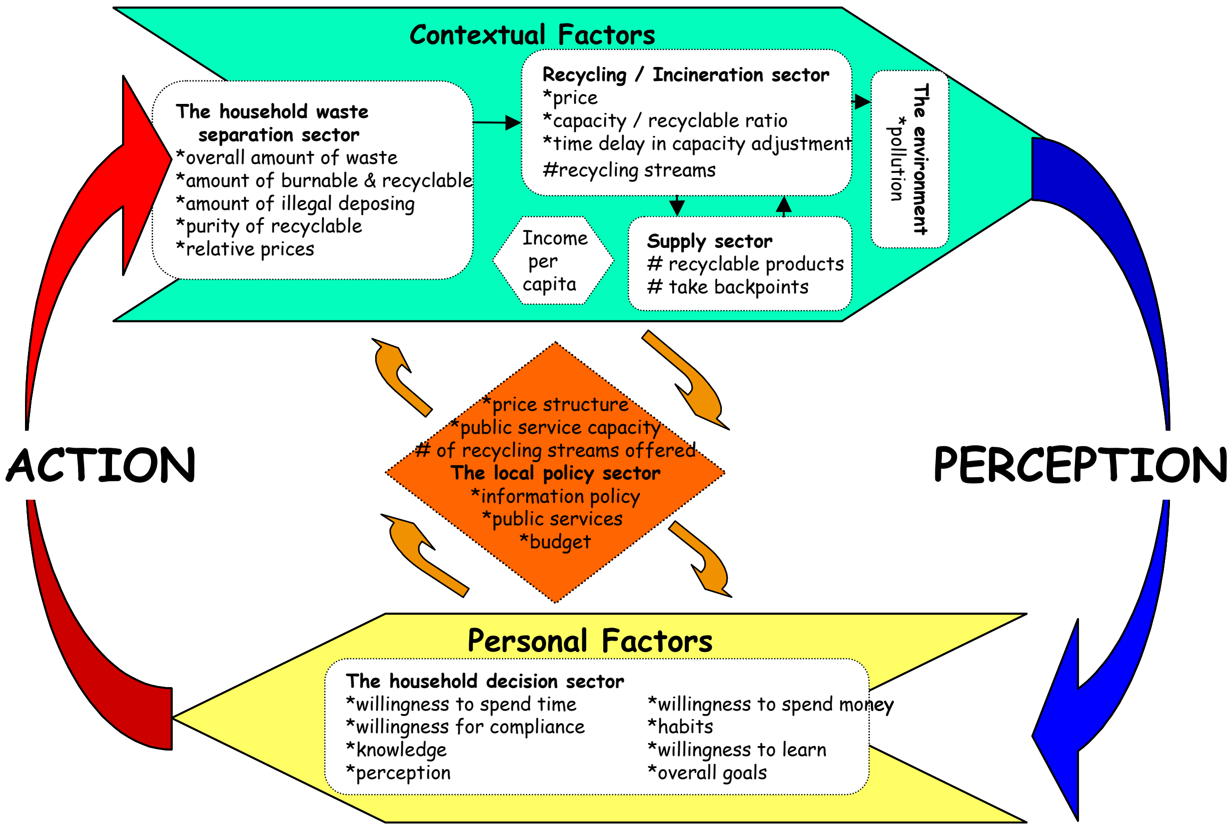


Figure 2: A feedback perspective on citizens' waste separation behavior and solid waste management.

Model conceptualization

In the following paragraph a brief overview of the model conceptualization and the dynamic hypothesis will be given. Both are well documented in Ulli-Beer (2003).

The problem guiding the model conceptualization and drawing the boundary is represented 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?*

For the case study the reference mode has been defined by the historical dynamics of the budget of solid waste management showing a recurrent deficit as well as the development of the fraction separated waste and of the number of recycling streams. Subsequently, the question "What caused the given development?" (Randers 1996) was addressed in the modeling process.

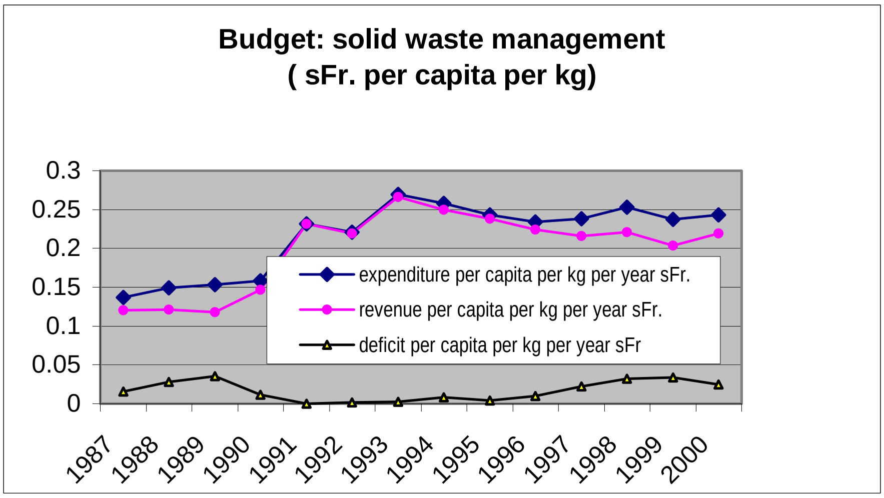


Chart 1: Municipal budget development for solid waste management in sFr. per capita, per kg, per year ((Ittigen 1985-2001). There is an upward trend in the unit cost that peaks in 1994 followed by a slight drop, and then it seems to reach a plateau. However the revenue continues to fall. There are two periods with a higher deficit (1987 – 1992) and (1996-2001). As the deficit has grown, the local authorities increased the tax for solid waste management and the volume related garbage bag charges.

In short, the postulated dynamic hypothesis can be described as follows.
Since the performance of citizens' separation behavior was low, the local authorities 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.
For a comprehensive illustration of the postulated causal loops explaining this development see (Ulli-Beer 2003).

The model structure

Before entering in the discussion of the detailed model structure a brief overview of the model is given. It gives the big picture justifying the chosen aggregation level and shows the different model parts and their relationships as well as basic feedback loops.

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. The overall model structure is described below and sketched in the Sector Diagram (see Figure 3):

The main sector is the local separation sector that is disaggregated in the following modules: the household waste separation module, the household decision module and the local policy module. These modules include endogenously operating dynamics deemed important to address the solid waste management problems and to conduct policy analysis.

The household waste separation module includes:

- The different flows and qualities of the burnable and recyclable waste that result from separation activities of different groups of citizens.
- The initial amounts of different waste qualities, and recyclable and burnable material will be given exogenously but will be modified by behavioral effects.
- The habits of different groups of people to dispose their waste and factors that lead to changes in habits (e.g. changes in relative prices and the number of recycling streams).

The household decision module will describe:

- What factors influence the decision of people to become willing / unwilling to separate the recyclable material?
- What influences the willingness to spend time or money on waste separation activities?

The local policy sector / solid waste management module includes:

- The development of the garbage bag charge and the municipal budget for solid waste management under different policy options.
- Capacity building processes and the effect of a backlog of separated waste.

The income per capita and the population are given exogenously.

