Wasting food on the level of a household

System Dynamics based study towards the potential effects of interventions

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Executive summary

Households are the major contributors to the waste of food in The Netherlands. In 2016, 41.2 kilogrammes of food per person were wasted on average. This waste of food was avoidable; it was edible when it was discarded or it could have been eaten before it became inedible. Next to the negative consequences for the household in financial terms, there are negative effects resulting from the discard of that amount of food for the environment too. Namely, to produce food the earth's biodiversity is sacrificed, greenhouse gases are emitted and large amounts of water are used. Looking at the increasing population which is dependent upon the same resources, the inefficient use of resources will cause problems in the long term in providing food for everyone.

Reducing the waste of food has positive environmental impacts. However, it has become clear that households do not reduce the waste of food by themselves. Reducing this waste of food can be realised by affecting the food waste related behaviour of households. This behaviour can be influenced by multiple stakeholders, resulting in a potential decrease of this waste of food. Interventions that are focussed on reducing the waste of food generated by a household are suggested in scientific literature. However, there is little evidence, as to what interventions do work and what interventions do not work.

On January 26th 2017 a national Task Force on food waste was created. This Task Force, an initiative by Wageningen University in collaboration with the Ministry of Economic affairs and the Alliantie Verduurzaming Voedsel, combines initiatives to reduce the food wasted within the Netherlands. The focus of this study is to provide insights for this Task Force regarding the potential effects of interventions on the waste of food generated by a household.

The objective of this study is to derive important insights regarding the waste of food on the level of household and transform these insights into recommendations for the Task Force. This main objective can be divided into multiple sub-objectives. First, this study aims to contribute to the understanding of the causal relations between the factors that are present within the system that represents the generation of food waste on the level of a household. Secondly, it aims to contribute to the understanding on what kinds of interventions are possible to reduce the food waste and what their potential effects are on the food waste behaviour of households. Thirdly, this study illustrates the possible effects of interventions and combinations of interventions on the food waste behaviour.

The factors and causal relations between factors are analysed and demarcated by developing a qualitative model that represents the system in which food waste is generated by a household. Interventions are identified by reviewing scientific literature. A set of interventions is considered during this study. To identify the potential effects of these interventions on the food waste within households, a quantitative model is created that is capable of simulating these effects. This quantitative model is based on the aforementioned qualitative model. The simulated results are transformed into insights and advice for the Task Force.

The system of food waste on the level of a household is conceptualised by designing a specific kind of qualitative model. In this study, a causal relation diagram is designed. Within this diagram, a process is identified which consists of multiple phases: the planning, the purchasing, the storing, the preparing, the consuming and the re-using leftovers phase. In each phase, causes for the generation of food waste are identified. Within the diagram, edible and inedible stored food and leftovers can be discarded. Besides, food is wasted when food is prepared wrong. Based upon the qualitative model, two major feedback mechanisms are identified.

A feedback mechanism for the storage of food and leftovers, and a feedback mechanism for the waste of food. The stored food and leftovers are partly considered while a household plans the food that needs to be bought. This results in less food planned by the household. Households that waste food are more willing to change their planning and preparing behaviour. This behavioural change results in less planned and prepared food, which results in less wasted food. The combined effect of these mechanisms is assumed to have a balancing effect on the food waste system.

Possible interventions are identified by reviewing scientific literature that can affect the changeable parameters from the qualitative model from a multi-stakeholder perspective. A set of interventions is considered based upon the responsible stakeholder, the social nature or technical nature of the intervention and the phase it affects. The following interventions are used to decrease the waste of food are considered in this study:

- *FridgeCam*; this **technical intervention** from a company perspective affects the planning phase. It increases the degree that a household can check their inventory while making a planning. Applying this intervention enables a household to estimate the food needed better while determining the planned food.
- *No discount and economies of scale*; this **technical intervention** from a supermarket's perspective affects the purchasing phase. If supermarkets remove their products with discounts, a decrease in the quantity of unnecessary food bought by a household, which makes it more likely that stored food will not be throw away.
- *Spoilage knowledge campaign*; this **social intervention** from a governmental perspective affects the storing phase. Increasing the knowledge can lead to food being stored and used within a longer time frames, which makes it more likely that the stored food will not be thrown away.
- *Awareness consequences food waste campaign*; this is a **social intervention** from a governmental perspective. Increasing the knowledge regarding the consequences of wasting food is assumed to increase the moral attitude within a household. Increasing the moral attitude results in a behavioural change of the planning and preparing behaviour within a household. Less food is planned to be bought and less food is prepared, both resulting in less food thrown away.

Incorporating the effects of these interventions in the causal relation diagrams results in temporary feedback mechanisms. An intervention affects the waste of food within a household, which results in a lower perceived food waste by the household. Following this, the effect of the intervention is reduced. Reducing the waste generated within a household by means of an intervention decreases the effects of the intervention itself. These causal mechanisms are assumed to also have a balancing effect on the food waste system.

A System Dynamics model is created based upon the causal relation model. The data needed was not always available. Assumptions are therefore inevitable. To cope with these assumptions, multiple important uncertain parameters are identified and considered during the robustness analysis during the model use.

The resulting System Dynamics model is tested and improved. Based upon the static and dynamic tests, it is concluded that the System Dynamics simulation model is usable for the intended purpose.

Simulating the System Dynamics model with no intervention resulted in a constant amount of food wasted on the longer term. This equilibrium can be explained by the balancing causal mechanisms that are incorporated within the System Dynamics model. Based upon the results of simulating the interventions individually, it is concluded that interventions do not have a big individual potential effect on the avoidable food waste. The waste of food can be reduced more effectively if multiple interventions are combined into intervention strategies, often from multiple stakeholders' perspectives. An enlarging effect can be identified when multiple interventions are combined. Based upon simulating combined interventions, it is concluded that households should know how to reduce the waste of food (i) and households should be willing to reduce the waste of food (ii). Combining interventions that affect both aspects enlarged each other's individual effect. Increasing the 'willingness' has a positive effect on the effect of the intervention that is focussed on the 'knowhow' within households. A counterproductive effect is also identified; combining interventions that both focus on the 'knowhow' resulted in a lower combined effect than accumulating the individual effects. This decreasing effect can be explained by that an intervention that focuses on the 'knowhow' decreases the food wasted within a household. Wasting less food results in a decrease of the effect of an intervention via the aforementioned temporary feedback loops. Thereby, combining two interventions that reduce the

food waste within a household results in a decrease or each other's effect, finally resulting in a decreased combined effect. Important uncertain parameters are varied during the simulation of an intervention strategy to test its robustness. Based upon the robustness analysis, it can be concluded that the behaviour of the intervention is robust, but that the actual size of the effect on the waste of food generated by the household is uncertain. The potential impacts given by the simulations cannot be taken for granted and should be considered carefully. However, the underlying enlarging or decreasing aspect within the System Dynamics system remains the same.

The Task Force is a promising initiative. All the important stakeholders needed to effectively reduce the waste of food are included within the Task Force. The waste generated within households is considerable. Effective interventions may reduce the waste of food by millions of kilogrammes. Based upon the results of the simulations, it is assumed that households are responsible for 22% to 31% of the total food wasted within the Netherlands. The waste of drinks are excluded and the unavoidable waste of food is not incorporated. Based upon the results of this study, recommendations are given. To effectively reduce the waste of food, design interventions or intervention strategies that focus on multiple causes of waste in multiple phases of the food waste process within a household. The waste of food is fragmented and effective reduction of this waste demands a multi-levelled approach. Besides, focus on the 'willingness' and on the 'knowhow' within a household when combining multiple interventions. Effectively affecting both aspects within a household results in a synergy; the effect of the whole is greater than the simple sum of its parts.

Keywords: Food Waste, Avoidable food waste, Interventions, Intervention strategies, Households, System Dynamics, Potential effects.

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1. Introduction

1.1 Problem content

This section elaborates on the problems surrounding the waste of food generated by households. The awareness regarding the importance of reducing food waste is increasing at a national (Quested et al., 2013), European (Reisinger et al., 2011), and a global level (Foley et al., 2011). However, still a lot of food is wasted. Households are the major contributor to the waste of food in developed regions (Griffin et al., 2009; Parfitt et al., 2010; Gustavsson et al., 2011; Koivupuro et al, 2012; Silvennoinen et al., 2014). For instance in the Netherlands, it is estimated that 41.2 kilogrammes per person is wasted in 2016. This is 14% of the all the food that enters a household (van Doornen, 2017). This waste of food was avoidable; it was still edible when it was discarded or it could have been consumed before it became inedible.

There are negative consequences regarding the waste of food. The world population is constantly increasing and meeting society's growing demand of food is a challenge (Foley et al., 2011). Feeding this growing demand is consequential; it sacrifices Earth's biodiversity, it increases the production of greenhouse gas emission due to the extra needed production, and it reduces the water supplies (Muir et al., 2010). Reducing the waste of food results in a decrease of these negative environmental consequences.

In the past, the government of the Netherlands took minor measures for reducing the waste of food within households. The Dutch government, via other institutions, mainly provided information on how to reduce food waste on the level of a household. This is done by means of information campaigns. To further reduce the food wasted in the Netherlands, a Task Force was created on the 26th of January 2017. This Task Force, which is an initiative by Wageningen University & Research, in collaboration with the Ministry of Economic Affairs, and the Alliantie Verduurzaming Voedsel, combines initiatives against the food waste within the Netherlands. This Task Force thereby it is assumed to the Task Force also focuses on the decreasing of the waste of food generated by households.

Households do not decrease the waste of food by themselves. To reduce this waste, collaborative action is needed and called for from multiple stakeholders, however, these actors may have different conflicting perspectives on the waste of food (Halloran et al., 2014). Many suggestions on how to reduce the waste of food generated by households are made in scientific literature. However, there is little evidence, as to what interventions work and what interventions do not work (Sharp et al., 2010). Empirical, comparative research on success factors of multiple food waste reductions initiatives across different actors is currently lacking. It is unclear which factors influence the success of these initiatives, how these factors are influential, and not least, how future consumer-related food waste initiatives may be developed based on these findings (Aschemann-Witzel, 2016).

In this study, the focus is on interventions and combinations of interventions that have a potential influence on the food wasted on the level of a household from a multi-actor perspective.

