SEN 1211 Final Project Report

A Plastic Recycling Model for Municipal Waste

Merih Koray Karabulut - 4754859
Shajeeshan Lingeswaran - 4748883

Chapter 1: Problem Formulation and Actor Identification

The Actors:

We identified 4 actors within this system, namely ***the government, the municipalities, the households, and the recycling companies***.

In the model, the government is regarded as an overarching agent who sets the context, sets the initial targets but lets the other agents find their best strategies within this setting. In this system, the government identifies the recycling plastic target for municipalities. It directly affects the policies that municipalities implement, and those policies directly affect the system as a whole. Therefore, it can be considered that the initial trigger comes from the government.

First type of actors within the system are the municipalities. By considering the target which is set by the government, municipalities need to find a set of policies which gives them a viable outcome. In this particular system, the outcome is about a trade-off between the recycling target and the municipal budget restrictions. They are setting the collection infrastructure, namely, “centralized” or “decentralized”, for the waste which is created by the households. They form business partnerships with recycling companies to dispose the waste, and to recycle the plastic with respect to the governmental targets.

Households are the second type of actors which are identified in our system. They are placed within the municipal borders and they are the producer of the waste which is being processed. Households have different types of residents so that their waste production habits can change respectively. Also, their understanding of waste processing is based on different parameters, such as the sensitivity to the infrastructure provided by the municipality or the type of the inhabitants, each affecting the overall waste production habits.

Lastly, the recycling companies are identified as actors. They are responsible for the recycling processes. They collect the waste based on the infrastructure provided by the municipality. Then, the collected amount is processed within the facilities. The whole procedure is done with respect to the contracts set between municipalities and companies. As private corporations, the profit they acquire is identified as the target of them. To increase their profit, it is possible for companies to invest in the new technologies.

The Research Problem:

Municipalities are assumed to be the client of this project. Since they are not able to affect all the variables within the identified system, the aim of this research is to inspect the changes in the variables which are available to municipalities. These policy levers can be exemplified by the desired contract duration or the amount of waste tax which is collected from the households. The research problem is identified as follows:

“*What are the effective sets of policy levers for municipalities to perform better with respect to the target recycled plastic rate without disrupting the municipality budget?”*

Chapter 2: System Identification and Decomposition

In this chapter, the boundaries of the model is set. For the sake of simplicity, the government is defining the recycling target policy at the beginning of the model. Although it is a key aspect, it is just an external variable, and therefore the government was removed as an agent from the system. As a result, our system is composed of three agents, namely, municipalities, households, and recycling companies.

As mentioned in the first chapter, municipalities are the agents which we identified as our clients. The aim is to achieve a set of policies which lets municipalities have viable positions within the system with respect to the recycling target set by the government and their municipal waste budget. The municipalities are responsible for the amount of waste supplied from the households placed in its borders. Since recycling companies can collect waste from centralized waste collection centers or decentralized garbage cans, these processes have different implications within the system. It is assumed that companies prefer to have the centralized system since they do not need to drive around the districts to collect the waste. However, the decentralized waste system makes it easier to dispose of the waste for households and thus it affects the overall waste disposal habits. Broadly speaking, the amount of created waste is based on the population size and distribution of the municipality. The fraction for the recyclable plastic within the waste can be affected by conducting some educational campaigns for the households which are placed in the municipality.

There are two types of campaigns conducted by the municipalities. First one is about the perception towards the recycling which affects the amount of plastic in the waste, while the second one is about the knowledge of recycling which affects the fraction of recyclable plastic. Municipalities conduct surveys by questioning a certain fraction of the households placed in their borders. If the surveys indicate that the recycling habits of the population are not in line with the targeted recycling rate, the municipalities decide to conduct campaigns. The priority is given to the knowledge campaigns but when the conducted knowledge campaigns are more than the perception related campaigns, the municipalities conduct perception campaigns to improve both perception and knowledge in a simultaneous way. Of course, the implementation of the campaign processes is restricted by the municipal budget. Also, the survey frequency differs from one municipality to the other.

The households are simply the population which are living in a municipality. They create the waste based on their characteristics. For example, the amount of waste which is created by a single person is not the same as the waste created by a family. Four types of households are identified within the system, namely, “single”, “couple”, “family”, “old”. Also, two attributes of these households are introduced, “Perception towards the plastic recycling” and “Knowledge about plastic recycling”. Values of these attributes change with respect to the type of a particular household, or the actions done by the municipality, or the infrastructure provided by the municipality. In the end, they affect the amount of plastic in the created waste and the quality of it. By quality, we mean the amount of recyclable plastic in the collected waste. The more quality

waste involves more recyclable plastic respective to the total amount of waste. The households pay the waste-tax for the waste handling operations of the municipality. This inflow of cash is utilized to finance the above-mentioned campaigns and also to cover the recycling service expenses.

The recycling processes are handled by private companies within the system. They dispose of the waste with various efficiency levels due to the different technological capabilities they have. As all other manufacturing facilities, the recycling companies' facilities also have a maximum capacity. One recycling company may not handle all the waste collected in a municipality, so municipalities can have multiple business partners to process all the waste. In these partnerships, while one company works with fully utilized capacity, there may be underutilized capacity issues for the other companies. Also, the underutilization can exist even if there are only one municipality and one company. Since the companies are profit focused, the viability of each business partnership is assessed by the companies with respect to the return that can be acquired. If their business conditions indicate the necessity, the companies can also invest in their processes. This can increase their efficiency and/or their capacity to handle waste. However, there is an implementation time for the investment. At this point, the budget of the companies is neglected since it is assumed that any investment can be financed by using the loans which can be acquired from any bank. Therefore, we decided not to put any monetary restrictions on the companies for their investments. The necessity of investments is evaluated when the companies are not chosen by any municipality as a viable business partner. They evaluate their operational efficiency and capacity with respect to the rival's efficiency and capacity levels, and if they are below the market average, then they invest respectively to strengthen their position in the market.

Lastly, the formation of the contracts and the operational decisions which are done with respect to the contracts are worth to mention as the interaction between the introduced agents. For the recycling processes, the municipalities request offers from companies when the existing contracts are expired. The companies respond to these requests by bidding various unit cost values. The unit cost changes for each municipality and company couple since the distance and the provided infrastructure are different. After the companies bid, the municipalities choose the best company among the received offers with respect to their interest. This notion of interest is represented by using weights for the importance of the price, the recycling target and the risk due to the fine cost. Multiple municipalities may choose the same company in the first round of requesting-bidding processes. The last word is given to the companies, so they pick the municipality that they want to work with among the municipalities which accept their offer. This requesting - bidding process continues until all the municipalities assign their expected waste, or the maximum capacity for each company is reached.