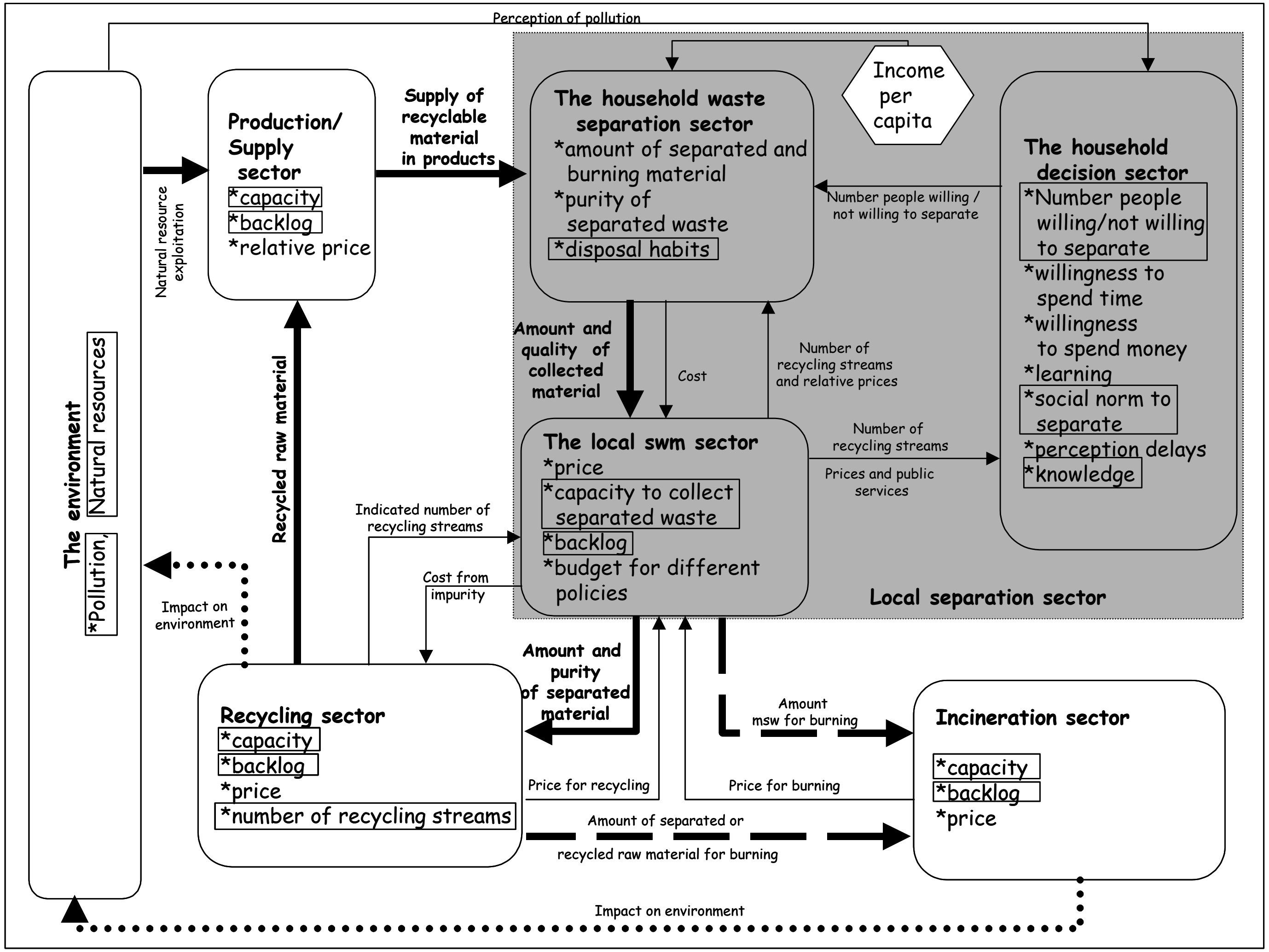


Figure 3: Sector Diagram of the extended SD-SWM-model

The modules of the model

This section describes the core model parts in depth. The concept of propensity – the propensity of citizens to separate – is crucial for the success of recycling programs. Therefore it will be modeled explicitly. A special weight is put on the formulation of the decision process guiding citizens' behavior to separate.

In the feedback perspective on human behavior and public policy (Kaufmann-Hayoz, Bättig et al. 2001d), contextual and personal factors in a decision making process are emphasized. Therefore in the SD-SWM-model, interactions between those are modeled explicitly. Elements of the personal structure are represented in the household decision and the household separation sector.

Designing propensity to separate: The household decision module

Theoretical and empirical evidence suggest that citizens' disposal behavior may be described partly as routine behavior and partly as planned behavior (Piorkowsky 1988; Scitovsky 1989; Dietz and Stern 1995; Dahlstrand and Biel 1997; Gorr 1997; Taylor and Todd 1997, Ajzen 1991). In Forrester's terminology this would be called an informal policy (Forrester 1994:58). These assumptions suggests that people decide once whether to separate or not. Once they have made this decision, they set a new routine, resulting in new separation habits. This implies that there are two main groups of citizens: a group of people willing to separate and a group of people not willing to separate. However, in each population we can distinguish sub groups that are transients (see Figure 4):

- In the group of people willing to separate there are some inexperienced people – they will show a lower separation performance than the experienced ones. But as they learn to separate they will move into the stock <*ep willing to separate*>. The <*time to learn*> determines how long this takes. In the model the <*time to learn*> is represented by the variable <*time on moving from iep to ep*>. It is a function of the <*average amount appropriately separated by nwiep*> and the <*normal amount appropriately separated wep*>[5].

In the group "people not willing to separate" there are experienced people that got disappointed from separation consequences. The <*experienced people not willing to separate*> will move into the stock <*ep not willing to separate*> as they will forget, they are changing their separation behavior and set up a simpler routine behavior. The <*average time to forget*> calculates when these people will move on.

[5] Acronyms: ep – experienced people; iep – inexperienced people, wep – willing experienced people, nwiep - not willing inexperienced people

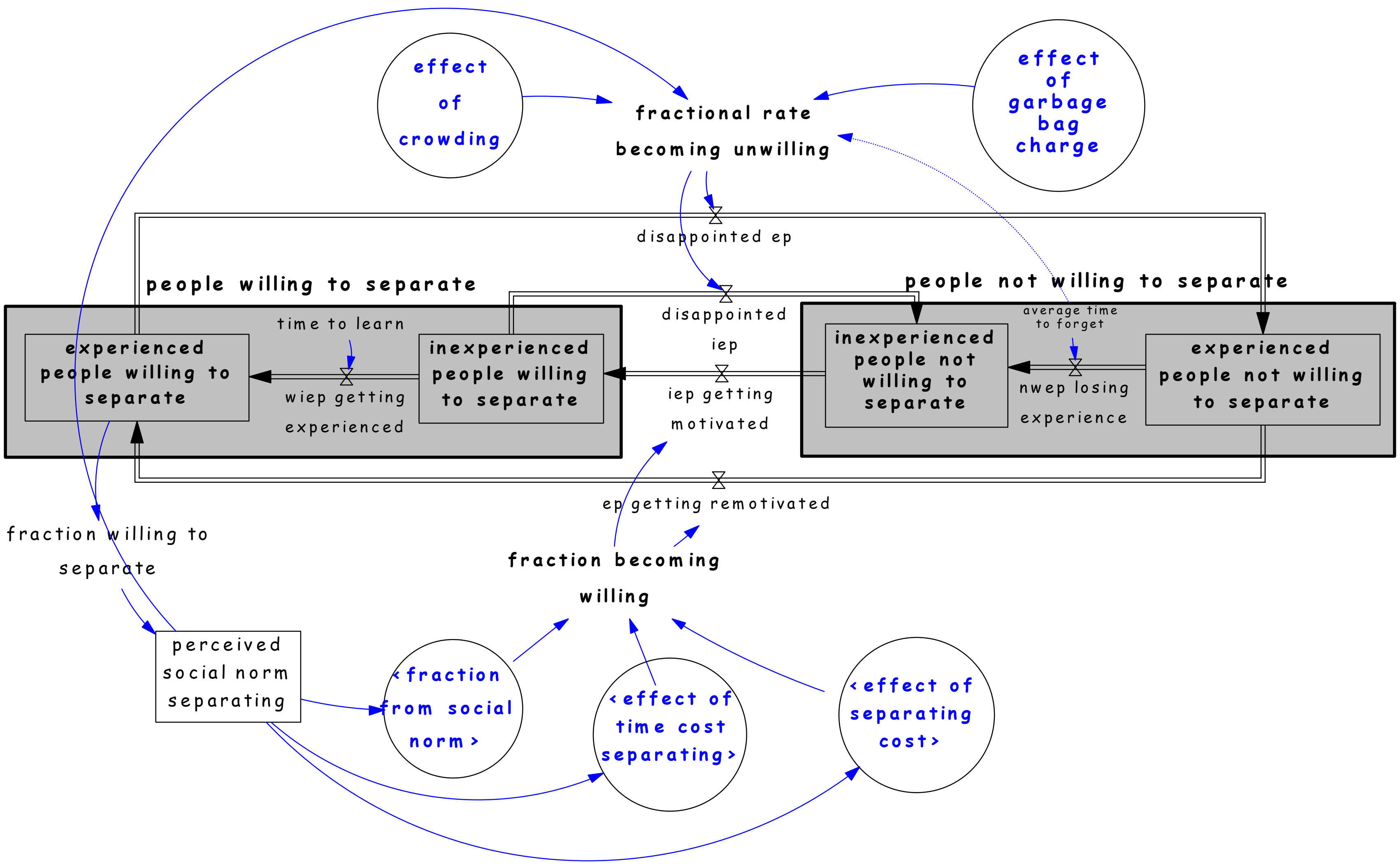


Figure 4: Changes in citizen's willingness to separate (ep: experienced people, iep: inexperienced people, wiep: willing inexperienced people, nwep: not willing experienced.

Decision rules
The decision to separate is influenced by the <*perceived social norm separating*>, the <*acceptable time for separating*>, and <*acceptable separating cost per year*>. The decision to become unwilling is influenced by alternative cost such as <*acceptable time burning*> and <*acceptable unit cost for burning*> and <*perceived social norm burning*>. The information about the decision cues (e.g. "time cost", "real cost", later on the "perceived policy effectiveness") are partly given exogenously.