1.2 Research problem

This section elaborates on the scientific aspects of the problem defined in previous section. Besides, knowledge gaps are identified. In scientific literature, it is argued that the research is focused on specific phases within the process of wasting food instead of the behaviour of the process as a whole at the level of a household (Quested et al., 2013; Parizeau et al., 2015; Principato et al., 2015; Roodhuyzen et al., 2017). *In this study, the focus is on the whole process in which food is generated by a household rather than on one phase specifically.* Roodhuyzen et al. (2017) concluded that a variety of factors are potentially associated with consumer food waste, but that the precise way in which they (particularly) exert influence is often uncertain as empirical research into the exact causal mechanisms is lacking. *This study aims to identify and approach the causal relations between the factors that are present within the food waste system responsible for* *the household food waste.* Considering the whole process of food waste within a household defined by Roodhuyzen et al. (2017), could increase the quality of interventions applied; possible known but also unknown effects of interventions can be considered better. The effects on the food wasted are not monitored or measured yet. *In this study the aim is to gain insight into the effects of multiple interventions, individually and combined on the waste of food generated by household.*

Based upon the research problem, the following knowledge gaps are identified:

- The factors and the causal relations between these factors that are responsible for the generation of the waste of food on the level of a household
- An overview of the possible interventions that can be used to reduce the food wasted on the level of a household
- The possible effects of interventions and the combined effects of multiple interventions on the waste of food on the level of a household

1.3 Research objective

This section elaborates on the objective of this research. The main research objective is to contribute to the overall understanding of the system in which food is being wasted on the level of a household. Besides, the potential effects of interventions and intervention strategies on this waste of food in the Netherlands are investigated. The aim is this study is to derive important insights and transform these insights into an advice for the Task Force. This main objective can be divided up into multiple sub-objectives. First, this study aims to contribute to the integral understanding of the causal relations between the factors that are present within the system in which the behaviour of food waste occurs. Secondly, it aims to contribute to the understanding on what different kinds of interventions are possible and what their potential effects are on the waste of food within households. Thirdly, this study aims to illustrate the possible effects of different interventions and combinations of different interventions on the behaviour of the waste of food within households. A qualitative model is designed to contribute to the understanding of the causality present within the food waste system. Based upon the qualitative model, a quantitative model is developed that is capable of simulating the potential effects of the interventions on this waste of food.

1.4 Research relevance

This section addresses the relevance of this research. Addressing the knowledge gaps identified in section 1.2 has a social and a scientific relevance. The *social relevance* is related to the contributions of the qualitative and quantitative model. As mentioned in section 1.1, a Task Force is initiated in the Netherlands to focus on the reduction of food waste on the level of households. The insights derived from the model can be used in this Task Force's advantage. This *scientific relevance* is related to the scientific field regarding the waste of food generated by households. This study introduces a new way of looking to the complex system of food waste on a household level. The focus is on identifying causal pathways between relevant factors that are needed to generate the food waste behaviour within households and simulating the effects of the interventions on the food waste system means of a quantitative model.

1.5 Research questions

The main research question and sub-questions that are used for addressing the knowledge gaps identified in section 1.2 are discussed in this section. The following main research question is considered: **"What are the possible effects of interventions on the food waste related behaviour on the level of a household?"**

To answer this main research question, 3 research questions are formulated to structure the research process. Based upon these sub-questions, a research design is formulated in next section.

- *"What are the main mechanisms resulting in the food waste behaviour on the level of a household?"*

This research question covers the first knowledge gap. The factors and the causal relations between these factors that are responsible for the generation of the waste of food on the level of a household are considered during this research question.

- *"How can the generation of food waste on the level of a household be influenced from a multi-actor perspective?"*
  This research question covers the second knowledge gap. An overview of the possible interventions that can be used for reducing the food that is wasted at the level of a household is identified from a multi-actor perspective.

- *"What are the effects of interventions on the waste food within households?"*
  This research question covers the third knowledge gap. To gain insights regarding the effects of interventions identified in previous research question, a quantitative model is needed. This quantitative model is based upon mechanisms defined during the first research question.

1.6 Research design

This section discusses the research approach on how to address the aforementioned research questions and thereby structures the research. Per research question, relevant research activities are identified. The research design is dived up into three parts. the specification & interpretation part, and the integration part(section 1.6.3).

The conceptualisation covers the capturing of the mechanisms that are responsible for generating the waste of food within a household, elaborated on in sub-section 1.6.1. The specification & integration part is discussed in sub-section 1.6.2. The specification part covers the translation of these mechanisms into a quantitative model. Interpretation is about discussing and understanding the results of the model. The integration part covers the transformation of the results of the simulations into a broader perspective, which is elaborated on in section 1.6.3. The resulting insights can be used by the Task Force while designing, developing or considering an intervention or combination of interventions on reducing the waste of food. Based upon this resulting research designs, a study outline is given in section 1.7 in which chapters are connected to these designs. In these chapters the research designs are described in more detail.

1.6.1 Part 1: conceptualisation

During the conceptualisation part, the first two research questions defined in section 1.5 are answered. Thereby, also the first two knowledge gaps defined in section 1.2 are considered. The aggregated research approach for the first and second research questions are visualised in figure 1 and figure 2. In this part, the food waste system is analysed and demarcated by designing a qualitative model. Besides, interventions are identified that are further considered during this study. The resulting qualitative model is the main structure for the quantitative model designed in the specification & interpretation part.

"What are the main mechanisms resulting in the food waste behaviour on the level of a household?"

The first research question covers the first knowledge gap: *the factors and the causal relations between these factors that are responsible for the generation of the waste of food on the level of a household*. To answer the first research question and to fulfil the first knowledge gap a combination of desk research, literature review, and interview approach is used. A systematic literature review by Roodhuyzen et al. (2017) is used for identifying the relevant factors for the waste of food generated by households. Extra factors needed for representing the food waste system are identified and added in this study. The factors based upon the Roodhuyzen et al. (2017) combined with the extra factors identified in this study are transformed into a qualitative model, which represents the system in which a household generates food. The resulting qualitative is discussed with experts. Based upon this discussion, the qualitative model is adjusted.

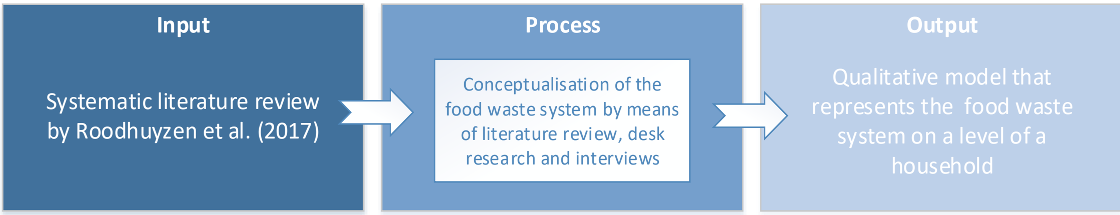


Figure 1: research design conceptualisation (i/ii)

The result of this research question is a demarcated qualitative model, which represents the waste of food generated by households. This qualitative model is transformed into a quantitative model during the specification part. The changeable variables that are identified in this section are used as anchor points for identifying relevant interventions during the following research question.

"How can the generation of food on the level of a household be influenced from a multi-actor perspective?"

The second research question covers the second knowledge gap: a*n overview of the possible interventions that can be used to reduce the food wasted on the level of a household.* To answer this question, desk research, literature review, and expert interviews are used. In this research question, the changeable parameters are identified based upon the qualitative model defined in the previous research question. Important stakeholders are deduced to identify possible opportunities regarding the interventions. The changeable parameters and the possible stakeholders are combined resulting in an overview per phase, resulting in an overview of multiple possibilities regarding the interventions. A combination of a literature review and desk research is used to add possible interventions to this overview. Based upon the available interventions, a set of interventions is considered during the simulations.

Figure 2: research design conceptualisation (ii/ii)

The result of this research question is a set of interventions that is considered further during this study. The effects of these interventions are simulated during the interpretation part. Based upon the available data, the qualitative model combined, and the identified interventions a modelling method is chosen at the end of this part.

1.6.2 Part 2: specification & interpretation

During the conceptualisation part, the first two research questions are answered, resulting in a qualitative model, which represents that represents the food waste system on the level of a household and a set of interventions that is considered further during this study. During this part, the third research question defined in section 1.5 is answered. Thereby, also the third knowledge gaps defined in section 1.2 is considered. The qualitative model identified in previous research question is transformed into a quantitative model during specification part. The resulting quantitative model is tested to identify its limitations and to improve the quantitative model. The set of interventions identified in previous research question is considered during the interpretation part. Based upon the improved quantitative model, the potential effects of the set of interventions are simulated. The aggregated research approaches for answering the third research question are visualised in figure 3, figure 4, and figure 5. The results of the simulations are transformed into insights during the integration part.

"What are the effects of interventions on the waste food within households?"

The third research questions covers the third knowledge gap: *The possible effects of interventions and the combined effects of multiple interventions on the waste of food on the level of a household.* To answer this research question, desk research, literature review, and expert interviews approach are used. To estimate the effects of the intervention, first available data is gathered and the model is build. Secondly, the model is tested and improved. Lastly, the improved model that resulted from the testing is used to simulate the interventions that are identified during the second research question.

Model building and data-gathering
To build a quantitative model and to gather data, a desk research and literature review are used. To design a quantitative model, first data needs to be gathered to estimate the relations between the variables and the values of the variables within the qualitative model. Based upon the available data and the qualitative model, a quantitative model that represents the qualitative model is designed.

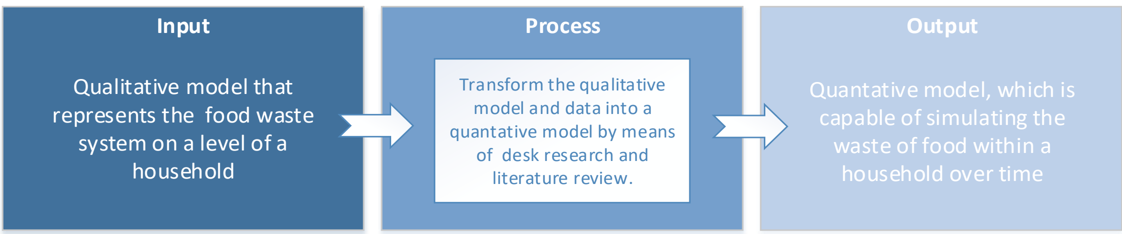


Figure 3: research design specification (i/ii)

The result of these steps is a quantitative model that is capable of simulating the food waste behaviour within a household over time. Following this, the model is tested during the model testing. Besides, a set of uncertain parameters is identified, which are also considered during the interpretation part.