As a result of this coupling process, the contracts are formed. Besides the unit operational costs and the duration, the contracts also have a unit cost of fine for mismatched waste supply. The municipalities are obliged to pay a certain amount of money with respect to the mismatched

waste they fail to supply. This amount is calculated as the difference between promised monthly waste amount on the contract and the real monthly waste amount.

Next to the variables of the agents, external parameters are existent. These parameters can be considered as the factors of environment around the agents As it is mentioned in the first paragraph of this chapter, the governmental recycling rate is perceived as an external variable. Besides this, the cost of conducting campaigns for the municipalities is also assumed to be set externally by the market. The unit cost of recycling processes for the companies, and also the unit cost of transporting the waste from municipalities to the companies are also regarded as external variables. Lastly, we consider that the selling price of the recycled plastic is determined by an external market and the companies in our system are operating with respect to this market rules.

Chapter 3: Concept Formalization

Municipalities have:

- ID (integer, x >= 0)
- Number of households (integer, x >= 0)
- Budget (float, -∞ < x < ∞)
- Waste recycling target (float, 0 <= x <= 1)
- Monthly accumulated waste (float, 0 <= x <= ∞)
- Monthly accumulated plastic waste (float, 0 <= x <= ∞)
- Monthly accumulated recyclable plastic waste (float, 0 <= x <= ∞)
- Type of infrastructure (string, “centralized” , “decentralized”)
- Costs (float, 0 <= x <= ∞)
- Estimated waste amount (integer, 0 <= x <= ∞)
- Promised waste amount written on the contract (float, 0 <= x <= ∞)
- Frequency of survey (integer, 0 <= x <= ∞)
- Number of campaigns for perception (integer, 0 <= x <= ∞)
- Number of campaigns for knowledge (integer, 0 <= x <= ∞)
- Importance of price (float, 0 <= x <= 1)
- Importance of fine (float, 0 <= x <= 1)
- Importance of recycling target (float, 0 <= x <= 1)
- Availability for contract formation (boolean, true, false)
- Set of contracts (list)
- Recycling performance (float, 0 <= x <= 1)

Municipalities do:

- Conduct surveys to check inhabitants performance of waste management
- Conduct campaigns to improve knowledge of households for recyclable materials
- Conduct campaigns to improve the perception of households towards plastic waste
- Request offers from companies for waste-recycling
- Select the best offer among received bids

- Form the contract
- Pay the contract price
- Pay monthly fine

Households have:

- Affiliated municipality(integer, $x >= 0$)
- Household type (string, “single”, “couple”, “family”, “old”)
- Factor of perception for waste creation habits (float, $0 <= x <= 2$)
- Factor of knowledge for recognizing recyclable plastic materials (float, $0<= x <= 2$)
- Sensitivity to campaigns conducted by the municipalities (float, $0<= x <= 2$)
- Sensitivity to infrastructure provided by the municipalities (float, $0<= x <= 2$)
- Monthly produced waste (float, $0 <= x <= \infty$)
- Percentage of plastic waste with respect to total waste produced (float, $0<= x <= 1$)
- Percentage of recyclable plastic waste in plastic waste produced (float, $0<= x <= 1$)

Households do:

- Produce waste
- Pay tax

Recycling companies have:

- Budget (float, $-\infty < x < \infty$)
- Technological efficiency (float, $0<= x <= 1$)
- Maximum capacity (float, $0 < x < \infty$)
- Utilized capacity (float, $0 < x < \infty$)
- Cost of recycling processes (float, $0 < x < \infty$)
- Cost of waste collection (float, $0 < x < \infty$)
- Revenue from recycled plastic (float, $0 < x < \infty$)
- Revenue from contracts (float, $0 < x < \infty$)
- Profit (float, $0 < x < \infty$)
- Expectation of recyclable waste fraction from partner municipalities (float, $0<= x <= 1$)
- Availability for contract formation (boolean, true, false)

Recycling companies do:

- Evaluate municipality requests
- Bid to municipality requests
- Choose the partner municipalities
- Collect waste from partner municipalities
- Recycle waste
- Sell recycled plastic in the market
- Receive fines from municipalities
- Receive contract prices from municipalities
- Evaluate profitability
- Invest with respect to the profitability

UML diagram:

UML class diagram is provided here to clearly indicate the formalization we made. Each agent with its attributes and related functions are described below in figure 1.