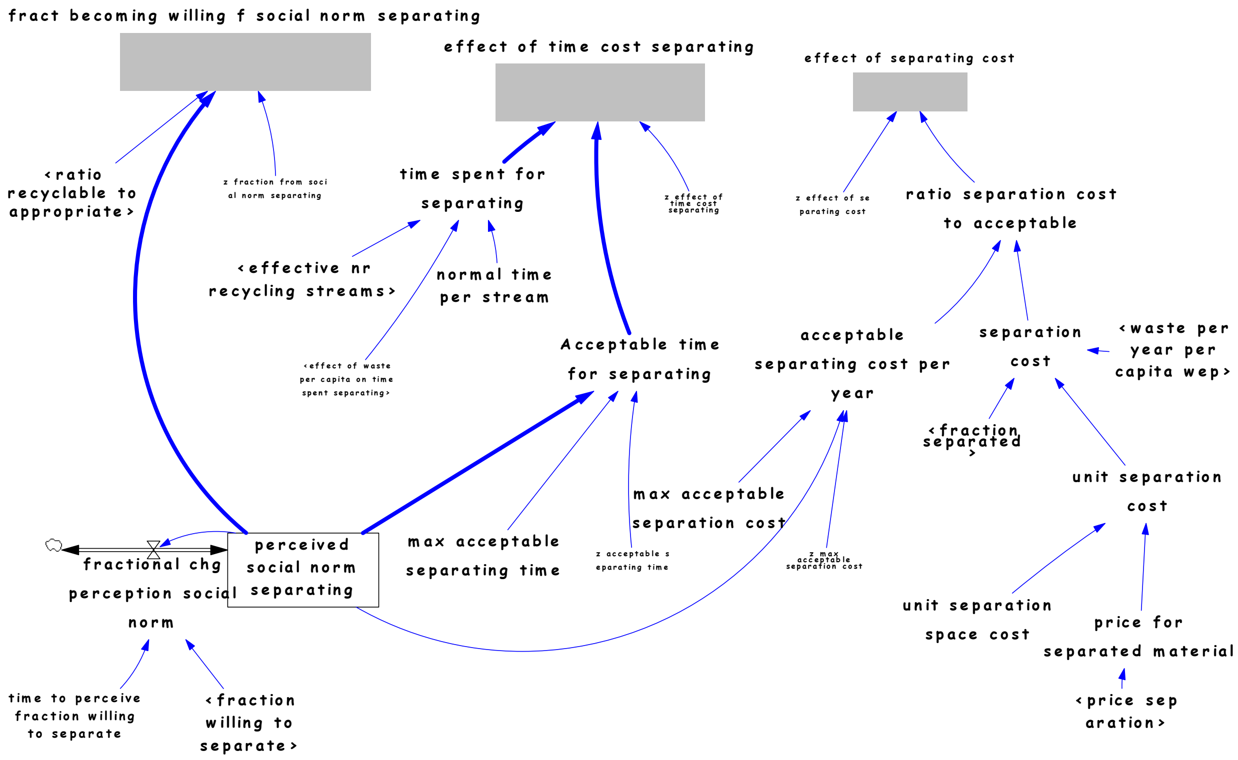


Figure 5: Interactions between contextual and personal factors

The <*fraction becoming unwilling*> is formulated in a similar way as the <*fraction becoming willing*>, but the effect of opportunity cost <*effect of time cost burning*> and <*effect of burning cost*>, as well as the <*fract becoming unwilling from social norm burning*> will determine the rate. The rates are determined by a multiplicative formulation, since any extreme value in each of them can dominate the other effects as well as one effect can also reinforce another. The concrete formulation for the <*fraction becoming willing*> is:
<*Fraction becoming willing*> = <*fract becoming willing f social norm separating*> * <*effect of time cost separating*> * <*effect of separating cost*>

In addition, it is assumed that the two stocks <*ep willing to separate*> and <*iep not willing to separate*> will never get to zero. There will always be a fraction that will not change its behavior. This design would represent people with strong beliefs, people that just do not see any reason for separating, or that are over occupied by the separating task.

The household waste separation sector

In the household waste separation sector, four different qualities of waste will be computed. The waste generated consists of recyclable material (A-waste) and non-recyclable material (B-waste). Therefore, the people have four different action choices to dispose the waste (see Figure 6).

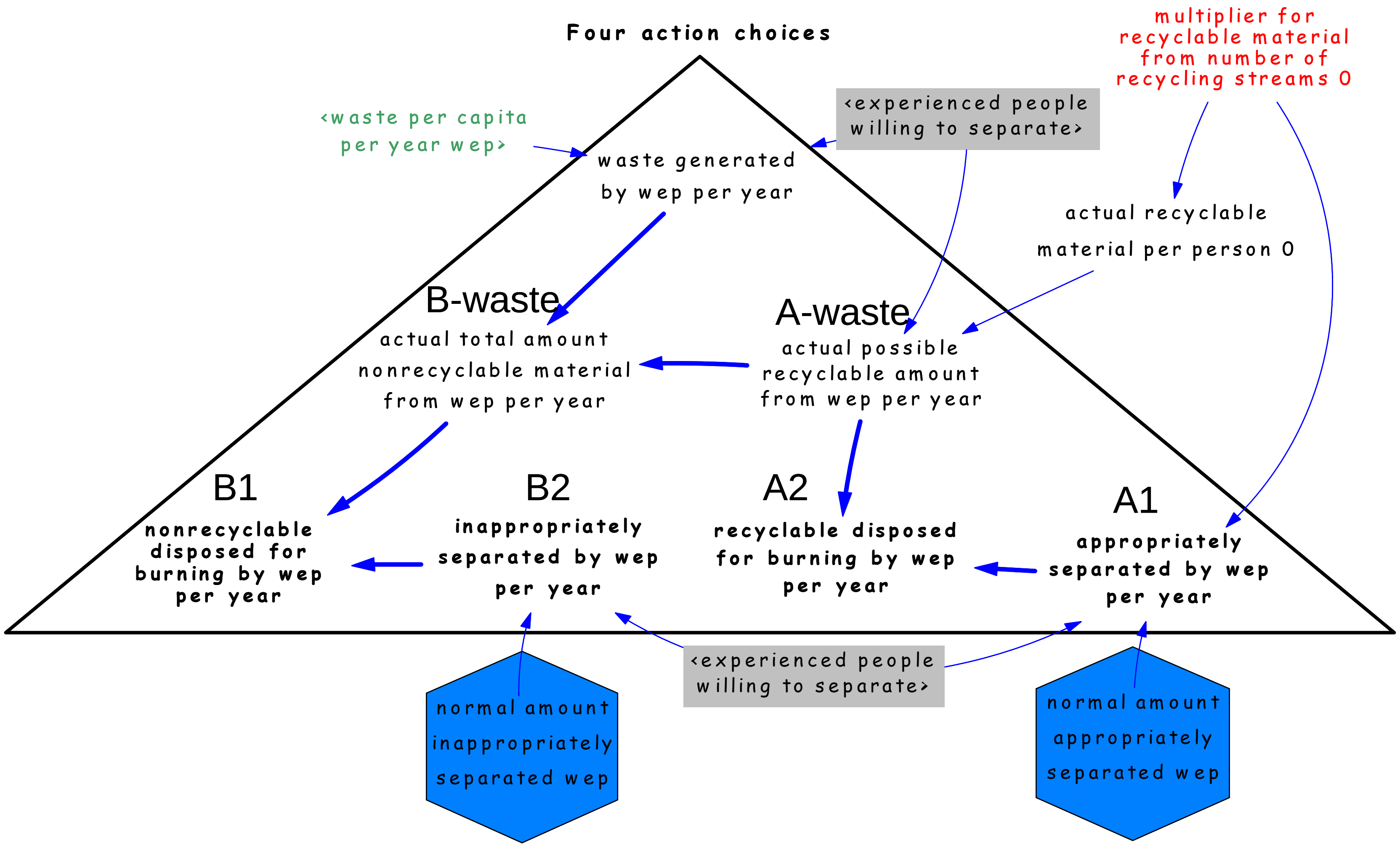


Figure 6: Action choices for disposing of the waste (wep: willing experienced people)
The behavioral variables (indicated by diamonds) represent disposal habits. They measure the normal amount inappropriately separated (B2-waste) and the normal amount appropriately separated (A1-waste). They also determine both counterparts: the amount recyclable disposed for burning (A2-waste) and the non-recyclable disposed for burning. (B1-waste).

A: The recyclable material can be appropriately separated (A1) or can be disposed for burning (A2).
B: The non-recyclable material can be disposed for burning (B1) or it can be inappropriately separated (B2) (generating impure and more expensive recycling material). Figure 6 illustrates how the different qualities of waste are computed.