Model testing
During the model testing, the resulting quantitative model from previous section is tested static and dynamically. To test the model, desk research, literature review, and expert interviews are used. First, possible static and dynamic test are identified. Following this, these test are performed. According to the results of the test, the model is adjusted and improved.

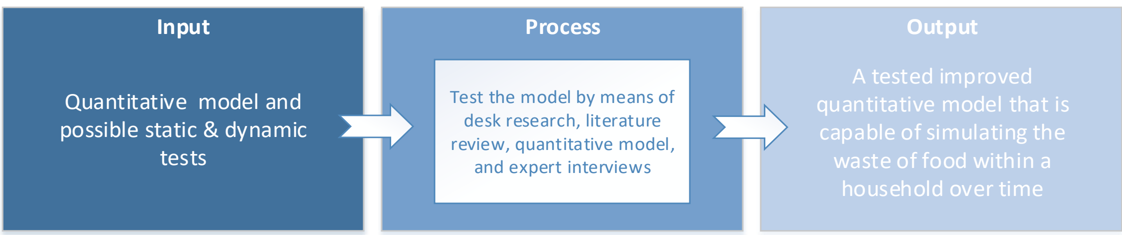


Figure 4: research design specification (ii/ii)

The result of these steps is an improved quantitative model that is capable of simulating the food waste behaviour within a household over time. This model is used during the interpretation part to simulate the effects of the interventions identified during the second research question.

Model use

In this part the interventions defined during the second research question are simulated by means of the improved quantitative model resulting from previous part. First the interventions are simulated individually. After, multiple interventions are simulated combined. Based upon the results, the most effective combination of interventions tested on its robustness. This is done by varying the important the uncertain parameter identified during the specification while simulating the most effective combination.

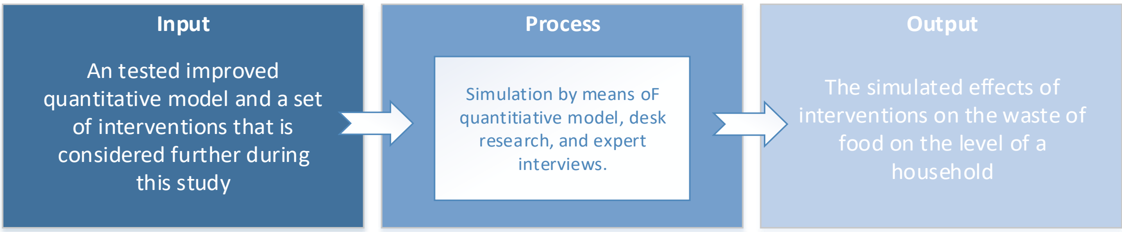


Figure 5: research design interpretation

The result of the model use is an overview of the effects of the interventions based upon the simulations. The individual, combined effects on the waste of food generated within a household are given. Besides, the robustness is tested of the most effective combination of interventions. Based upon the results, insights are derived and considered during next part, the integration part.

1.6.3 Part 3: integration

During the conceptualisation phase, the first two research questions are answered and thereby also the first two knowledge gaps. During the specification & interpretation part the third research question defined is considered and thereby also the last knowledge gap. The results of previous part are the simulated potential effects of the interventions based upon the quantitative model. These results are considered in more detail in this part. Insights are derived from the results by reviewing the results from a broader perspective. Based upon this review, insights are derived and transformed into advice for the Task Force.

1.7 Structure of study

The setup of this study as follows: chapter 2 and 3 cover the conceptualisation part. The food waste system on the level of a household introduced in chapter 1 is transformed into a demarcated qualitative model in chapter 2. Based upon this qualitative model combined with relevant actors, interventions are identified that can be implemented to reduce the food wasted. This is done in chapter 3. The combined result of chapter 2 and 3 is a qualitative model and the interventions that can are able to influence this qualitative system. This is the basis for the second part, the specification & interpretation part. During the specification, data is gathered, the quantitative model is build, and the quantitative model is tested and improved. The available data regarding the relations and parameters within the qualitative model is gathered in chapter 4. Based upon this, the available data, qualitative model, a quantitative model is built in the same chapter. Chapter 5 elaborates on the static and dynamic tests that are performed to improve the quantitative model. Chapter 6 focuses on the use of the model; interventions defined in chapter 3 are simulated by means of the improved quantitative model resulting from chapter 5. The interventions are simulated individually and combined. One combination of interventions, one intervention strategy is considered while varying important uncertain parameters to test its robustness. Chapter 7 reviews the results of this study and puts them in a broader perspective. Lastly, Chapter 8 concludes this study by answering the main research question, offering a discussion, and giving recommendations for further research. An overview of the structure of this study is given in figure 6.

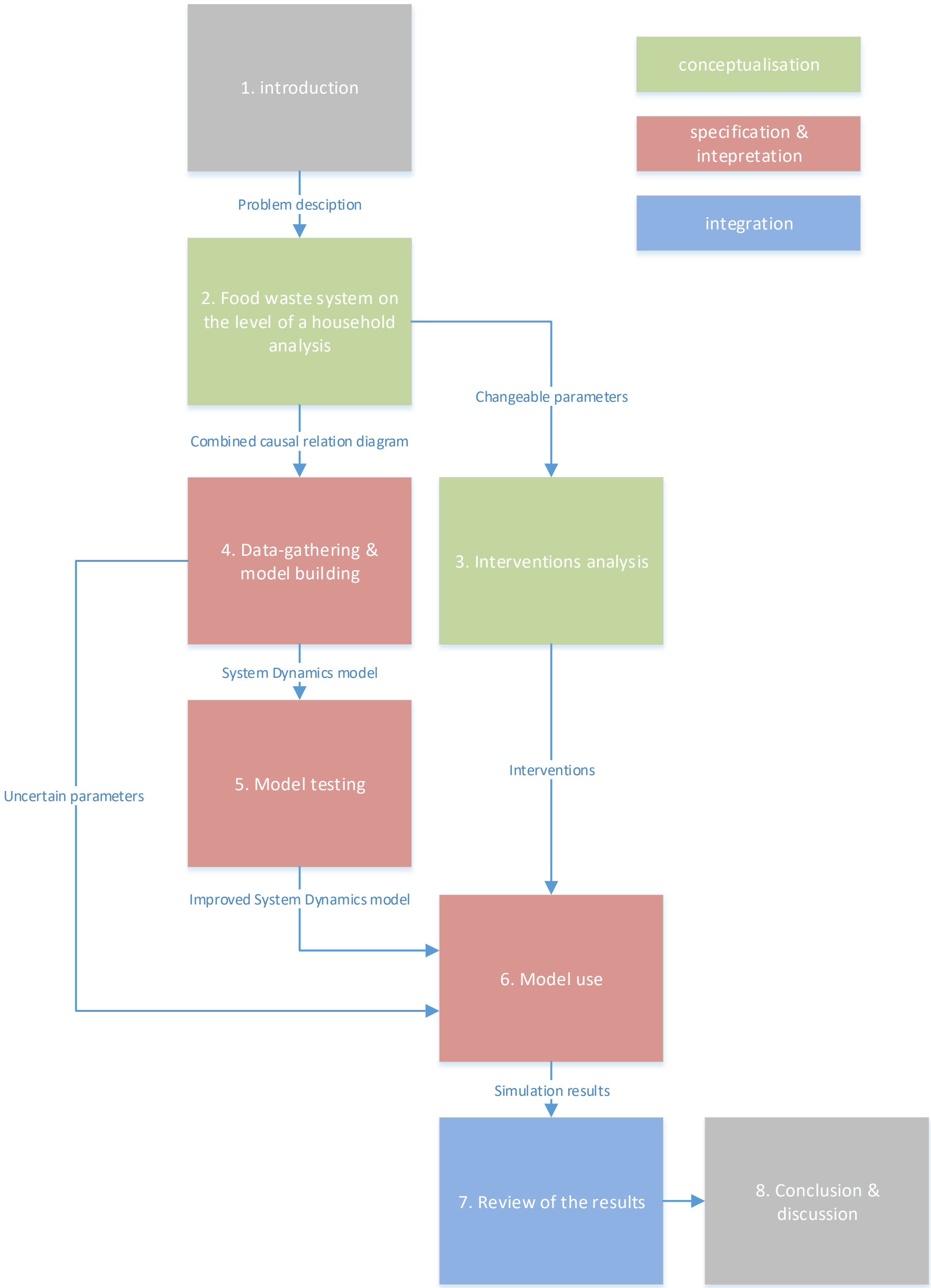


Figure 6: study outline

2 Qualitative food waste system analysis

This chapter describes a qualitative model that represents the food waste system of the research problem defined in previous chapter. Therefore, the chapter is structured as follows: a definition of food waste is given in section 2.1 to scope the system. The approach on how to design the qualitative model is described in section 2.2. Based upon this approach, qualitative sub-models are discussed in section 2.3. These sub-models are connected to each other in section 2.4 resulting in a combined qualitative model. Different feedback loops that are present within this combined model are elaborated on in section 2.5. The most important insights regarding the aforementioned discussions are concluded in section 2.6. The resulting combined qualitative model is used in chapter 3 to identify possible interventions and in chapter 4 as basis for the quantitative model. A more detailed overview of the factors, variables, and causal relations are elaborated on in more detail in **appendix A.**

2.1 Defining food waste

This section defines the term food waste to scope this study. As mentioned in the introduction, multiple terms and definitions of food waste are used from multiple perspectives. Food waste is for example defined from a social, a zoo-technical, and an environmental perspective (Garrone et al., 2014). The waste of food is divided into different kinds of waste (food loss and food waste) depending on the stage within the food supply chain in which the waste of food occurs. Food loss is defined by Lipinski et al. (2013) as food that is spilled, spoiled, incurred an abnormal reduction in quality by means of bruising or wilting, or otherwise gets lost before it can reach the consumer. Food loss takes place during the production, postharvest, and processing stage of the food supply chain (Kummu et al., 2012). Food waste is defined by Lipinski et al. (2013) as edible food that is fit for human consumption, but does not get consumed because it gets discarded either before or after it spoils. This type of food waste takes place during the distribution and consumption stage of the food supply chain (Kummu et al., 2012). A further distinction of food waste is made between unavoidable, possible avoidable, and avoidable food waste (Beretta et al., 2013; Monier et al., 2011; Parfitt et al., 2010; Principato et al., 2015). Another type of categorisation is made by using activity related practices like storing waste or kitchen waste (Katajajuuri et al., 2014).