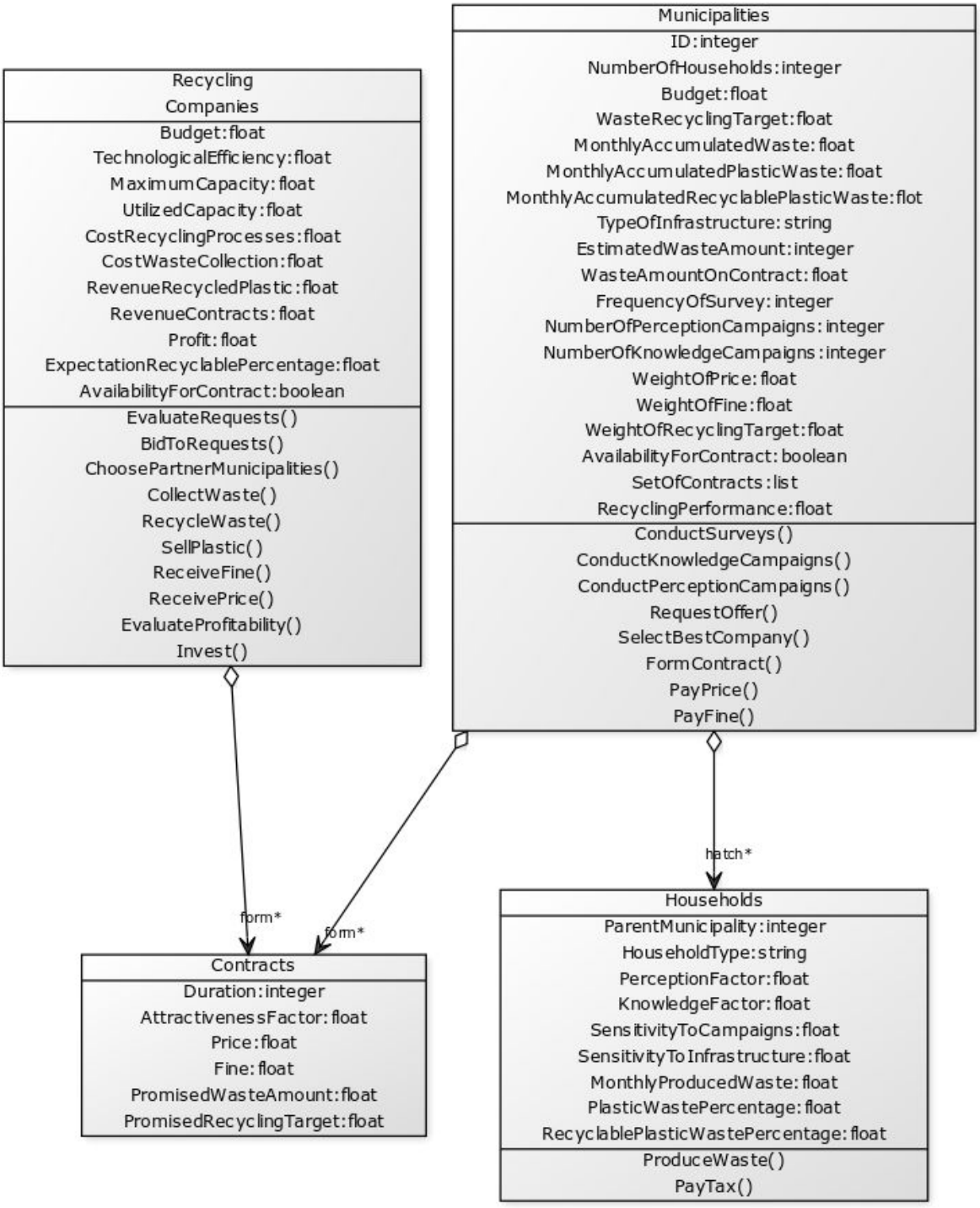

Figure 1. UML Class Diagram for the concept formalization

Chapter 4: Model Formalization

The actions which happen per time tick are represented by a UML sequence diagram below in figure 2. We believe this type of representation is easier to follow. Each vertical line represents an agent or object in the system which interacts or affiliated with something else. The horizontal arrows show the sequence. Time ticks as the diagram is followed from top to bottom, while it can be understood that the actions happen simultaneously if they are horizontally aligned.

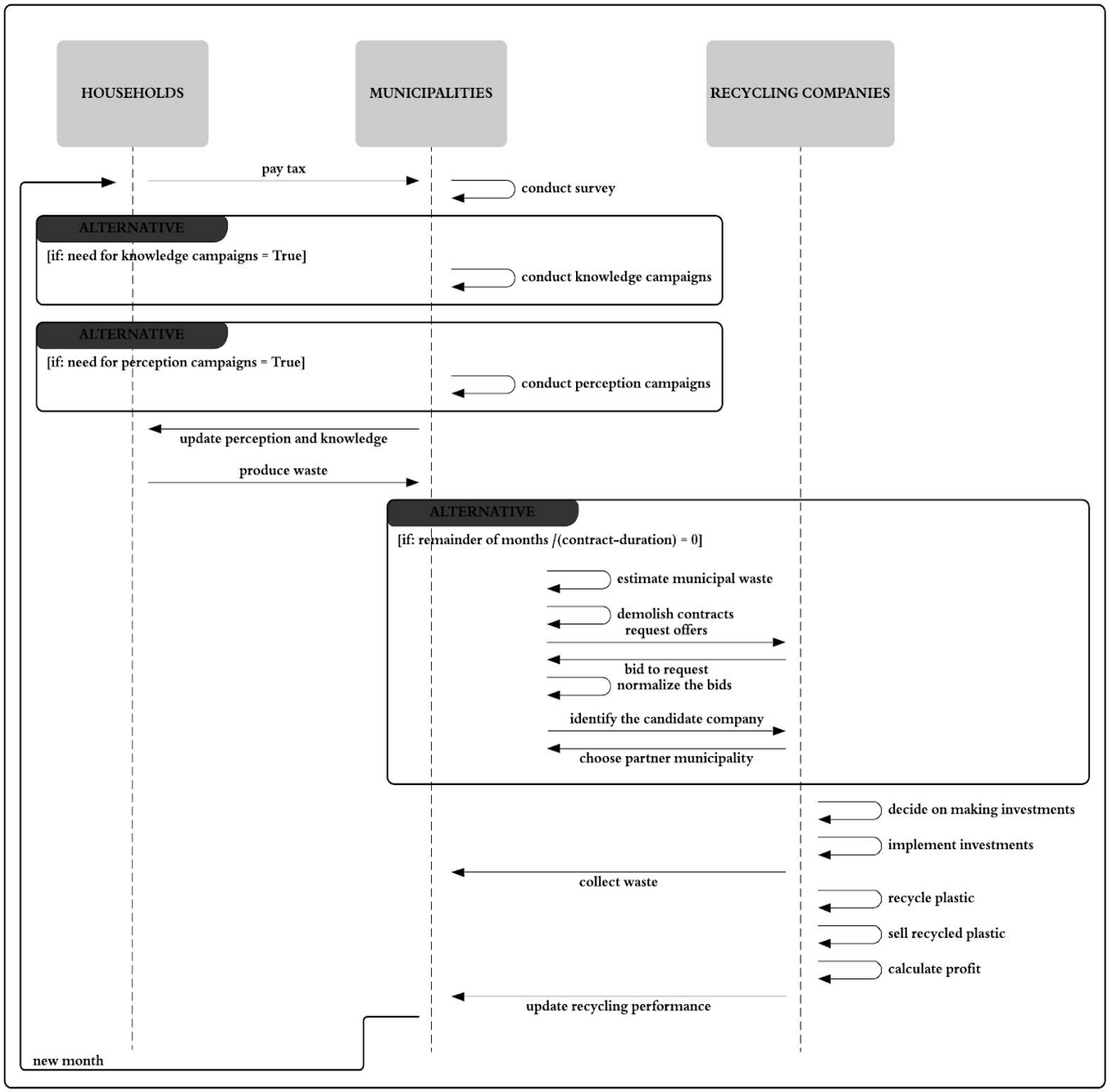

Figure 2. UML Sequence Diagram for the model formalization

Chapter 5: Software Implementation

The model itself is created by using NetLogo software. During the coding phase, we utilized the above-mentioned formalizations extensively. As we encountered difficulties in coding which occured due to either NetLogo's incapacity or our lack of knowledge and experience in NetLogo coding, we were forced to go beyond the formalizations and try to find loopholes to solve the issues. However, it can be stated that the provided formalizations constitute the backbone of the code itself.

The formalization part was conceptualized as a group so that we had the holistic idea of what the code was about. By considering this, we split the work agent by agent, first identified agents and functions which do not need any interactions with the other agents. At the end both models were merged into one model

While coding, we did not skip the comments, so that it was relatively easy for us to track what we did. However, the lack of decent debugging tools within Netlogo was a major issue. This was overcome by creating buttons for each function in the interface, and, when necessary, split the functions into multiple parts so that we could focus on the actual problem in the function. When we needed to debug, we were using these artificial buttons one by one, with the sequence. At the end of the software implementation, these buttons were erased from the interface.