The local policy sector

The local policy sector includes two basic structures. Firstly, a simple budget structure with a price building policy determining the garbage bag charge and secondly, a simple capacity building structure for collecting points under a regime of a prepaid disposal tax for recyclable material. These structures capture important feedback loops between different financing alternatives of solid waste management (garbage bag charge, prepaid tax or prices for separated material) and the separation behavior of the people. Specifically, they also represent a *non price mediated resource allocation system (Sterman 2000:172)*. With this structure the model boundary includes all the important feedbacks that where detected in the proposed dynamic hypothesis and are thought to include the most relevant structures in order to address the problem statement endogenous to the model.

Policy structure: Garbage bag charge

In this policy structure the <*garbage bag charge*> is computed endogenously. Its adjustment is controlled by numerous feedback loops. The basic underlying decision policy is a goal seeking decision-rule leading to a zero deficit budget. The following Figure 7 emphasizes the three main feedback loops in a simplified model structure. In the case of increasing cost of solid waste management the two reinforcing loops – **"less burning increases price"** and **"more separation increases cost"** - lead to a steady increase in the <*garbage bag charge*> where as the balancing loop **"less burning reduces cost"** would limit the growth. But since the pool of people that could become "willing to separate" is limited the growth in the <*garbage bag charge*> will be restricted by the overall number of <*people separating*>, as well.

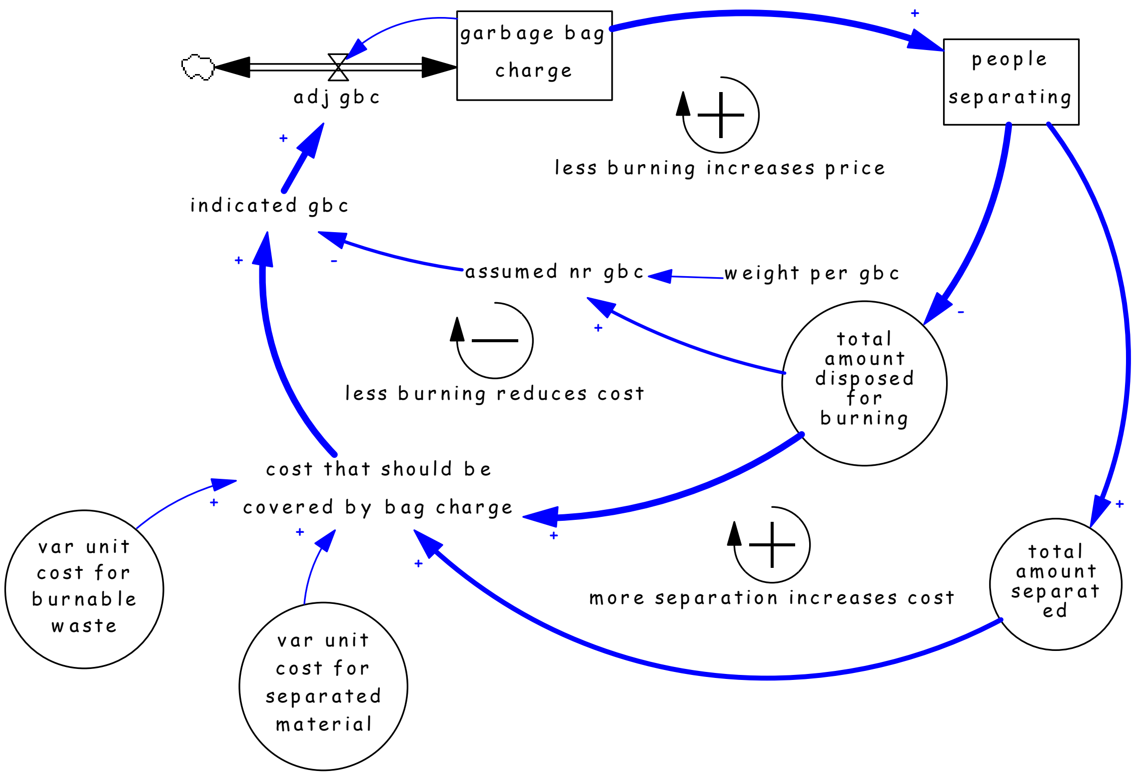


Figure 7: Main loops controlling <*garbage bag charge*> adjustment.

The variable cost that should be covered by bag charge is mainly determined by the amount of the different waste qualities and the unit costs. Revenues from sources like taxes or from selling separated waste are subtracted.

Policy structure prepaid disposal tax
Figure 8 depicts the model structure that allows simulating the impact of a prepaid tax policy. In the policy structure **prepaid disposal tax,** the decision rules guiding the capacity building process in the take back points is illustrated. On the one hand, *the <average amount recovered material>* determines <*capacity building*>. On the other, the <*perceived revenue from the prepaid disposal tax*> limits the capacity building process. A gap between the <*average amount recovered material*> and the <*capacity in the collecting points for recovering*> leads to a crowding effect. The crowding effect feeds into the **household decision** and **household separation sector** influencing the rate <*fraction becoming unwilling*>.

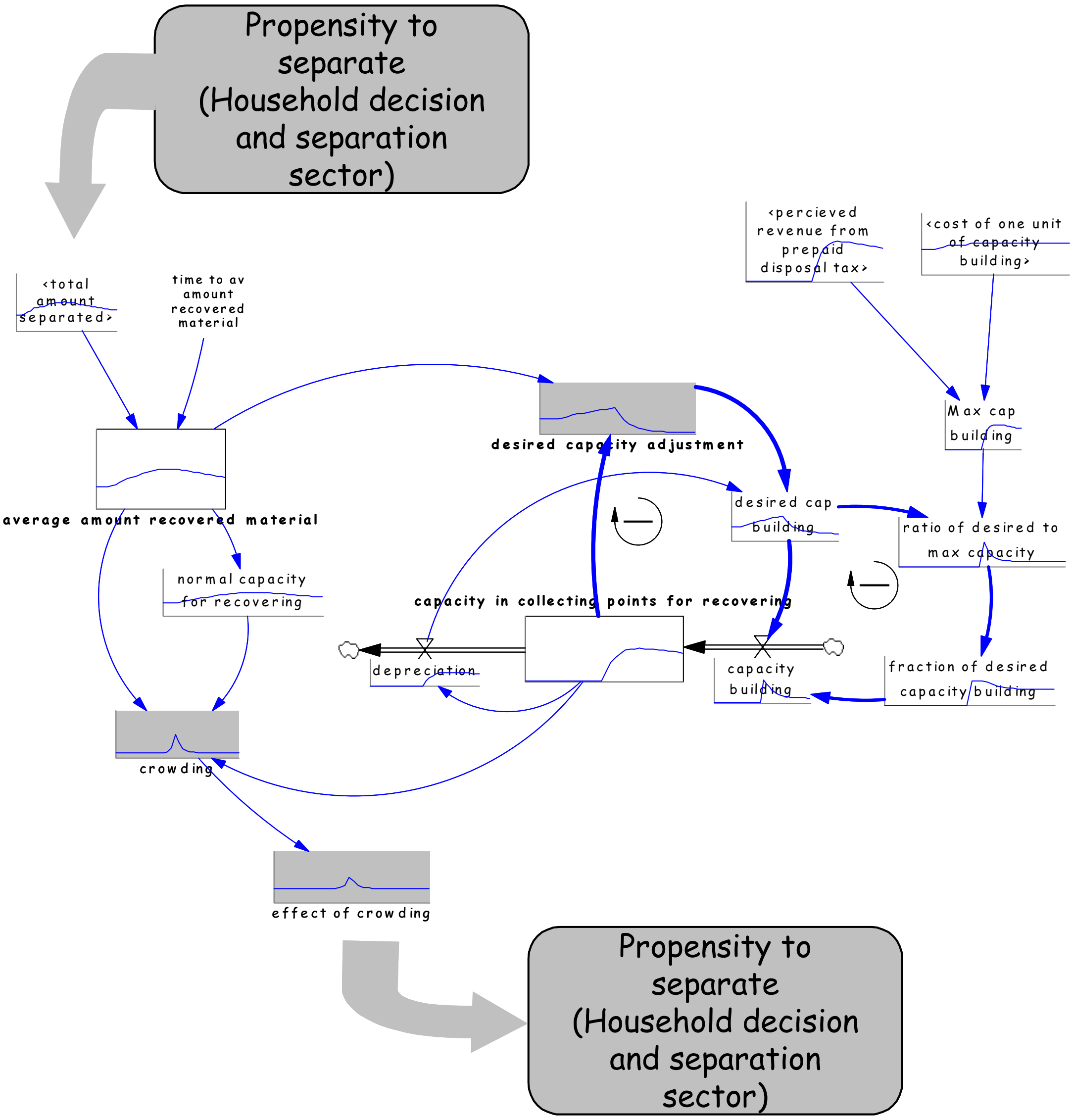


Figure 8: Policy structure: Prepaid disposal tax.