To scope the research the following definition, based upon the previous definitions of food waste is used in this study:

"All the avoidable food that is discarded during the storing of food, preparation of food, and the leftovers that are discarded within a household, either before or after it spoils, by the human members within a household"

2.2 Qualitative analysis approach

To structure the qualitative analysis, the conceptual framework identified by Roodhuyzen et al. (2017) is used as a point of departure, which is found in figure 7**.** It is argued by Quested et al. (2011) that: "The generation of food waste is not a behaviour in itself, but results from the interaction of multiple behaviours relating to planning, shopping, storage, preparation, and consumption of food. Indeed, by the time food is thrown away, the opportunity to prevent that food from becoming waste has often passed'' (p. 463). This food waste process on the level of a household with similar phases is also derived by Roodhuyzen et al. (2017), Parizeau et al. (2015), and Principato et al. (2015). The conceptual framework of Roodhuyzen et al. (2017) gives insights into the different type of factors that should be considered while investigating the waste of food by households. This framework helps to imagine the possible causal pathways that are present within this food waste system. Besides, the framework illustrates how these pathways can be shaped and effected by interacting factors. The different types of this framework are used to categorize the process in which food is wasted.

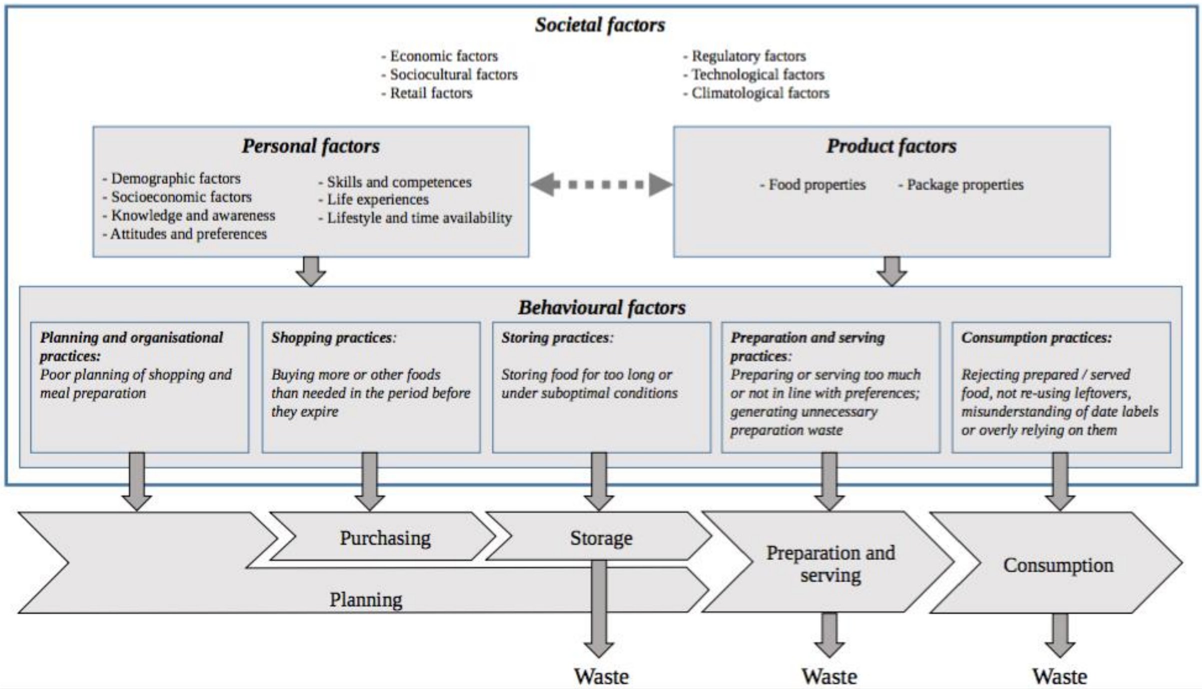


Figure 7: framework introduced by Roodhuyzen et al. (2017)

In this study, the different types of practices illustrated in the conceptual framework by Roodhuyzen et al. (2017) are used for identifying possible phases. These phases are used to categorize the different factors needed to represent the food waste system. Based upon the framework, the following phases are considered during this study to structure the analyses:

1. **Planning practices:** planning practices result in the behaviours regarding the planning of food in households. The planning behaviour within households must be considered since poor planning practices result in planning to buy more food than actually needed. Planning to buy more food is correlated with the waste of food. The factors that are needed to generate the planning behaviour are considered during the *planning phase.*
2. **Purchasing practices:** purchasing practices result in the purchasing behaviours of the households. The purchasing of food must be considered since households tend to buy too much food, even more than initially planned. Buying too much food is correlated with the food waste. The factors that are needed to generate the purchasing behaviour are considered during the *purchasing phase.*
3. **Storing practices:** the purchased food is stored within the households. This storing behaviour is a result of the storage practices. The storage of food is considered since storing food too long results in food waste. Buying too much food may result that it cannot be consumed on time. Therefore food becomes inedible and is discarded. Besides, storing food too long may result in edible food discarded. The factors that are needed to generate the storing behaviour are considered during the *storing phase.*
4. **Preparing & serving practices:** the food that is stored needs to be prepared before it is consumed. Preparation practices that create the preparation behaviour are therefore considered in this study. Preparing food wrong or preparing too much food may result in food waste. The factors that are needed for generating the preparing & serving behaviour are considered during the *preparing phase.*
5. **Consuming practices:** prepared food is consumed, which is the consuming behaviour in this system. These consuming practices are important to consider since it results in the food that is leftover or discarded right away. The factors that are needed to generate the consuming behaviour are considered during the *consuming phase.*

Leftovers play an important role regarding the waste on the level of a household since these leftovers can be discarded, which results in the waste of food. To cope with this kind of food waste, an additional *re-using leftover phase* is considered in this study and added to the aforementioned phases. During this study a distinction is made between the planning, purchasing, storing, preparing, consuming, and re-using leftovers phase to structure the analyses.

Research steps are required to develop a qualitative model. A visualisation of the research approach used in this chapter is given in figure 8**.** Based upon the research steps, the qualitative model representing the food waste system on the level of a household is designed and discussed in this chapter.

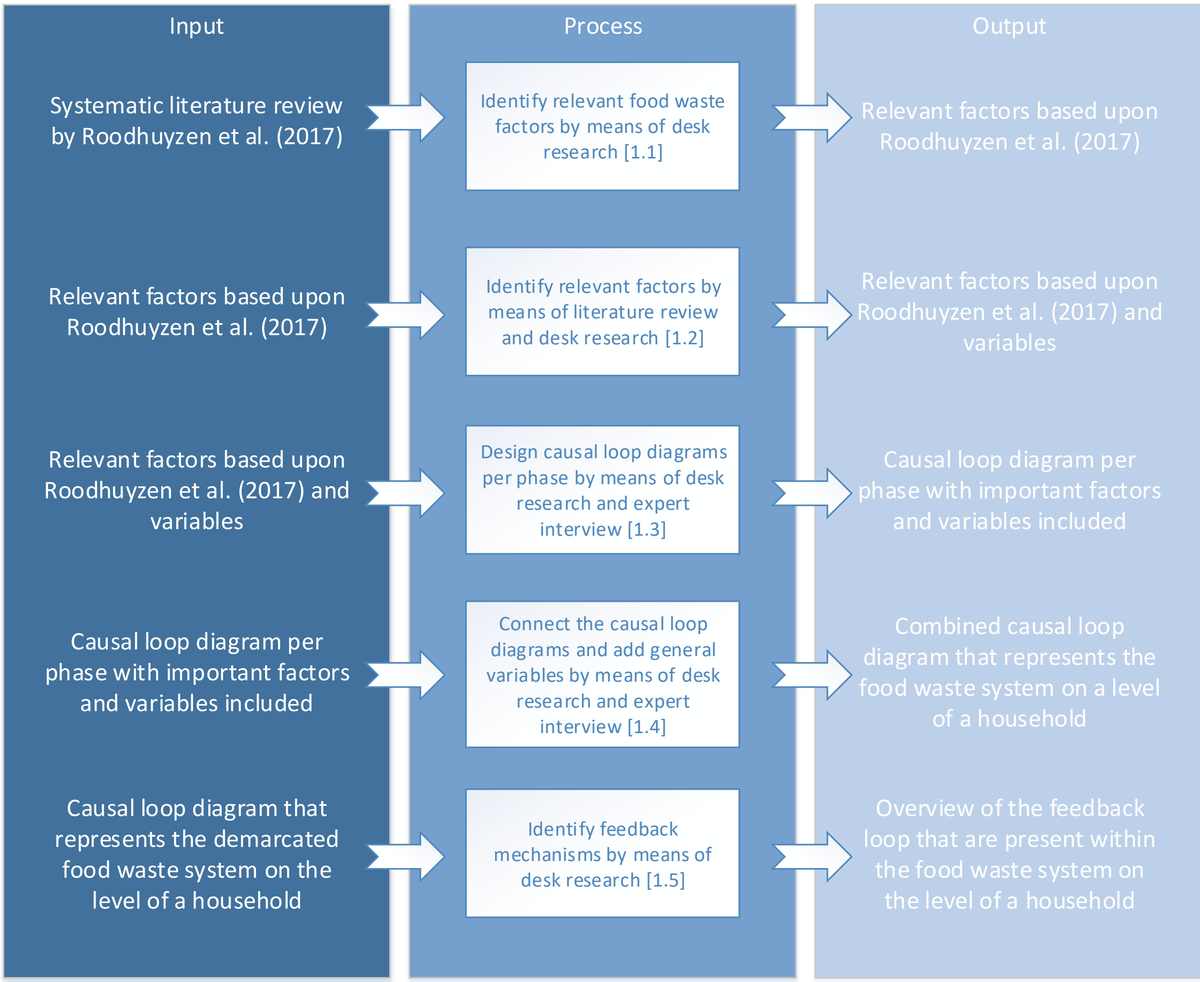


Figure 8: overview research design qualitative analysis

Step 1: identify important factors based on the literature review of Roodhuyzen et al. (2017)
Roodhuyzen et al. (2017) reviewed 42 peer-reviewed articles to create an overview of the potential factors related to food waste on the level of a household. These factors are distilled from scientific literature and are systematically collected. Of the 42 articles reviewed, 9 articles are not considered due to the geographical location of the studies or due to the topics of these articles. The resulting 32 articles are analysed. Roodhuyzen et al. (2017) derived two kinds of factors. *Studied factors*: qualitative or quantitative empirically investigated factors and *derived factors*: factors that have a secondary source and conclusions included by the authors from their study results. These studied and derived factors are considered while defining important factors that are needed for designing the qualitative model that represents the food waste system. The factors are identified and categorized per phase. The most important factors that are considered in this

study are described in section 2.3. A more detailed elaboration of the factors considered is given **appendix A.**