Chapter 6: Model Verification

In this chapter, the model was verified whether the software implementation matches the model conceptualisation. Therefore, different scenarios was designed in which the parameters of the model are set so that we can anticipate the outcome, and compare the actual results of the model with our expectation. During the verification of the model, the random seed is fixed to purely evaluate the effect of changes. The Table 1 below shows the results of this verification process.

Description	**Result**
Higher recycling target leads to lower municipality budgets	✔
Lower recycled plastic market price creates lower company budgets	✔
No municipality scenario yields 0 waste, 0 profit for companies, 0 cost for municipalities	✔
No company scenario yields 0 recycling cost for municipalities, 0 profit for company budgets	✔
Available knowledge for waste production habits improves the municipality performance	✔

Lower budget for municipalities decreases the campaigns, so the overall recycling performance	✔
Higher amounts of waste tax lead to better performance for municipalities	✔
Higher contract duration leads later convergence of technological efficiency for the companies	✔
Higher capacity levels result in less number of contracts in a term	✔
Increased unit costs negatively affect the overall recycling and collection costs	✔
Higher tech implementation time postpones the efficiency convergence for the companies	✔
As the fraction of old people increases, the overall recycling performance is affected negatively.	✔
Increased plastic rate yields more profitable business for the companies.	✔
Municipalities conduct campaigns if the survey results indicate poor performance	✔
Municipalities cannot conduct campaigns even if the surveys show the need, if the budget is not available	✔
Companies invest in their businesses to increase their attractiveness if they fail to get a contract during the formation process	✔
One municipality can have multiple contracts	✔
One company can have multiple contracts	✔
Municipalities keep requesting contracts as long as they have accumulated waste	✔
Each household type is of respectively different perception and knowledge levels	✔
The total waste in a municipality is the aggregate waste of households of this municipality	✔
When the contracts are terminated the capacity of the companies is restored	✔
The contracts are terminated after the contract duration	✔
Agreed contracts are chosen among the set of best contracts in each formation process	✔

Table 1. Verification of the model structure

Chapter 7: Experimentation

As mentioned in Chapter 1, we are interested in understanding a set of policy levers of the municipalities to reach their recycled plastic target without upsetting the municipality budget. Therefore, experiments are conducted by measuring the key performance indicators (KPI): waste management budget of the government per household and the achieved recycling rate. The only policy options the municipalities have within our model are the following three: contract duration with recycling companies, monthly waste tax from household and the preference of municipalities in considering price, fine and/or recycling rate in their choice of accepting the waste management contract offered by the recycling companies. Thus, the experiments are varied over the parameters weight of price, weight of fine, weight of recycling target, contract duration and monthly waste tax. Next to the KPI, the frequency of survey is tracked during the experiment to understand whether a constant monitoring will lead to a better performance.

Experiment Design

- General Setup:
    - Ticks [240]: Each tick = 1 month
    - Repetitions [100]: Good sample for a decent experiments runtime
- Parameter Settings:
    - number-municipalities [6]
    - number-recycling-companies [10]
    - max-number-households [115000]
    - min-number-household [25100]
    - recycled-plastic-price [0.126€]
    - weight-of-fine [20, 50, 80]
    - weight-of-recycling-target [20, 50, 80]
    - weight-of-price [20, 50, 80]
    - waste-production-knowledge [true false]: Exploration of the sensitivity of the mere knowledge of waste production curve.
    - waste-tax-monthly [10 5 30]: Exploration of right waste-tax to absorb the additional cost of different campaigns to reach the target.
    - contract-duration" [12 24 60]: Results for short-, mid- and long-term contracts
- Output at each tick
    - The tick
    - Random-seed
    - Budget-per-household for each municipality
    - Recycling-target of municipalities
    - Frequency-of-survey of municipalities
    - Type-of-infrastructure of municipalities

Chapter 8: Data Analysis

In this chapter, the data obtained from NetLogo behavior space experimentation is used to shed light on the possible policy options to reach their recycled plastic target without disrupting the municipality budget.

Visualization

In the following, the two key performance indicators are visualized in Figure 3 and in Figure 4, waste management budget of the municipality per household and the achieved recycling rate.