The Base run

In this section, the actual implemented solid waste policy (**inertia policy**) as the base-run is described. The simulation runs allows to test the correspondence of the model behavior to the reference modes and show the dynamics of the model-structure with the **inertia policy**. 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 respectively not willing to separate: *<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>*.

Those indicators are thought to be crucial for measuring the performance of the inertia policy and further policy-packages that can be analyzed with the model structure within different experiment designs.

Inertia policy

The base run describes the model behavior with the actual policies in place: an increase in *<effective nr recycling streams>* and an increasing *<garbage bag charge>* (endogenously computed **inertia policy 2**). The simulated *<fraction separated>* and *<fraction for burning>* closely tracks the smoothed real data (see Chart 2 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%).

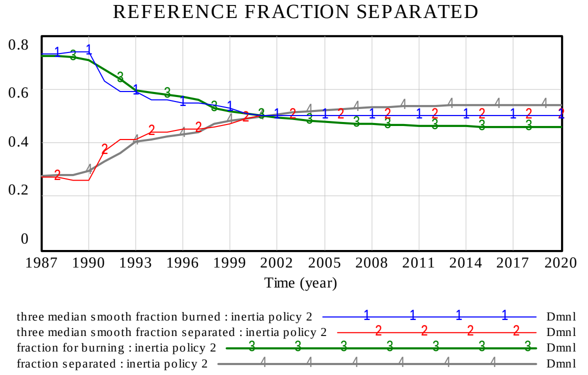
The dynamics are created by the flow of people respectively by changes in the number of the four different groups of people willing / not willing to separate. Chart 2 B shows a clear increase in the number of *<ep willing to separate>* beginning in 1991, and a decrease in the number of *<iep not willing to separate>*.

Chart 2 C illustrates an increasing trend in separated material. However, the price incentives lead to a sudden increase in the *<tot amount inappropriately separated>* in 1991. But the decreasing trend in the number of *<iep not willing to separate>* causes a smoothed decline in the *<tot amount inappropriately separated>* seeking equilibrium. This dynamics represents a classical "first-worse-before-better" behavior pattern. As a consequence of this behavior the gap between *<total amount recyclable material>* and the *<tot amount appropriately separated>* decreases, resulting in a smaller constant compliance gap.

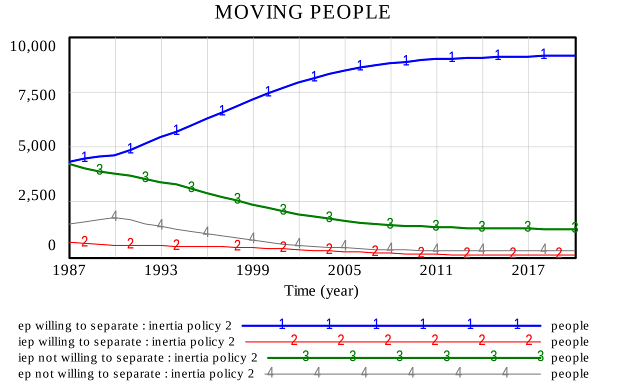
Chart 2 D illustrates the increase in the *<garbage bag charge>*. The model structure computes a *<garbage bag charge>* that seeks a zero profit goal. A change in the *<effective nr recycling streams>* creates the opportunity for people to separate more material, which has two effects. Firstly, it reduces 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 a short and minimal budget deficit due to price adaptations delays in the *<garbage bag charge>*. The *<garbage bag charge>* levels off at 2.1 CHF/bag (D).

However, those price adaptation delays are much longer in the real system. This adaptation delay creates the observed budget deficit in the real world. Chart 2 E illustrates this case in the **inertia**

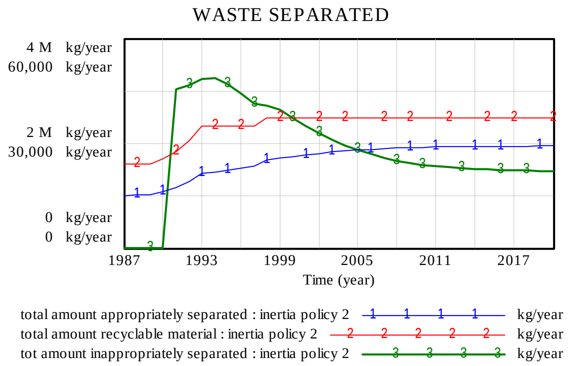
policy 1-experiment (garbage bag charge exogenously given). It is simulated with the <*garbage bag charge exogenous*> resulting in a budget deficit between 1993 and 2000, appearing again after 2001 (see gap between line 4 and 5 <*profit solid waste management*> and <*non-profit threshold*>)[6].



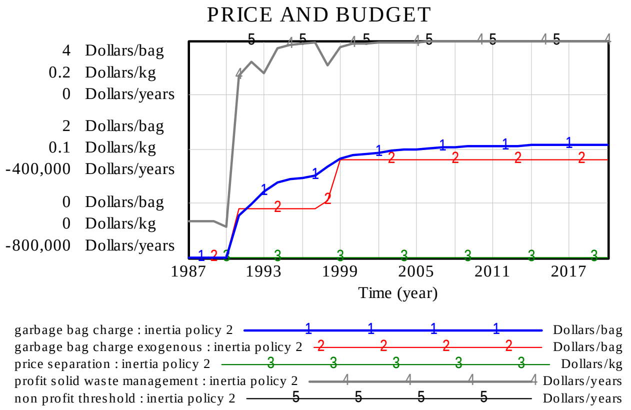
(A) (Line 1 and 2 are three median smoothed real data)



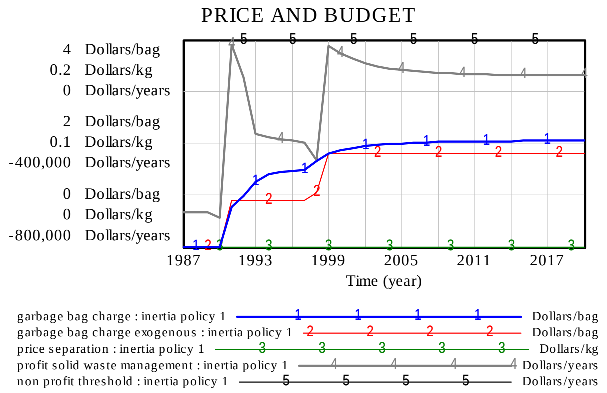
(B)



(C)



(D)



(E)

Charts 2 A-E Dynamics of the base runs

The simple base runs illustrate a good plotted fit (Chart 2 A , for example line 2 and 4) to the reference mode. It also reveals a recurrent deficit as observed in reality. However, the model behavior was explored further around different policy-experiments. Mainly three streams of policy-experiments were conducted (see Figure 9).

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

1. back-casting policy-experiments depicting the actual policy in place (inertia policy), as well as further “what if” policy-experiment exploring what would have happened with different policies
2. forecasting[7] policy-experiments analyzing the effect of new policies such as implementing prepaid taxes
3. policy-experiments under different scenarios over the time horizon 1987 to 2020.

While a comprehensive report on those policy experiments can be found in Ulli-Beer (2003) for the back-casting experiments, and Ulli-Beer, Andersen et al (2004), for the forecasting and scenario experiments, in this paper only a rough idea on the policy-experiments under different scenarios addressing uncertainty in the system can be given after the following conclusions on model behavior and testing.