Step 2: identify other important factors
More factors are needed to fully represent the food waste system. Not all the needed factors are identified by Roodhuyzen et al. (2017). These extra factors are identified by means of literature review and desk research. A difference is made between factors that represent the main structure of the food waste process, food waste factors, and factors that are needed but not mentioned by Roodhuyzen et al. (2017). All the factors that are considered in this study are discussed and transformed into variables in section 2.3. A more detailed elaboration of the variables that are considered is given **appendix A.**

Step 3: design causal relation diagrams
A specific type of qualitative model is used to represent the important variables per phase needed to generate the food waste behaviour. Causal relation diagrams are used in this study. In a causal relation diagram all the important variables needed to generate the desired behaviour are considered. The causal relations between the factors that are relevant to the food waste system are depicted. A causal relation diagram is a good starting point for quantitative models. The causal relation diagrams categorized per phase are elaborated on in section 2.3. A more detailed elaboration on the variables and relations present within the causal relation sub-diagrams is elaborated on in **appendix A.**

Step 4: connecting the different phases into a combined causal relation diagram
The causal relation diagrams that are identified in previous research step are connected to each other. Designing one causal relation diagram provides an overview of the total food system on the level of a household. Important general variables identified by the literature review of Roodhuyzen et al. (2017) are incorporated. Also general food waste variables, main process variables, and extra variables needed are considered. The causal relation diagram that results from this analysis is discussed with three experts from Wageningen University. Based upon their feedback, the causal relation diagram is adapted and improved. The improved causal relation diagram is discussed in section 2.4. A more detailed elaboration on the variables and relations present within the causal relation diagram is given in **appendix A**

Step 5: Identifying feedback loops
Describing the feedback structures that are present within this causal relation diagram summarizes the food waste system on the level of a household. These feedback mechanisms are considered while specifying the model in chapter 4. The feedback mechanisms present are identified and discussed in section 2.5.

2.3 The system of interest

This section provides a demarcated overview of the variables needed to generate desired behaviour per phase by means of a causal relation diagram. Per phase, the variables that are considered are described. Following this, the causal mechanisms between these variables are discussed and illustrated by causal relations. In this section the planning (2.3.1), the purchasing phase (2.3.2), the storing phase (2.3.3), the preparing (2.3.4), the consuming phase (2.3.5), and the re-using leftover phase (2.3.6) are considered. A more detailed overview of the variables considered during the qualitative analysis are elaborated on in **appendix A**. An overview of the main process in which food is wasted, illustrated by a causal relation diagram in figure 9. Within the causal relation diagrams in this section a distinction between the following types of variables is made:

- *Main process variables:* these variables represent the flow of food within a household. These variables represent the amount of planned, bought, consumed, prepared, and consumed food. Besides, the amount of leftovers stored and the amount of leftovers consumed are also incorporated. These variables are necessary to generate the food waste behaviour, but are not specifically mentioned in scientific literature. **These variables are depicted in green within the causal relation diagrams in this section.**

- *Variables based upon the factors identified by Roodhuyzen et al. (2017):* these are the important variables that are based upon the factors identified by means of the systematic literature review by Roodhuyzen et al. (2017). **These variables are depicted in blue within the causal relation diagrams in this section.**
- *Extra variables:* these variables are needed to generate the food waste behaviour but are not referred to by Roodhuyzen et al. (2017) and cannot be represented by *main process variables*. These variables are derived by means of desk research. **These variables are depicted in orange within the causal relation diagrams in this section**.
- *Food waste variables:* the food waste variables represent the waste that occur within the food waste system on the level of a household. Food waste variables are present within the storing, preparing, consuming, and re-using leftovers phase. These variables are based upon the literature of Roodhuyzen et al. (2017) and desk research. **These variables are depicted in red within the causal relation diagrams in this section.**

The main structure of the food waste process is based upon the aforementioned phases in previous section. The phases are represented by the main process variables illustrated in the causal relation diagram in figure 9. The causal relations between the factors are depicted by arrows with a positive and negative sign. A positive sign illustrates a positive causal relation and a negative sign represents a negative causal relation. The causalities present within this food waste system are elaborated on in more detail in the following sub-sections.

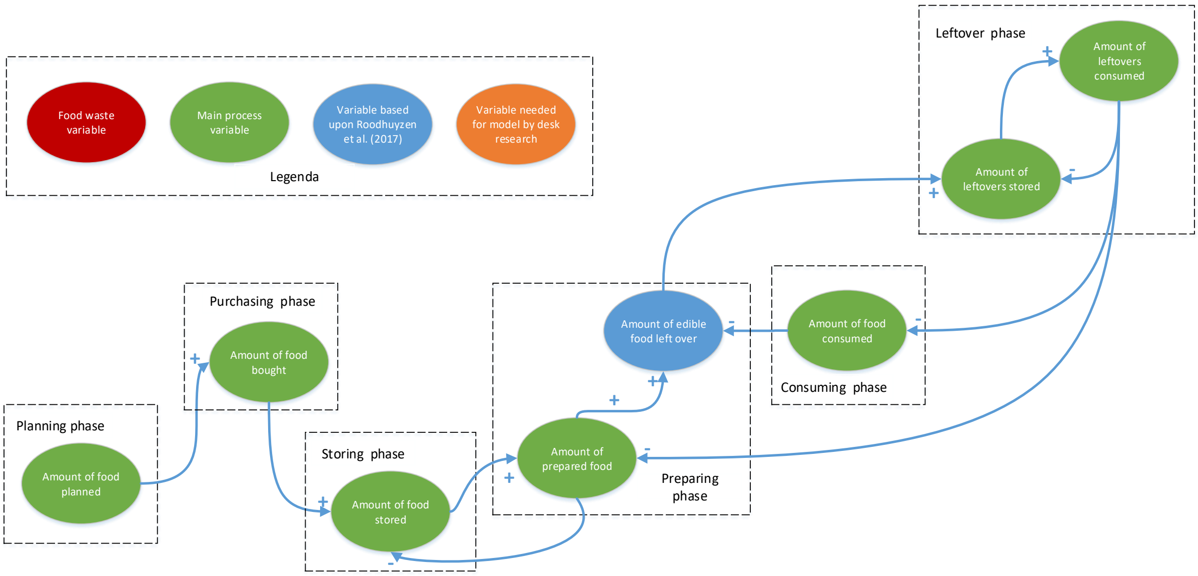


Figure 9: overview main process variables on the level of a household

This section results in multiple causal relation diagrams, each representing a phase with the important variables and the causal relations between these variables incorporated. In next section, these causal relation diagrams are connected to each other, resulting into one causal relation diagram that represents the total food waste system on the level of a household.

2.3.1 Planning

This sub-section elaborates on the important variables and causal relations that are considered during the planning phase. The *Amount of planned food* needed for a household is the central variable in this section. Based upon the factors identified by the systematic literature review by Roodhuyzen et al. (2017) 3 variables are considered: *Degree of inventory checking, Degree of over* *planning,* and *Degree of using shopping lists.* The units, description, and scientific sources of these variables are given in table 1. The following 2 main process variables are needed to generate the planning behaviour: *Amount of stored food,* and *Amount of leftovers stored.* Regarding the planning phase, 2 extra variables are needed to generate the planning behaviour. These variables are the *Perceived amount of inventory* and the *Average amount of food needed for a household.* The *Perceived amount of inventory* is needed to illustrate the known amount of stored food and leftovers. The second variable, the *Average amount of food needed for a household* is needed to represent the actual needed amount of food for the household. For the planning phase, a total of 8 variables are considered. The result of this sub-section is a causal relation diagram presented in figure 10 that illustrates the variables and the relations between these variables present within the planning phase. Important is the planning behaviour; households tend to plan to buy more food than actually needed for consumption.

Table 1: planning variables identified by Roodhuyzen et al. (2017)

Variable	Unit	Description	Based upon studied factors by:	Based upon derived factors by:
Degree of inventory checking	Fraction between 0 and 1	To check the available food within a household, this amount needs to be checked by the members within a household. This degree is the percentage of the time that a household checks his inventory while determining the *Amount of planned food*.	Quested et al. (2013), Ganglbauer et al. (2013), and Farr-Wharton et al. (2014).	Parfitt et al. (2010), Principato et al. (2015), and Graham-Rowe et al. (2014)
Degree of over planning	Fraction between 0 and 1	People tend to plan to buy more food than they actually need unintentionally. This additional amount is represented by this degree. It is the percentage of food planned above the *Average amount of food needed for a household.*	Evans (2012) and Quested et al. (2013)	Graham-Rowe et al. (2014), Jörissen et al. (2015), and Parfitt et al. (2010)
Degree of using shopping lists	Fraction between 0 and 1	People who use a shopping list do not buy unnecessary things that they already have or do not need at all. Using a shopping list results in a lower *Amount of planned food.* The degree is the percentage that a household uses a shopping list.	Jörissen et al. (2015), Ganglbauer et al. (2013), Quested et al. (2013), and Fonseca (2014)	Graham-Rowe et al. (2014), Parfitt et al. (2010), and Principato et al. (2015).

The *Amount of planned food* is a result of the *Degree of over planning, Degree of using shopping lists, Perceived amount of inventory,* and the *Average amount of food needed for a household. The Average amount of needed for a household* is used as input for the *Amount of planned food*, which is represented by a positive causal relation. A higher *Average amount of food needed for a household* results in a higher *Amount of planned food*. A higher *Degree of over planning* leads to a higher *Amount of planned food*, which is expressed by a positive causal relation. If a higher *Degree of over planning* is applicable, more food is bought. Using shopping lists more often increases the accuracy of the *Amount of planned food*. It approaches the value of the *Amount of food needed for a household* and thereby decreases the *Amount of planned food*, which results in a negative causal relation*. The Perceived amount of inventory* is also connected to the *Amount of planned food. If* there is a higher P*erceived amount of food of inventory* present, less food needs to be bought since it is already present. A negative causal relation exists between the variables.