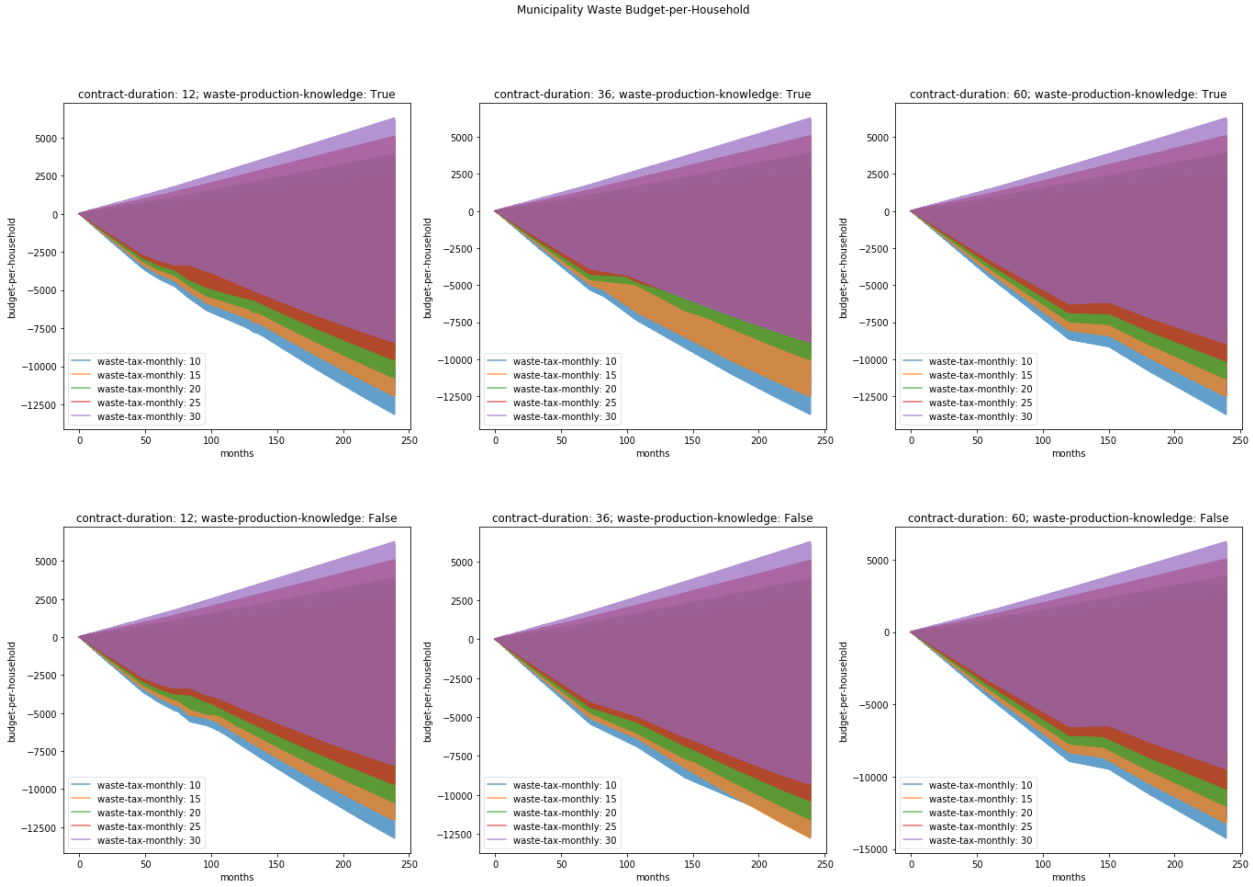

Figure 3. Analysis of municipal waste budget per household

This visualization enables us to derive the first conclusion. In Figure 3, it is shown that waste management budget of the government per household is independent of contract duration and the knowledge about the future waste production. Furthermore, since there is a high variance of the outcome, we can derive that the waste management budget of the municipality is highly uncertain. However, higher waste taxes shifts the dispersion the waste production upwards along the y-axis.

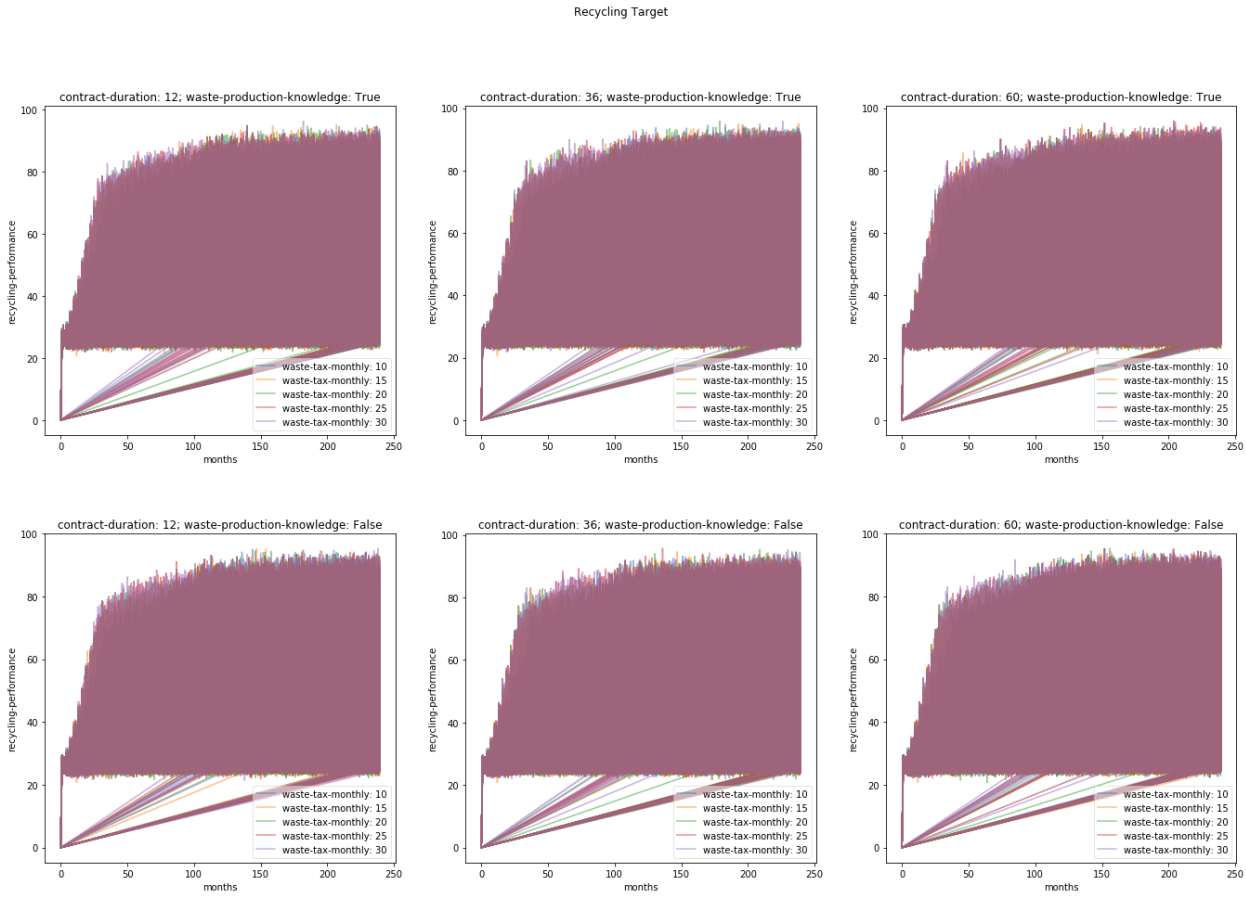

Figure 4. Analysis of recycling performance of municipalities

In Figure 4, the recycling target of 60% is achieved in nearly 35 months and converges to recycling rate of 90% after 50 months. As it was already observed in Figure 3 of waste management budget of the municipality, the recycling rate is independent of contract duration and the knowledge about the future waste production. Moreover, we can state that from the first exploration of data, it is also independent of the waste-tax.

Scatterplot

Following the visualization, scatter plots are used to identify the correlation between the two KPIs. Moreover, deeper insights are generated by adding policy levers as a third dimension. These scatter plots are generated by utilizing data from the last month (240) of the model.

The first conclusion, we can derive from Figure 5 is that a positive budget balance leads to a higher recycling rate. By looking into the third dimension of the scatterplots, we can derive further interesting insights. First, the knowledge of waste production does not affect our KPIs. Secondly, as seen earlier, the monthly waste tax increases the waste budget of the municipality and thereby it increases the achieved recycling rate. By comparing the scatterplots with the different weights/preferences of municipalities in deciding on their contracts with recycling companies, we can see that the consideration of the price is leading to better performance of

our KPIs. An additional interesting insight is that municipalities with centralized infrastructure are performing better than municipalities with decentralized infrastructure. However, this must be further explored since it is presumed that the sensitivity of households towards this variable is deeply uncertain. Finally, the constant monitoring of the recycling rate does not affect our KPIs.