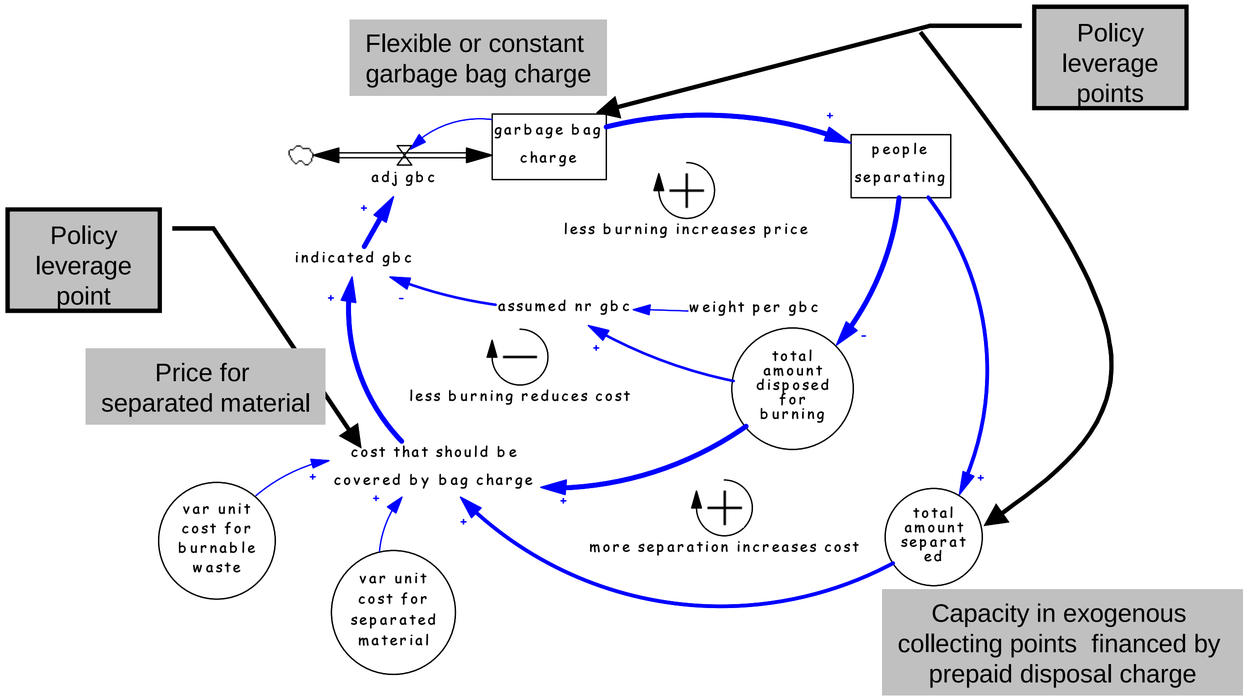


Figure 9: Policy-leverage points in the simplified model structure: The CLD depicts the policy-leverage points in the system and illustrates their impacts on the main loops determining system behavior.

Summary model behavior and testing

Testing the model was an integral part of the modeling process, including structure assessment and behavior reproduction tests. The units of each variable and equation were specified during the modeling process and helped to build up a model structure that is both dimensionally consistent and based on variables that have real world meaning (they are operationalized). In addition, the model structure is based on theoretically and empirically well-founded assumptions that generate a plausible behavior and shows 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.

[7] 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.

Sensitivity Analysis: The tipping point and policy sensitivity

With sensitivity analysis the effect of uncertainty in model assumptions on policy conclusions were tested. These tests assess the robustness of policy implications that can be drawn from the model output. The basic idea is to test if the model behaves plausible under different parameter values, and if changes in parameters lead to different policy implications. A further objective of sensitivity testing was to find the most influential parameters. This would be the best intervention points for effective policies. The choice-structure of the model can be very sensitive to small parameter changes, since it features a tipping point. If parameter values operate near the tipping point the implications drawn from a policy-experiment become weak. Hence it was indicated to conduct sensitivity analysis.

The main stock and flow structure of the model (see Figure 4) has similar characteristics as basic epidemic and innovation diffusion models such as the SIR-model[8] or the Bass-model[9] (see Kermack and McKendrick 1927; Bass 1969; Bass, Krishnan et al. 1994 in 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.

As mentioned above, the tipping point can be decisive. If the diffusion process does not take off the policy initiative is likely to die. The question of whether the policy initiative will succeed is a question about which feedback loops are dominant (see 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[10]"** otherwise the initiative will fail (see Figure 10).

The strength of the loops is determined either by the "fraction becoming willing" or the "fraction becoming unwilling". If the <*fraction becoming willing*> gets stronger than the <*fraction becoming unwilling*> the model exhibits s-shaped growth otherwise it exhibits s-shaped decay. Therefore, some small changes in parameters could change a growth-trend to a decay behavior.

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[8] The SIR-model is widely used in epidemiology for simulating the infection process of acute diseases. It mainly contains three stocks, the susceptible population (S), the infectious population (I) and the recovered population (R).

[9] The Bass-diffusion-model mimics the diffusion of innovation of new product growth and is widely used in marketing and for strategy-development and management of technology.

[10] 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".

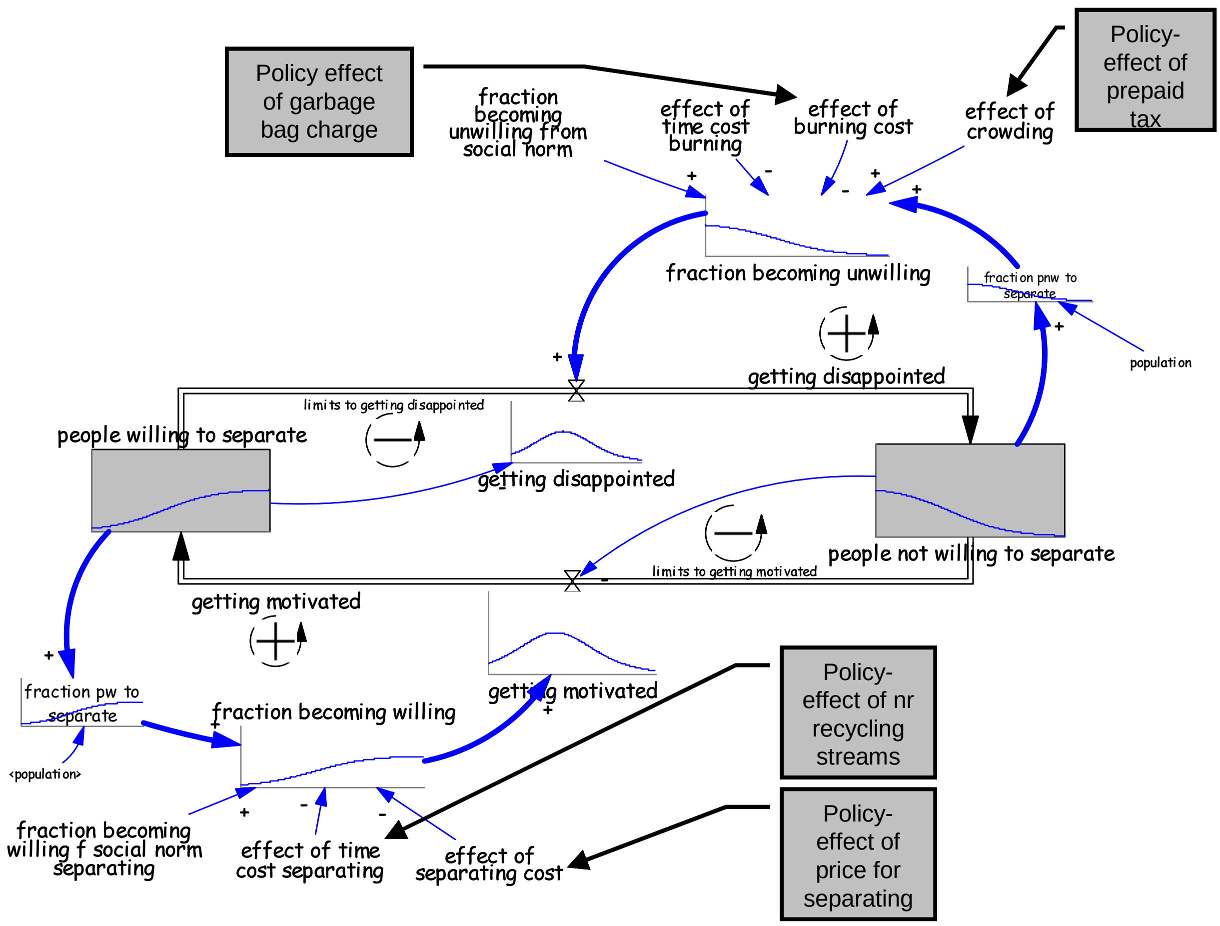


Figure 10: Simplified model structure and policy effects. A higher garbage bag charge weakens the loop **"getting disappointed"** whereas an increase in the <*effective nr recycling streams*> increases the <*effect of time cost separating*>. This will weaken the loop **"getting motivated"**. A price for separated material will have the same effect. Furthermore, it is assumed that a prepaid tax could lead to a <*effect of crowding*> [11] resulting in an enforcement of the loop **"getting disappointed".**

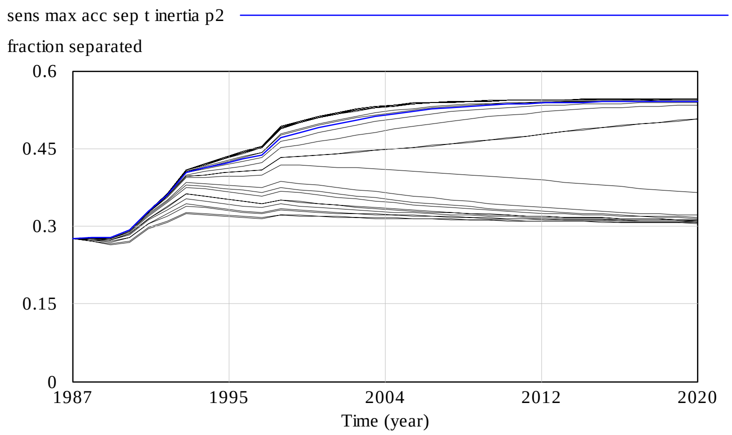
For policy analysis those parameters are important that are uncertain, such as <*max acceptable separating time*> or those that are highly relevant to political interventions, such as <*normal time per stream*>. In the following paragraph, exemplarily one sensitivity test will be briefly reported that demonstrates policy sensitivity of the personal factor <*max acceptable separating time*>.