The Perceived amount of inventory is influenced by multiple factors. *The Amount of leftovers stored* and the *Amount of stored food* represent the amount of inventory that is present within a household. A higher amount of leftovers and food stored results in a higher *Perceived amount of inventory*, which is represented by two positive causal relations. However, a household should check whether this *Perceived amount of inventory* is available. *The Degree of inventory checking* represents the degree that a household actually checks the *Amount food and leftovers stored*. If a higher *Degree of inventory checking* is present, a higher *Perceived amount of inventory* is known, which leads to a lower *Amount of planned food.* There is a positive causal relation between the *Degree of inventory checking* and the *Perceived amount of inventory.*

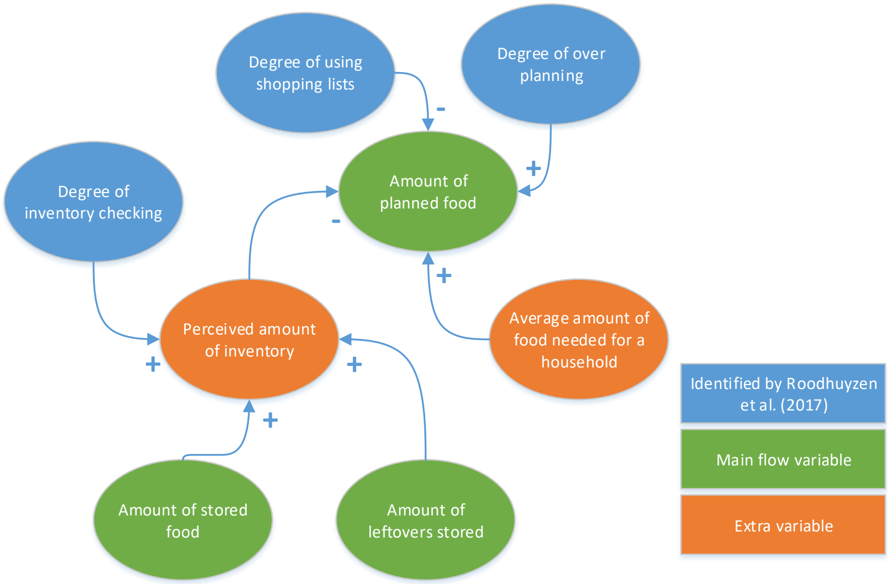


Figure 10: causal relation diagram for the planning phase

2.3.2 Purchasing

This sub-section elaborates on the important variables and causal relations that are considered during the purchasing phase. The *Amount of bought food* is the central variable in this phase. Based upon the factors identified by the systematic literature review by Roodhuyzen et al. (2017) 5 variables are considered: *Degree of appropriate amount of food, Degree of overbuying, Frequency of shopping, Price-awareness* and *Effect of economies of scale and discounts.* The units, description, and scientific sources of these variables are found in table 2. The following main process variable is needed to generate the buying behaviour: *Amount of planned food.* For the purchasing phase, a total of 7 variables are considered. The result of this sub-section is a causal relation diagram, presented in figure 11 that illustrates the variables and the relations between these variables present within the purchasing phase. Important is the purchasing behaviour; households tend to buy even more food that they initially planned to do.

Table 2: purchasing variables identified by Roodhuyzen et al. (2017)

Variable	Unit	Description	Based upon studied factors by:	Based upon derived factors by:
Frequency of shopping	Trips to the shop per week	These are the number of trips a household tends to make per week for doing groceries. Planning to purchase food at relatively fixed intervals, buying roughly the same things each time, which are easily thrown out of balance.	Evans (2011), Jörissen et al. (2015), Williams et al, (2012). and Evans (2012)	n.a.

Price awareness	Fraction between 0 and 1	Higher household price awareness was associated with lower food waste due to the fact that they tend to eat everything and buy not more than exactly needed. The *Price-awareness* is the fraction of the *Degree of overbuying* that is used within a household.	Williams et al. (2012), Koivupuro et al. (2012), Jörissen et al. (2015), and Parizeau et al. (2015)	Parizeau et al (2015), Silvennoinen et al. (2014), and Halloran et al, (2014)
Effect of economies of scale and discounts	Fraction between 0 and 1	A lower price per kg for bigger amounts of food results in more food bought per household. This amount of food is not always needed and thereby eaten in the end. The *Effect of economies of scale and discounts* is the fraction that a household buys extra. This is represented by the *Degree of overbuying*.	Koivupuro et al. (2012), Ganglbauer et al. (2013), Jörissen et al. (2015), and Evans (2011)	Koivupuro et al. (2012), Gjerris & Gaiani (2013), Jörissen et al. (2015), Halloran et al.(2014), Silvenius et al. (2012), and Williams et al. (2012)
Degree of appropriate amount of food	Fraction between 0 and 1	Households can buy the amount of food they desire, however it may happen that the desired amount of food is not available, ending up buying a bigger package with a higher amount of food. *Degree of appropriate amount of food* is the fraction that a household buys more. This is represented by the *Degree of overbuying*.	Koivupuro et al. (2012), Ganglbauer et al. (2013), Jörissen et al. (2015), and Evans (2011)	Koivupuro et al. (2012), Gjerris & Gaiani (2013), Jörissen et al. (2015), Halloran et al.(2014), Silvenius et al. (2012), and Williams et al. (2012)
Degree of overbuying	Fraction between 0 and 1	The Degree of overbuying is the percentage of food that is fraction of food bought more than actually planned by a household. It is the fraction that is extra bought above the *Amount of planned food*.	Evans (2012), Ganglbauer et al. (2013), and Koivupuro et al. (2012)	Graham-Rowe, et al. (2014), Beretta et al. (2013), Williams et al. (2012), and Verberge et al. (2015)

The *Amount of bought food* is a result of the *Price awareness, Degree of overbuying,* and the *Amount of planned food.* The *Amount of bought food* is based upon the *Amount of planned food.* A higher *Amount of planned food* leads to a higher *Amount of bought food*; a positive causal relation exists. Households with a high *Price awareness* have the tendency to buy no more food than needed. A negative causal relation towards the *Amount of planned food* represent this. Households that have a higher *Price awareness* result in a lower *Amount of bough food. The Degree of overbuying*, households have the tendency to buy too much, resulting in a higher *Amount of bought food.* A positive causal relation is present. A higher *Degree of overbuying* results in more food bought.

The variable *Degree of overbuying* is dependent on three variables; the *Effect of economies of scale and discounts*, *Degree of appropriate amount of food,* and the *Frequency of shopping*. A higher *Degree of appropriate amount of food* leads to a lower *Degree of overbuying*, which is illustrated by a negative causal relation. Households tend to buy more food if the correct package is not available. When the correct package is absent, most of the times a bigger package is bought. The *Effect of economies of scale and discounts* of food has a positive causal relation towards the *Degree of overbuying.* If the *Effect of economies of scale and discounts* increases for bigger amounts of food, then people tend to buy more food due to the economies of scale, resulting in a higher *Degree of overbuying.* The *Frequency of shopping* is connected to the *Degree of overbuying,* a higher *Frequency of shopping* leads to a better estimation of the food needed for a household. A negative causal relation between the *Frequency of shopping* and the *Degree of overbuying* is therefore present.

There is an important difference between the *Price-awareness* and the *Effect of economies of scale and discounts*. Both variables consider the buying of extra food regarding the food for the households due to the *Effect of economies of scale and discounts* and the *Degree of appropriate amount of food*. The difference lies in the perspective on the price of food. Households that have a higher *Price-awareness* do not want to waste any food. Buying food that is discounted or buying bigger packages of food does not result in a higher *Amount of bought food* when the *Price-awareness* is high. Households with no *Price-awareness* tend to buy more food than that they actually need due to the financial advantages. Instead of eating it all, these households generate more food waste. The increase of the *Price-awareness* results in a lower *Amount of bought food* and an increase of the *Effect of economies of scale and discounts* results in a higher *Amount of bought food*.

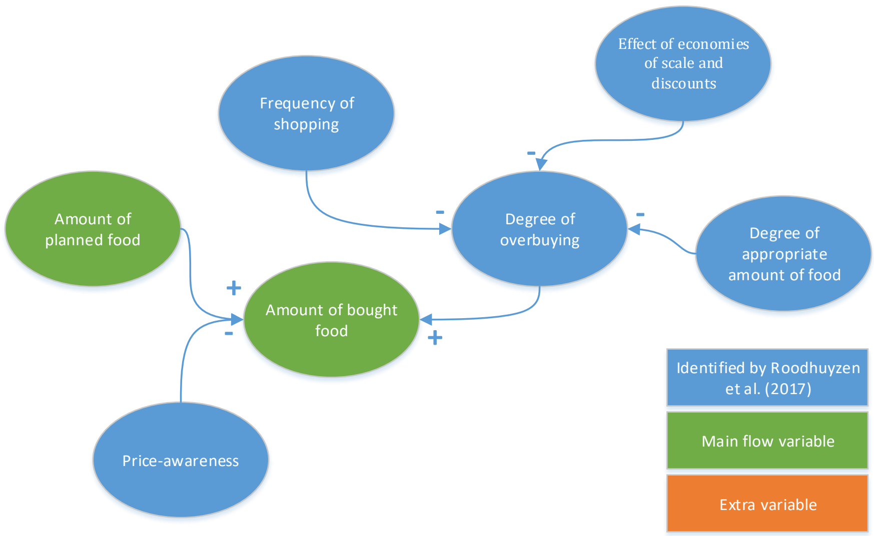


Figure 11: causal relation diagram for the purchasing phase

2.3.3 Storing

This sub-section elaborates on the important variables and causal relations that are considered in during storing phase. The *Amount of stored food* needed for a household is the central variable in this phase. Based upon the factors identified by the systematic literature review by Roodhuyzen et al. (2017) 4 variables are identified: *Storing conditions, Use by date, Best before date,* and *Spoilage knowledge.* The *Use by date* and *Best before date* are interpreted in this study as the time before it reaches the *Use by date* and the *Best before date.* The units, description, and scientific sources of these variables are given in table 3. In this phase, the following 2 main process variables are needed to generate the storing behaviour: *Amount of bought food,* and *Amount of prepared food.* 2 extra variables are needed: *Affected best before date* and the *Affected use by date.* These extra variables are needed because they represent the perception of the households regarding the best before and use by dates, based upon the *Spoilage knowledge* and *Storing conditions*. 2 variables regarding the waste of food occur during this phase; *Amount of edible stored food discarded* and *Amount of used to be edible food discarded.* For the storing phase, a total of 11 variables are considered. The result of this sub-section is a causal relation diagram, presented in figure 12 that illustrates the variables and the relations between these variables present within the storing phase. Important is the storing behaviour: the *Amount of bought food* is stored, which results in an *Amount of prepared food*, possibly in an *Amount of edible stored food discarded* and possibly in an *amount of inedible stored food discarded*. The latter two variables represent the food waste that is generated within the storing phase.