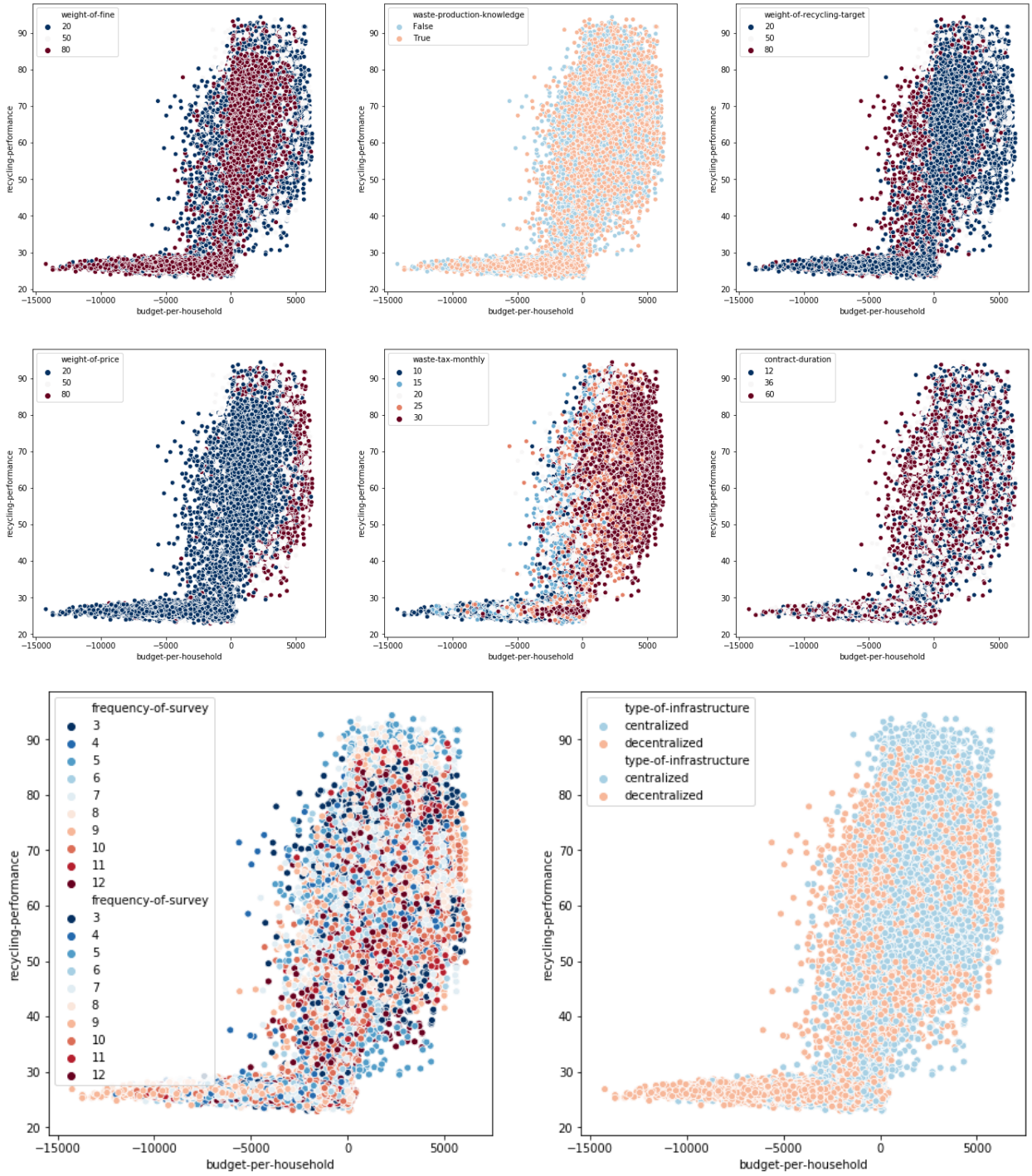

Figure 5. Scatter plots for the identified KPIs and effect of variables on them

Global Sensitivity Analysis

Although a local sensitivity analysis was conducted in the subsections above, a global sensitivity analysis is done to determine the most influential policy levers on our KPIs. In contrast to traditional global sensitivity analysis, a random forest approach based on feature scoring is used. As feature scoring is normally used to identify the most relevant factors to include in a model, we are using the feature scoring to determine our main policy levers.

From our feature scoring analysis in Figure 6, we can conclude two crucial insights which transpired already from the previous analysis. First, monthly waste tax is the main driver in our model. Second, for municipalities, the choice of the contract with recycling companies should be driven by price rather than fine or recycling target. Apart from this, we want to highlight the two additional policy levers: type of infrastructure and frequency of survey. This should be in particular considered if the adjusting of the waste tax is not an option due to political reasons.