The parameter <*max acceptable separating time*> operationalizes an average willingness to spend time on separating. If the time required for separating is higher than the average willingness then the loop **"getting motivated"** will lose some numerical strength. Therefore, the parameter is influential. Furthermore, its real empirical value is unknown and therefore in the model it is defined with a high uncertainty by the modeler. For the sensitivity test the uncertainty range in this parameter is specified as follows.

[11] The <*effect of crowding*> refers to the stated dynamic hypothesis of prepaid disposal charges, that is designed as the archetype structure of non-price mediated resource allocation system adopted from Stermann 2000 and explained in Ulli-Beer (2003).

Test settings <max acceptable separating time>		
Distribution: random uniform, 30 runs		
Model value: 2	Minimum value: 1	Maximal Value: 3 (hours/week)

Chart 3 illustrates that in this range of uncertainty the model operates near a tipping point. The model shows a behavior mode sensitivity; it generates different patterns of behavior ranging from s-shaped growth to overshoot and collapse to a smoothed decline. Comparing these test-outcomes with the **Base run** shows that the parameter <*max acceptable separating time*> exhibits policy sensitivity. The model has two different basins of attraction resulting from a shift in the dominance of the two positive feedback loops. The confidence bounds diminish as the parameter values near the borders of attraction. The behavior bifurcates when <*max acceptable separating time*> falls below 1.65 hours/week (tipping point). ¨



A inertia policy2 –

Chart 3: Sensitivity analysis <max acceptable time> with inertia policy 2 depicting the dynamics of <fraction separated>.

The sensitivity test emphasized exemplarily that the tipping point is an important insight that has to be taken into account for policy recommendations. It determines the failure or success of a recycling initiative and knowledge about the critical system parameters is decisive. In order to take account of the identified tipping point and to analyze its policy implications a series of scenario policy-experiments in the sensitivity analysis mode were conducted. The robustness of different policies under worst- and best- case conditions were investigated.

Policy-experiments under different scenarios and imperfect information

Different scenarios are determined through changes in the surroundings that are not initiated by local authorities (see Figure 12). Contrarily, the conditions in the external environment will determine certain conditions of the solid waste management system, as well as the effectiveness of local policies. In the model, changes in exogenous parameters define different scenarios. The scenario leverage point **solid waste generation** reflects the trend in the overall waste generation and in the <*total amount recyclable material*> (determined by a growth in the variable <*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.

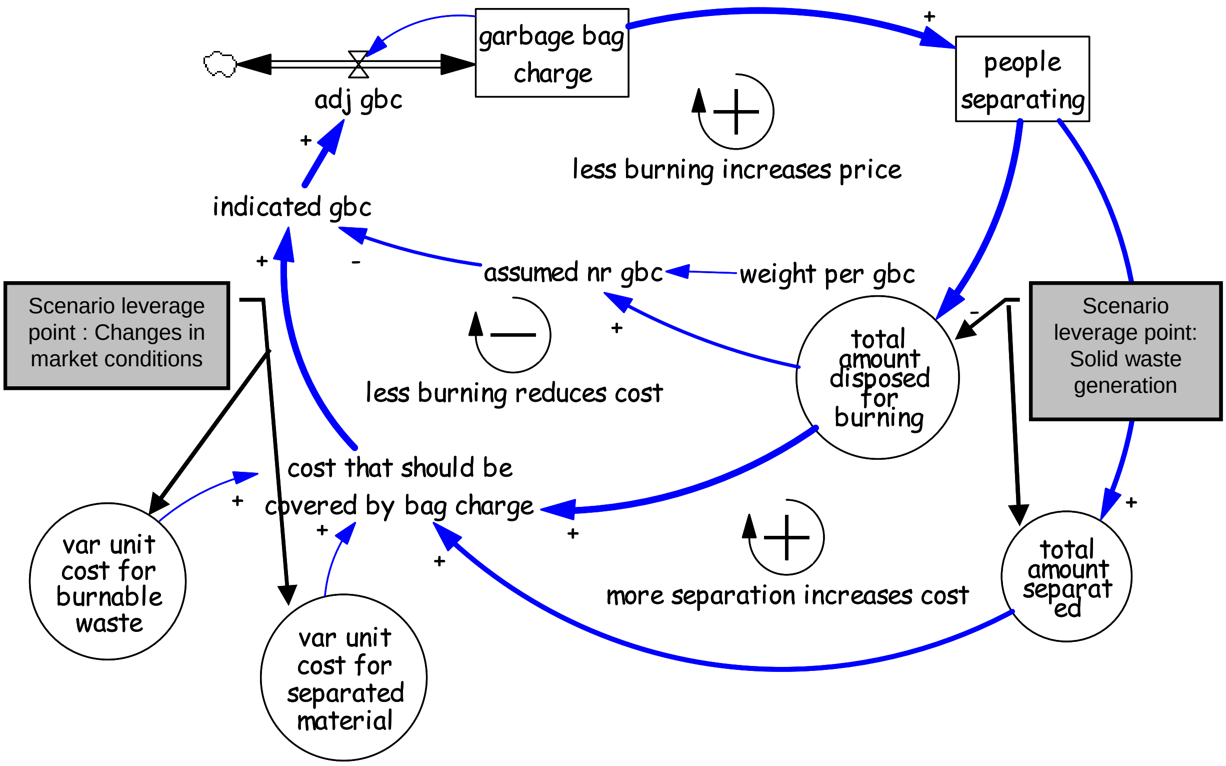
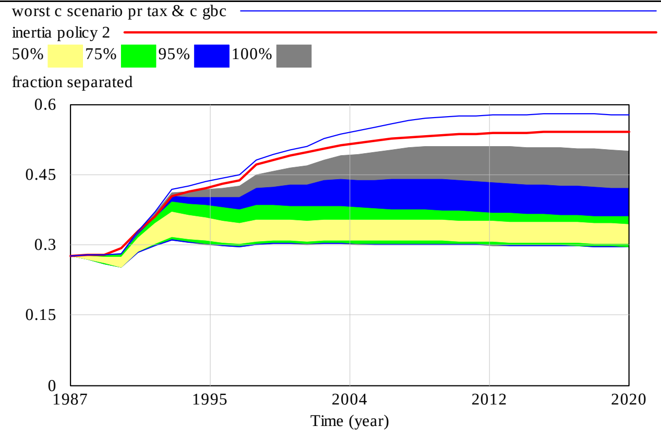


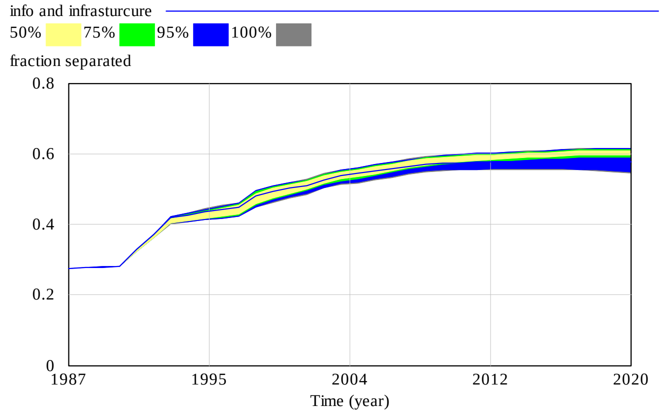
Figure 12: Scenario leverage points influencing main loops.

In the scenario-experiments two-dimensional changes in the scenario parameters, determining either best-case or worst-case conditions, are analyzed. 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 results of the various scenario-experiments under uncertain conditions (conducted in the sensitivity analyzing-mode) give evidence that the design of policy-packages matters the most under worst-case conditions.
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 effective. 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, such as in *<acceptable separating time>* may have a significant effect on the outcome (see Chart 4).



(A) Fraction separated: Prepaid tax policy with constant garbage bag charge under worst case conditions.



(B) Fraction separated: Prepaid tax policy with constant garbage bag charge under worst case conditions but with a higher *<acceptable separating time>*

Chart 4: Hypothesis test: The hypothesis that small changes in *<acceptable separating time>* can lead to robust policy outcome even under worst case condition was tested.