Table 3 variables that are taken into account during the storing phase

Variable	Unit	Description	Based upon studied factors by:	Based upon derived factors by:

Storing conditions	Fraction between 0 and 1	Not using the fridge and freezer effectively for storing food. Not considering food that is well suited to the freezer as 'proper' food,. Not using the fridge at 4 Celsius degrees but instead using it at 7 Celsius degrees. The *Storing conditions* level of conditions represented by a fraction where a fraction of 0 is no conditions at all and 1 perfect storing conditions.	Evans (2011), Graham-Rowe, et al. (2014), Farr-Wharton et al. (2014), and Koivupuro et al. (2012)	Jörissen et al. (2015), Parfitt et al. (2010), Williams et al. (2012), Brown et al. (2013), Buzby & Hyman (2012), Gjerris & Gaiani. (2013), Griffin et al. (2009), Parfitt et al. (2010), and Principato et al. (2015)
Use by date & best before Date	Days	Strict, unquestioning adherence to the recommendations of Best before dates ('objectification of edibility') seemed to increased household food waste, while using one's senses to judge edibility ('internalization of edibility') seemed to reduce it. The *Use by date & best before Date* is the amount of days needed before these dates are reached.	Ganglbauer et al., (2013), Evans (2012), Blichfeldt et al. (2015), Parizeau et al. (2015), Silvennoinen et al. (2014), Williams et al. (2012), and Jörissen et al., (2015)	Beretta et al. (2013), Brown et al. (2013), Garonne et al. (2014), Buzby & Hyman (2012), Gille (2013), Jörissen et al. (2015), Koivupuro et al. (2012), Williams et al. (2012), Graham-Rowe et al. (2014), Koivupuro et al. (2012), Parfitt et al. (2010), Principato et al. (2015), and Silvenius et al. (2012)
Spoilage knowledge	Fraction between 0 and 1	The competencies and skills to judge edibility of food. Households that rely on their senses more than on the *Use by date & Best before date* to judge the edibility of food. The *Spoilage knowledge* is expressed by an fraction, ranging from no knowledge at all by a fraction of 0 and to perfect knowledge by a fraction of 1.	Blichfeldt et al. (2015)	Jörissen et al. (2015), Koivupuro et al. (2012), and Williams et al, (2012)

The *Amount of stored food* is a result of the *Amount of edible stored food discarded, Amount of inedible stored food discarded, Amount of bought food* and the *Amount of prepared food. The Amount of bought food* is connected to the *Amount of stored food*. All food that is bought needs to be stored. A higher *Amount of bought food* leads to a higher *Amount of stored food*, which is represented by a positive causal relation. The *Amount of prepared food* is also connected to the *Amount of stored food*, preparing food demands the usage of food stored and therefore a negative causal relation exists between the *Amount of prepared food* and the *Amount of stored food*. Besides the connection from the *Amount of prepared food* and the *Amount of stored food* there is also a vice versa connection: a higher *Amount of stored food* leads to a higher *Amount of prepared food*, resulting in a positive causal relation. In this study it is assumed that having more food stored results in a higher *Amount of prepared food*.

The *Affected best before date* and the *Affected use by date* are both influenced by *Spoilage knowledge,* a positive causal relation illustrates the relations in both cases. Having a better *Spoilage knowledge* results in higher amount of days before food becomes inedible. Households with a higher *Spoilage knowledge* are better at deciding if food is still edible, even when it has surpassed the *Use by date*. The *Affected best before date* and the *Affected best before date* are also influenced by the *Storing conditions*: a positive causal relation exists. Better *Storing conditions* results a higher *Affected best before date* and *Affected use by date* due to the effects of the improved conditions.

In this phase there are two food waste variables; *Amount of edible stored food discarded* and *Amount of inedible stored food discarded.* The *Amount of edible stored food discarded* is dependent on the on the *Affected best before date.* There is a negative causal relation between the variables, having a higher *Affected best before date* results in a lower *Amount of edible stored food discarded.* The same is applicable for the variables *Amount of inedible stored food discarded* and the *Affected use by date.*

There is a difference between the *Use by date* and the *Best before date.* The *Best before date* represent the quality of the food and are stretched more than the *Use by date*. The *Use by date* represents the safety of food and this date must be followed strictly. Therefore, the *Use by date* cannot increase much.

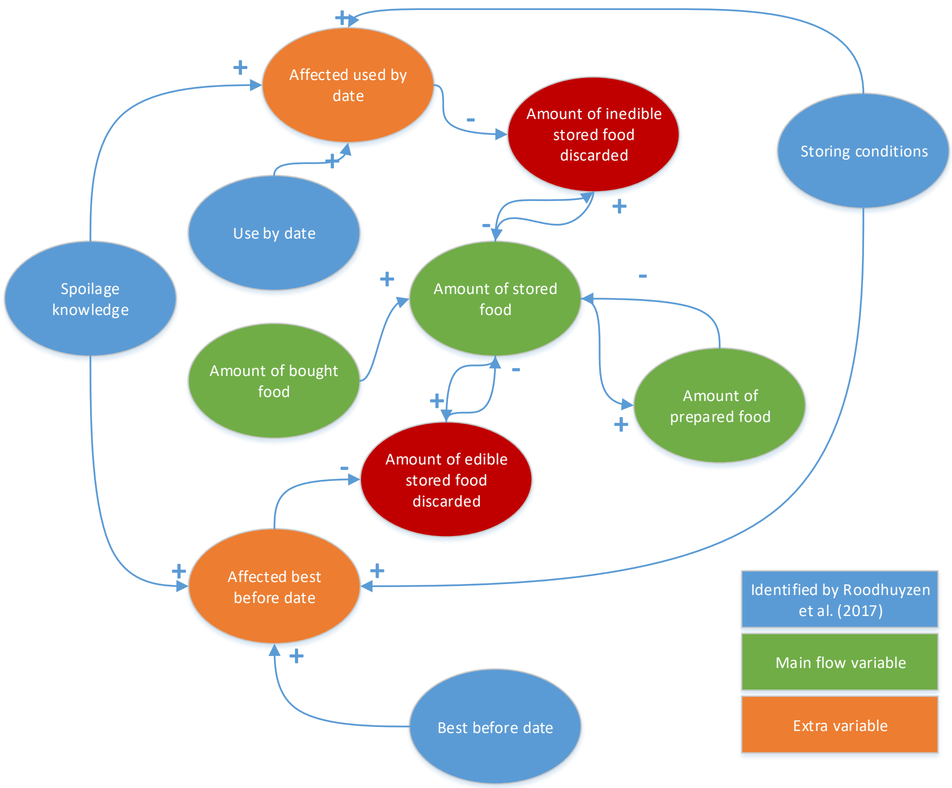


Figure 12: causal relation diagram for the storing phase

2.3.4 Preparing

This sub-section elaborates on the important variables and causal relations that are considered during the preparing phase. The *Amount of prepared food* needed for a household is the central variable in this sub-section. Based upon the factors identified by the systematic literature review by Roodhuyzen et al. (2017) 3 variables are identified; *Amount of edible food leftover*, *Cooking skills* and *Provision factor*. The units, description, and scientific sources of these variables are presented in table 4. The following 2 main process variables are needed to generate the preparing behaviour: the *Amount of stored food* and the *Amount of consumed food.* 1 variable is added to complete the causal relation diagram; the *Average amount of food needed for a household.* This amount is used to estimate the *Amount of prepared food.* In this phase, 1 food waste variable is present; the *Amount of inedible prepared food discarded.* For the preparing phase, a total of 8 variables are considered. The result of this sub-section is a causal relation diagram presented in figure 13 that illustrates the variables and the relations between these variables present within the preparing phase. Important is the storing behaviour, which is that households tend to prepare more food than they actually need, resulting in an *Amount of edible food leftover*. Also, food is wasted during this phase due to a lack of *Cooking skills*, which results in an *Amount of inedible prepared food discarded.*

Table 4 variables that are taken into account during the preparing phase

Variable	Unit	Description	Based upon studied factors by:	Based upon derived factors by:
Cooking skills	Fraction between 0 and 1	Wastage of edible parts of food because of inappropriate or over-preparation methods of preparation. *Cooking skills* is expressed by a fraction, ranging from no skills with a fraction of 0 to perfect skills with a fraction of 1.	(Parizeau et al., 2015)	Beretta et al. (2013) and Jörissen et al. (2015)
Provision factor	Fraction between 0 and 1	People tend to prepare more food than actually eaten within a households. The amount extra prepared is presented by the *Provision factor.* It is the extra fraction prepared regarding the *Average amount of food needed for a household*. A fraction of 0 is no extra prepared food and a fraction of 1 is twice as much prepared.	Jörissen et al. (2015), Williams et al. (2012), and Silvennoinen et al. (2014)	Koivupuro et al. (2012), Parfitt et al. (2010). Jörissen et al. (2015), Graham-Rowe, et al. (2014), Williams et al. (2012), Beretta et al. (2013), Principato et al. (2015), and Gille, (2013)
Amount edible food leftover	Kg/week/ household	This variable represents the amount of food that is left over after dinner. It is the difference between the *Amount of prepared food* minus the combined *Amount of inedible prepared food discarded* and the *Amount of consumed food.* This amount is expressed in kilogram food per week per household.	Williams et al. (2012), Jörissen et al. (2015), and Silvennoinen et al., 2014)	Koivupuro et al. (2012), Parfitt et al. (2010), Jörissen et al. (2015), Graham-Rowe, et al. (2014), Williams et al. (2012), Beretta et al. (2013), Principato et al. (2015), Parfitt et al. (2010), and Gille (2013)

The *Amount of prepared food* is a result of the *Provision factor, Average amount of food needed for a household,* and the *Amount of stored food.* The *Average amount of food for a household* has a positive causal relation regarding the *Amount of prepared food*; if the *Average amount of food needed for a household* increases, then the *Amount of prepared food* also increases. The *Provision factor* illustrates the fact that households tend to prepare more food than they actually need. A higher *Provision factor* leads to more food prepared; a positive causal relation exists. A higher *Amount of stored food* has a small positive influence on the *Amount of prepared food*. Having more food results in making more food. *The Amount of prepared food* is connected to the *Amount of stored food*, the *Amount of edible food leftover*, and to the *Amount of inedible prepared food discarded*. If food is prepared, the *Amount of stored food* decreases since these amounts are needed for the preparation, which is illustrated by a negative causal relation.