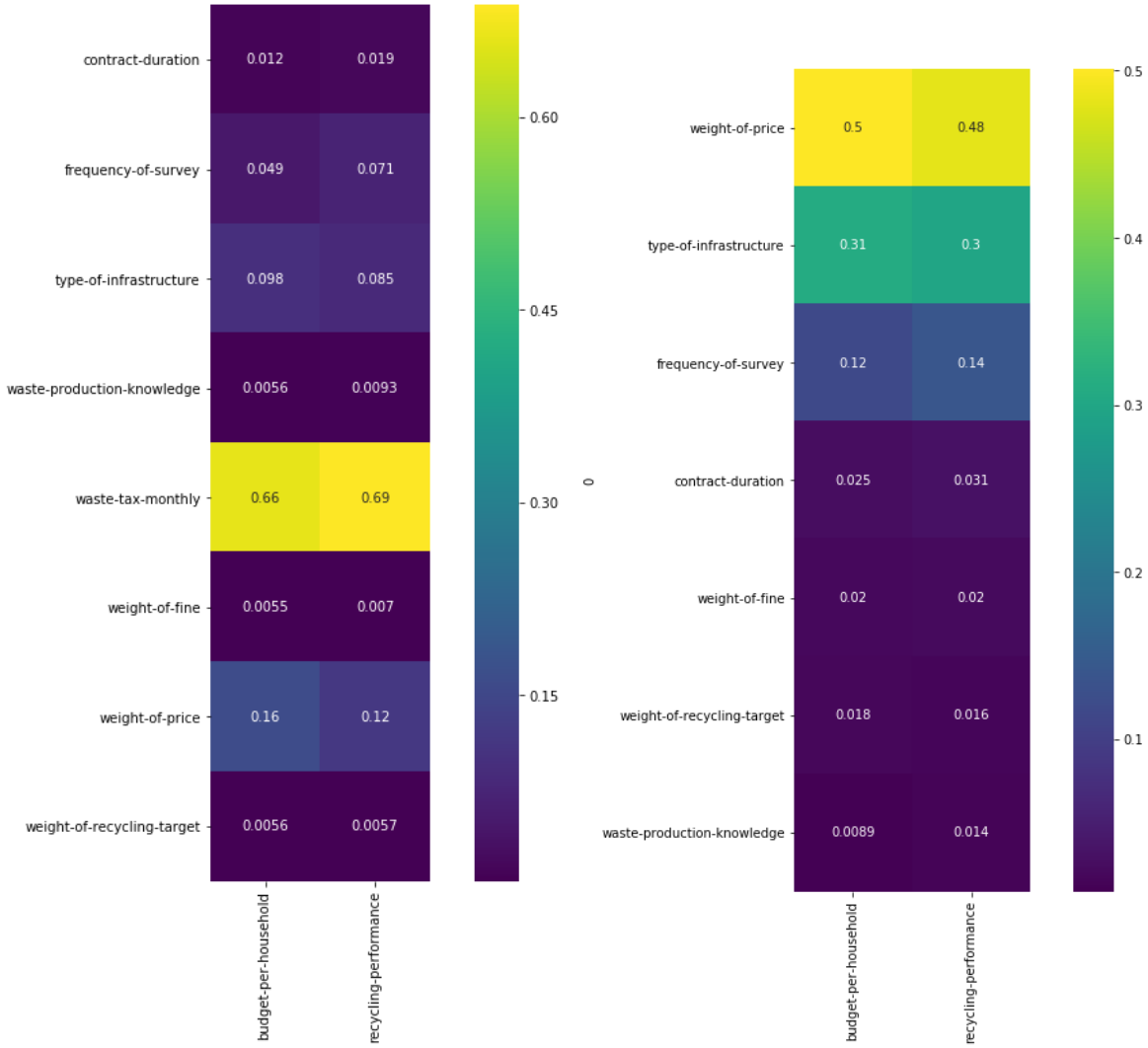

Figure 6. Results of global sensitivity analysis

Chapter 9: Model Validation

In this chapter, we determine whether the designed model represents the real system. However, the system was never intended to reflect the reality. Therefore we do not have a real system which we can compare our model with. Thus, this chapter focus on the capabilities and drawbacks of our model and the possible future expansions so that we can support the practicality of the model.

This model is capable of representing simple investment structures for the companies. The competition is in the center of the model, and being a market loser is chosen as a triggering event. Also, the campaigns are represented with a structure in the model. The survey method is introduced as a tool to detect whether a campaign is needed. Lastly, at the core of the model, overall waste production schemes, waste management structures, and recycling operations are discussed.

On the other hand, like every model, this model has its limitations. The households are modeled quite statically in our design. They are influenced by the actions of municipalities, however, there is no direct interaction identified between them and the recycling companies. More importantly, the households do not interact with each other. For example, they do not learn from the community. Also, population growth is not included in the model. Model is also limited to the influence of infrastructure on households' waste creation habits. Households change their behavior respective to the campaigns or infrastructure provided by the municipality, however, any waste tax change or company operation does not affect the households. Lastly, population movements are excluded. We did not cover the migration from rural to urban life, and the possible effects of these dynamics.

As mentioned before, the municipalities are identified as the client, and thus we tried to model the municipalities as detailed and realistic as possible to be able to provide feasible policy recommendations. In this regard, a couple of limitations were identified. One of them is that the municipalities do not interact with each other, but the other agents. Another one is the fixed infrastructure for the municipalities. They are not able to change their decentralized infrastructure to a centralized one, or vice versa. Lastly, the surveys that municipalities conduct to measure the overall recycling performance of their households are of fixed frequency over the modeling period. In our model, it is not possible for the municipalities to adjust the frequency of the surveys.

One of the most significant limitations for the recycling companies is their investment decisions. Investment making is represented in a quite simple manner. The companies invest if and only if they fail to get any contracts. Therefore, if a company is the business leader, it is not investing in its businesses. Only the losers of the market are improving their operations to increase their attractiveness. Also, there is no communication between companies, which neglects the effects of learning from each other's success stories and mistakes.

For the future work, the above-mentioned limitations can be omitted. However, we also would introduce some additional features which can enrich the model. One idea is to introduce a detailed recycled plastic market where the prices are changing with respect to the actions of players. Another idea is to improve the regulations. Currently, the model has the recycling target identified by the government and it is enforced to the municipalities. However, there may also be incentives for the municipalities or subsidies for the recycling companies etc. We think a better set of external features can be introduced so that a more accurate and insightful analysis can be achieved.

Chapter 10: Model Use

In the first chapter, we identified the research problem of this study as "*What are the effective sets of policy levers for municipalities to perform better with respect to the target recycled plastic rate without disrupting the municipality budget?"*. The model is designed to be able to achieve this outcome, and experiments are set respectively. The data is analyzed to extract the insights from the designed model. This chapter concludes the discussion by providing with the desired values for the chosen policy levers. Also, the assumptions of the research are shared here to guide the reader while examining the results.

Policy Recommendation:

The following table 2 is the description of the data with 60% and higher recycling rate and a positive budget from the experiments (see Chapter 7).

Policy Levers	Monthly waste tax	Weight of price	Weight of fine	Weight of recycling target	Contract duration
Mean	24.5	49.9	39.3	38.9	7.5
Standard deviation	5.4	25.7	23.3	23.1	2.9
Minimum	10	20	20	20	3
25%	20	20	20	20	5
50%	25	50	20	20	8
75%	30	80	50	50	10
Maximum	30	80	80	80	12

Table 2. Description of the data points with 60% and higher recycling rate and positive budget

Based on the table and our analysis in Chapter 8, we propose municipalities to increase the monthly waste tax to 24.5€ per household. Second municipalities should put the emphasis on price in the choice of the contract. In the choice of the contract, the price can be weighted with 40% whereas fine and recycling target can be weighted with 30%. However, this policy recommendation should be considered carefully since effects of campaigns on households or

effects of the infrastructure type on households are deeply uncertain. Furthermore, models are just a reflection of the reality and thus based on many assumptions. The assumptions of this model are mentioned in the following subsection.

Assumptions:

During the modeling phase, we give the priority to practicality rather than accuracy. Therefore, most of the data is based on the assumptions we made. Also, there are several points where we needed to make some structural assumptions to either simplify the model to be able to manage the level of detail or make it more meaningful to the client. This section is devoted to the list of assumptions we made during the study.

External assumptions:

- It is assumed that the external recycling target stays the same during the time period we examine. In a way, we assumed the model is going to be used to project the upcoming 20 years with respect to the recycling roadmap of the government which is set already.
- It is assumed that each tile on the interface represents 10 km of unit distance.
- It is assumed that the municipalities and companies are able to form their contracts in an instant, without affecting the monthly operations. There is no delay due to the absence of a contract.
- Contract formation process is step-wise. In each step, companies with the best offer form a contract with a municipality. This process continues until there is no company capacity to allocate, or there is no municipal waste to be processed. This step-wise approach happens without updating the time in the system so that it works compatibly with the assumption above.