Discussion and Conclusions

The study focused on relationships and interactions between important factors that influence the separation behavior of citizens. Using the system dynamics syntax of stock and flow and the mathematical formalization a material[12] dynamic theory for recycling dynamics including a SD-choice structure for policy compliance is suggested. Complex multivariate relations and processes

12 Glaser, B. G. and A. L. Strauss (1967). The Discovery of Grounded Theory. Strategies for Qualitative Research. Chicago, Aldine. distinguish material from formal theories. A material theory is developed for a specific topic (such as solid waste management) whereas a formal theory is more abstract and refers to conceptual issues such as environmentally relevant behavior.

over time were visualized in causal loop diagrams that explain the observed phenomena in solid waste management (see Figure 4 and Figure 7).
In this section those insights will be summarized and discussed.

The success or failure of a recycling initiative depends on the relative strength of the two loops **“getting motivated”** and **“getting disappointed”.** The loop dominance is crucial. Therefore, those factors are crucial that determine the strength of a loop. Sensitivity analysis and various policy experiments under different scenarios helped to identify high leverage points for controlling the system behavior. These insights help to determine why and when which preconditions for environmentally sound action should be adjusted.

In the course of the study, a switch in perspective took place. While in the preliminary study the focus was on key-factors explaining environmentally relevant behavior, in the System Dynamics analysis key-loops were under investigation. System Dynamics offers the unique possibility to identify feedback loops as causes of system behavior. Richardson and Pugh (1981) point this out as follows :

> *“The feedback view antiquates the notion of a simple, linear, left-right causality. Chickens and eggs are not a causal dilemma if one focuses on what they cause together, namely, exponential growth in the barnyard. So, in hunting for the causes of model behavior, we seek feedback structures, not isolated variables. While a single factor can change the strength of a feedback loop and affect its dominance in the rest of the model, it is more useful to see the loop, not the factor, as the causal agent in the system” (268).*

With this focus the research questions can be discussed from a key-loop-perspective. With the help of the SD-SWM-model **five main loops were identified as the causes of the observed behavior patterns**, they are listed in the Table 6.1 below. Furthermore, the factors are identified that influences their strength. In addition, they are traced back to personal and contextual factors. Also, the theoretical concepts are named that explain the applied rationale forming the model structure and subsequently the loops.

The result of this key-loop-analysis can be structured according to compliance, natural environmental effectiveness and economic rationale issues (see Table 1):

Under the aspect of ***citizens’ compliance*** with the recycling initiative no further interventions may be necessary, since currently the loop **“getting motivated”** dominates the loop **“getting disappointed”.** Under the given situation the recycling initiative in the municipality under investigation is successful.
However, the identified tipping point in the systems give evidence that a successful separation-strategy has to be sensitive to the <*effective nr recycling streams*> that are offered to citizens. Thus it is indicated that the cost efficient recycling strategy “offering different recycling streams and investing in citizens’ separation behavior” has to be adjusted as soon the max separation capacity of citizens is reached. It depends on the <*acceptable time for separating*> that interacts with the <*perceived social norm separating*>. The upper limit of <*max acceptable time separating*> indicates the maximal capacity of citizens to separate their waste. The dynamics in impurity is a consequence of an initial policy resistance and adjustment delay in personal factors such as in <*acceptable time for separating*> and <*acceptable unit cost for burning*>.

However, the ***economic rationale*** contradicts this observation. The recurrent deficit and the high cost of solid waste management for the municipality are dissatisfying. The growing cost is mainly a consequence of a successful recycling initiative but also of impurity and growth in solid waste generation. 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. The dynamics of countervailing price effects lead to a trade off between policy effectiveness and a zero profit budget goal. Whereas an effective policy tends to lead to a deficit, policy failure tends to lead to a profit. Hence the economic rationale suggests further interventions. Subsequently the dominance of the three loops **“less burning increase price”**, **“less burning reduce cost”**, and **“more separation increases cost”** together with the two compliance loops **“getting disappointed”** and **“getting motivated”** have to be carefully controlled.

In addition, the Table 1 brings out a rather astonishing point related to aspects of ***environmental effectiveness***. In the model no loops controlling the environmental effectiveness were identified. This can have several reasons: The model boundary may be too narrow or no controlling loop may exist at the local level, or this structure is missing in the model.

Main issue	Important loops	Main factors and effects determining the strength of the loops	Personal and contextual factors influencing the strength of the effect on the loops	Underlying theoretical concepts
Compliance	“Getting disappointed”	• Effect of burning cost, • Effect of crowding	• Capacity in collecting point • Garbage bag charge • Acceptable unit cost for burning • Perceived social norm for burning	• Opportunity cost, • Planned behavior • Non-price-mediated resource allocation • Planned behavior (choice concept)
	“Getting motivated”	• Fraction becoming willing from social norm separating, • Effect of time cost separating	• Perceived social norm separating • Acceptable time for separating (Max acceptable separating time) • Time spent for separating (effective nr recycling streams, normal time per stream)	
Environ-mental effective-ness	No controlling loop!	Underlying theoretical concepts • Habits • Separation capacity of citizens • Sufficiency strategy (self-modification strategies) • Efficiency strategy • (Technological progress) • Consistency-principle		
Economic rational	“Less burning increase price”	• Number people separating • Zero deficit budget policy	• Price policy of community • (cross subsidizing, price adjustment delays, base tax)	• Economic incentive • Polluter pay principle • Cross subsidizing effect • Cost recovery and break-even point
	“Less burning reduces cost”	• Number people separating • Cost that should be covered by bag charge • Zero profit budget policy	• Incineration cost per unit • Unit cost for collecting burnable material • Total amount disposed for burning	
	“More separation increases cost”	• Cost that should be covered by bag charge • Zero deficit budget policy	• Capacity in collecting points • Total amount separated	

Table 1: Key loops and key factors explaining recycling dynamics.

Summing-up, the shift in perspective gives evidence that the significance of preconditions for environmentally sound actions depends on the loop dominance. Driving forces in the systems are the dynamics and not single factors. Identifying the dominant loop in the system may be seen as a sine qua non for effective policy interventions. Secondly, we have seen that personal precondition for environmentally sound actions may be an important intervention point under unfavorable contextual recycling conditions. This gives further evidence for the relevance of changes in preferences explaining policy outcome.

From a public policy perspective this study suggests that the interactive effects of personal (such as willingness to invest time in specific behavior) and situational variables are important for understanding the effectiveness of policy initiatives. Understanding the processes that help to unfreeze harmful habits and to establish new ones represents a further significant opportunity for improving policy effectiveness and to break path dependency in a system.
While for the specific case of recycling dynamics a micro choice structure for citizens' separation behavior is suggested, further research is indicated in order to synthesize a choice structure that can be generalized for other contexts of applications. This line of research could found a generic SD structure of choice, e.g. related to policy compliance issues of citizens, consumers, firms, or organizations in different realms.

The main strengths of this modeling and simulation approach to theory building are summarized in the following points.

- Important insights about interactions of personal and contextual factors could be found and important intervention points were identified. Furthermore the effectiveness of different policy-packages could be tested.
- The SD-SWM-model is relatively simple and is therefore suitable for the purpose of enhancing the understanding of how important personal and contextual structures cause internal dynamics and produce the observed behavior pattern.
- The model has been carefully tested, and different sensitivity analyses were conducted. The test results give evidence of its robustness and consistency as well as correspondence.
- The System Dynamics modeling syntax allows evaluating the SD-SWM-model as a theory applying general criteria for evaluation theories such as suggested by Bacharach (1989). A systematic critique of the theory will be beyond this study but could be done by other researchers pushing the debate of computer-assisted theory building further. Furthermore, the concepts and constructs included in the model (such a habits, preferences, social norms, planned behavior) may help to bridge the gap between other theories and to suggest refinements of pre-existing theories.

However this study has also its specific limitations.

- The SD-SWM-model could still be improved. Furthermore the parameters and graphical functions need to be empirically substantiated.
- The SD-SWM-model cannot be used to address detailed issues of policy implementation such as a decision aid about which communication instrument to choose. Furthermore, it cannot be used for precise prediction of the outcomes of a policy intervention at a specific year.
- It is important to emphasize that the policy conclusion bears not only the methodological meta-assumption (see Andersen 1980) but also the modeler's own assumptions made in the model building process. Furthermore the applicability of the model is bounded to the specific family of solid waste management systems dealing with recycling dynamics. However the model includes some generic structure components that could be used as building blocks in other contexts of applications.

Although the study has its specific limitations, it demonstrates an innovative approach of environmental policy analysis that focuses on loops as causes of behavior and traces the loop dominance back to personal and contextual factors. Therefore it provides a broader basis for policy analysis and policy design allowing a higher variety of intervention and implementation options.

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