Assumptions which are related to municipalities:

- The cost of conducting a campaign to increase the knowledge or perception of inhabitants about the waste recycling is assumed to be external and fixed for municipalities. In a way, these campaigns are perceived as projects which are done by external companies to meet the request coming from municipalities, and these companies set the price fixed for anyone.
- To have a scope, we considered a minimum and maximum amount of households which can be settled in a municipality.
- During the contract forming process, it is assumed that the municipalities evaluate the offers by checking the unit fine, the unit price, and the performance with respect to recycling target. These are reflected by using weights.
- It is assumed that the municipalities conduct surveys with a random frequency. 15% of the total population of the municipality is asked about their waste creation habits.
- The knowledge campaigns are given the priority, but this priority is not that huge since it is also assumed that in general, the number of campaigns should increase together. Therefore, it is checked by the municipality before conducting a campaign whether the

number of each campaign types are equal or there is one type which has a higher frequency.
- The success rate of a campaign is assumed to be directly related to the target households' sensitivity.
- Waste tax is assumed to be fixed for all municipalities. Therefore, more crowded municipalities are able to have more revenue. Different waste tax schemes can be added to the model to have a more realistic projection, but this part is disregarded to have a simpler model.
- The municipalities estimate the amount of waste which is produced in their municipal borders and use this estimation to request offers from the companies. We assumed two scenarios where the waste production equation we use is known by the municipalities so that they are able to estimate the future waste production values precisely, and it is not known by the municipalities so they have to use the particular month's waste values so the estimation error is higher.
- We assume after requesting offers the municipalities do not change the estimated amount of waste.
- The municipalities do not counter-offer the first offers from the companies but choose the most suitable one.
- Among the received offers, municipalities choose the best offer with respect to the multiplication of normalized values on the contracts and the importance factor of these values in the eye of municipalities.
- Municipalities do not prioritize the companies during the waste collection processes. If there is a mismatched supply of waste, then this mismatched amount is reflected each partner company in proportion to the total assigned waste to them.
- Surveys are assumed to be cost-free.

Assumptions which are related to recycling companies:
- The implementation time for a technological advancement is assumed to be fixed for each company in the market.
- It is assumed that the recycling companies support the centralized infrastructure, and if the municipality is of the decentralized, then they calculate the cost with the additional decentralized infrastructure factor which increases the unit costs.
- It is assumed that the efficiency levels and the capacity levels of the companies differ around a mean level which we identify in the model's interface.
- It is assumed that each company has a perception which changes randomly for the municipalities, and this perception affects the companies' decision making while offering costs.
- The unit cost of recycling processes for the companies, and also the unit cost of collecting waste from partner municipalities are regarded as external variables, whose values are determined in the market.
- The selling price of the recycled plastic is determined by an external market.

- During the contract formation process, the tendency is to have the least number of business partners to have a leaner business. Therefore, each municipality or company offers or requests the maximum possible amount of waste.
- It is assumed that the companies do not seek for profit based on the contracts, but they use the contracts to compensate for the operational costs. Therefore, the prices are set respectively to the amount of waste which is going to be processed and the unit recycling and collection costs. The companies acquire profit by selling the recycled plastic in the market.
- It is assumed that the fine is the compensation of the opportunity cost. When there is a mismatched supply of waste, it means that the company is unable to recycle the material and sell it in the market. The companies calculate the unit cost of fine by multiplying their expected fraction of recyclable plastic in the mismatched amount with their efficiency and the market price.
- Recycling companies are of the last word during the contract formation process. Among the municipalities which regards them as the candidate business partner, companies choose the ones which they want to allocate their processing capacity for.
- Companies evaluate their eligibility for the municipalities. If they were able to form contracts during the last contract formation period, the result of the evaluation is positive and there is no need to improve the current business scheme. However, if the evaluation shows that the company was unable to get any contract, then they immediately invest in their businesses and improve their attractiveness to be able to get a share in the market in the next contract term.
- When the companies see the need for investments, they decide on what type of investment they want to make by checking the market itself. If they are doing a poor job with respect to the average market level of efficiency, then they invest in their operational efficiency. If there is a lack of capacity with respect to the market levels, then they improve their capacity. If both aspects are worse than the market averages, the companies invest in both of them.
- It is assumed that there is no budget restriction on the investment decision of the companies. The investments are financed through loans from banks, and this is external to our model. Therefore, the investments do not have any immediate effect on the budget of the recycling companies.

Assumptions which are related to households:

- The growth is excluded, the population is assumed to be fixed over 20 years.
- To have an initial point, it is assumed that the fractions of household types are 22%, 37%, 16%, and 25% for “single”, “family”, “couple”, and “old” respectively.
- It is assumed that without effect from campaigns or infrastructure, couples and families have a perception towards plastic recycling so that this perception amplifies their performance, while it is opposite for the singles and old people.
- The knowledge, on the other hand, is assumed to be higher for singles and family households follow them, while there is a lack of knowledge for couples and old people.

- We assumed the most sensitive household type for the campaigns are households, due to the fact that the parents may want to be good examples for their children and it can affect the overall performance of family households. However, campaigns are not that effective for old people since we assumed the effect of conservatism against new regulations can be more powerful for this type of households.
- The sensitivity for infrastructure has different dynamics than the sensitivity for knowledge. The old people are the most sensitive household type for the infrastructure due to the fact that the convenience of the decentralized structure is much higher for old than it is for young people.
- It is assumed that the households support to have a decentralized infrastructure.
  We assumed that there are 100 identical households in a municipality with respect to the identified attributes. Therefore, each household within the system is a representative of 100 households. This helps us to decrease the allocated computational power to the model.
- Each household is placed on the coordinates of the municipality that they are affiliated with.
- The type of provided infrastructure affects the perception of the households negatively if it is centralized. The base value of this effect is assumed to be 20%, but this effect can be amplified with the additional influence of sensitivity of the households.
- The waste production is done with respect to the equation provided by the project description, this amount is assumed to be the monthly waste production, while the “x” value in the equation is taken as the months.
- Households pay taxes to their municipalities for the waste management services, however, we assume there are no budget constraints for households to pay these amounts. A more extensive model can take into account the effect of taxes on household budgets and also their behavior, but for the sake of simplicity, we disregarded that part.
- It is assumed that if the infrastructure of the municipality is decentralized, perception stays the same, if it is centralized, perception is 80% of the base perception level of the particular household.