The *Amount of edible food leftover* is the difference between the *Amount of prepared food* and the *Amount of consumed food* combined with *Amount of inedible prepared food discarded.* When the *Amount of consumed food* increases, the *Amount of food leftover* decreases, resulting in a negative causal relationship between these variables. When the *Amount of inedible prepared food discarded* increases, the *Amount of food leftover* decreases, resulting in a negative causal relationship between these variables. For the *Amount of prepared food* and there is an opposite relation, a higher *Amount of prepared food* leads to a higher *Amount of food left over,* resulting in a positive causal relation.

Food waste occurs during this phase; the *Amount of inedible prepared food discarded*. This food waste is a combination of *Cooking skills* and the *Amount of prepared food*. *Cooking skills* influence this type of waste, where higher *Cooking skills* prevent this waste from happening. If a household is better at preparing food, less food is ruined during the preparation. A negative causal relation is identified between the *Cooking skills* and *Amount of inedible prepared food discarded*. A higher *Amount of prepared food* results in a higher *Amount of inedible prepared food discarded.* Preparing more food increases the probability of ruining food. This relation is presented by a positive causal relation.

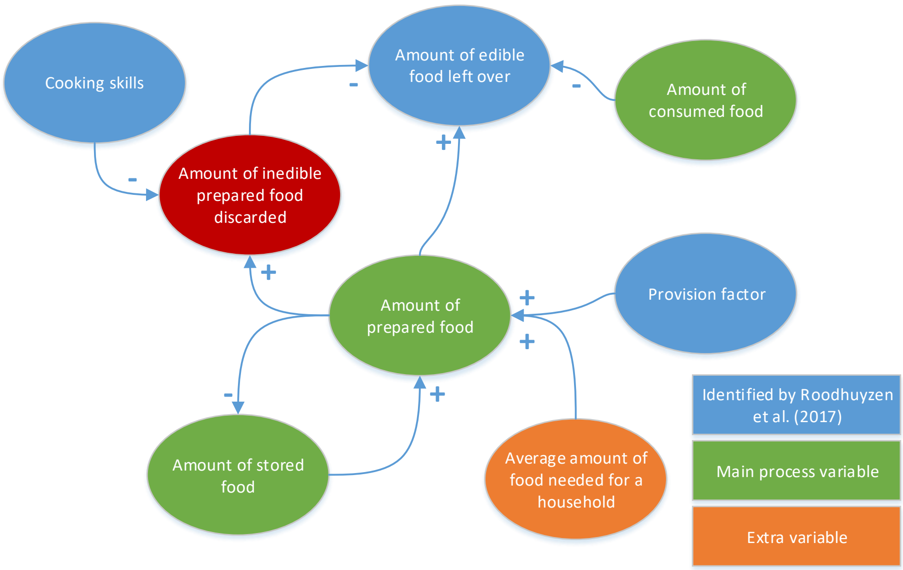


Figure 13: causal relation diagram for the preparing phase

2.3.5 Consuming

This sub-section elaborates on the important variables and causal relations that are considered during the consuming phase. The *Amount of consumed food* is the central variable in this phase. Based upon the factors identified by the systematic literature review by Roodhuyzen et al. (2017) 3 variables are identified; *Amount of edible food leftover*, *Preference within a household,* and *Unpredictability lifestyle household*. The units, descriptions, and the scientific sources have are given in table 5**.** 1 extra variable is added to complete the causal relation diagram; the *Average amount of food needed for a household.* This amount is needed to estimate the actual amount of food that is consumed. In this phase, 1 food waste variable exists; *Amount of leftovers discarded directly.* For the consuming phase, a total of 6 variables are taken into account. The result of this sub-section is a causal relation diagram presented in figure 14 that illustrates the variables and the relations between these variables present within the consuming phase. Important is the consuming behaviour; households tend to prepare more food than they actually need, which results in an *Amount of edible food leftover.* Also, food is wasted in this phase; food that is left over after a meal may be discarded directly after a meal. This food waste is represented by the variable *Amount of leftovers discarded directly.*

Table 5: variables that are taken into account during the consuming phase

Variable	Unit	Description	Based upon studied factors by:	Based upon derived factors by:
Preference within a household	Fraction between 0 and 1	Members within households may have different opinions regarding how much need to be eaten and what needs to be eaten while consuming the food. The *Preference within a household* is expressed by a fraction where a fraction of 0 is no preference at all and a	Koivupuro et al. (2012), Parizeau et al. (2015), Cappellini & Parsons (2012), and Evans (2012).	Beretta et al. (2013) and Jörissen et al. (2015).

		fraction of 1 is full preference where no food at all is eaten.		
Unpredictability lifestyle household	Fraction between 0 and 1	Members within a household may have different lifestyles, people who tend to have a more heretic lifestyle will not always be able to attend diner, even when he or she is considered for dinner. The *Unpredictability lifestyle household* is expressed by a fraction where 0 is a total predictable household and 1 is a total unpredictable household.	Ganglbauer et al. (2013), Evans (2011), Evans (2012), Farr-Wharton et al. (2014), and Cappellini & Parsons (2012).	Gjerris & Gaiani (2013), Parizeau et al. (2015), and Williams et al. (2012). Parizeau et al. (2015).
Amount edible food leftover	Kg/week/ household	This variable represents the amount of food that is left over after dinner. It is the difference between the *Amount of prepared food* minus the combined *Amount of inedible prepared food discarded* and the *Amount of consumed food*. This amount is expressed in kilogram food per week per household.	Williams et al. (2012), Jörissen et al. (2015), and Silvennoinen et al., 2014)	Koivupuro et al. (2012), Parfitt et al. (2010), Jörissen et al. (2015), Graham-Rowe, et al. (2014), Williams et al. (2012), Beretta et al. (2013), Principato et al. (2015), Parfitt et al. (2010), and Gille (2013)

The *Amount of consumed food* is a combination of the following variables: *Preference within a household, Unpredictability lifestyle household,* and *Average amount of food needed for a household.* The *Amount of consumed food* is based upon the *Average amount of food* needed for a household for which would a positive causal relation is identified. Needing more food on average results in a higher amount consumed. The *Preference within a household* affects the actual *Amount of consumed food*. The preference represents the likes and dislikes of the members regarding the food. If a household has a bigger preference among its members, less food is eaten. Members within the households prefer than to not eat the food. The actual *Amount of consumed food* becomes lower when the *Preference within a household* increases. This results in a negative causal relation between the variables *Preference within a household* and the *Amount of consumed food*.

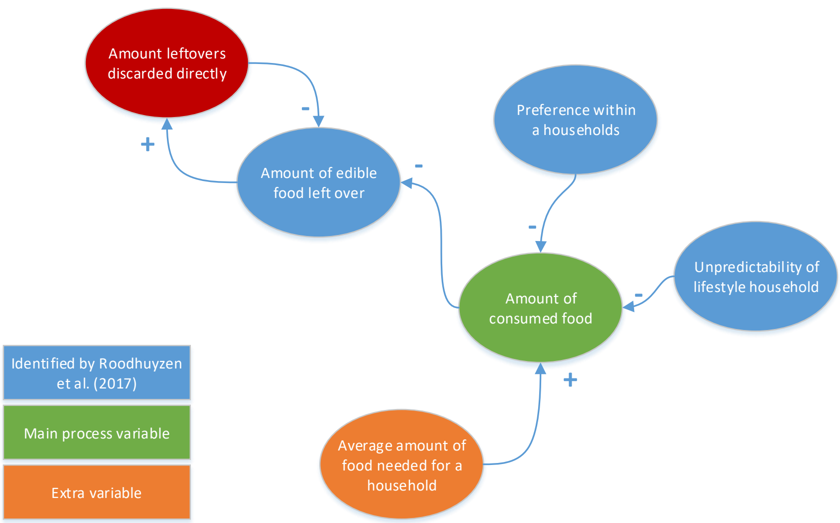


Figure 14: causal relation diagram for the consuming phase

The *Unpredictability lifestyle household* affects the *Amount of consumed food.* Households who have more predictable lives have a more constant consumption pattern resulting in a negative causal relation between the *Unpredictability of a household* and the *Amount of consumed food*.

One food waste variable occurs during this phase; the *Amount of leftovers discarded directly*. Having more food leftover increases the amount of leftovers thrown away directly, resulting in a positive causal relation between the *Amount of edible food leftover* and the *Amount of leftovers discarded directly*. However, discarding leftovers directly results in a lower *Amount of edible food leftover*. This is represented by a negative causal relation.

2.3.6 Re-using leftovers

This sub-section elaborates on the important variables and causal relations that are considered during the re-using leftovers phase. The *Amount of leftovers stored* and the *Amount of leftovers consumed* are the central variables in this phase. Based upon the factors identified by the systematic literature review by Roodhuyzen et al. (2017) 3 variables are identified; *Desire to consume leftovers, Leftover knowledge,* and *Amount of edible food leftover*. The units, description, and scientific sources of these variables are described in table 6. The following 2 main process variables are needed to generate the re-using leftovers behaviour*;* the *Amount of prepared food* and *Amount of consumed food.* 1 variable is added to complete the causal relation diagram; the *Moulding time leftovers.* The *Storing time leftover is* needed to represent the moulding process of the leftover. In this phase, 1 food waste variable exists; *Amount of leftovers discarded.* For the leftover phase, a total of 9 variables are considered. The result of this sub-section is a causal relation diagram presented in figure 15 that illustrates the variables and the relations between these variables present within the re-using leftover phase. Important is the re-using leftovers behaviour: the food leftover is stored, after which it is partly eaten and thrown away.

Table 6: variables that are taken into account during the re-using leftovers phase

Variable	Unit	Description	Based upon studied factors by:	Based upon derived factors by:
Desire to consume leftovers	Fraction between 0 and 1	The desire to consume leftovers represents the attitude of a household towards eating leftovers. *Desire to consume leftovers* can be expressed by a fraction ranging from no desire at all by a fraction of 0 to a desire where all leftovers are eaten by a fraction of 1.	Farr-Wharton et al. (2014) and Evans (2012).	Parizeau et al. (2015), Verghese et al. (2015), and Jörissen et al. (2015).
Amount edible food leftover	Kg/week/ household	This variable represents the amount of food that is left over after dinner. It is the difference between the *Amount of prepared food* minus the combined *Amount of inedible prepared food discarded* and the *Amount of consumed food*. This amount is expressed in kilogram food per week per household.	Williams et al. (2012), Jörissen et al. (2015), and Silvennoinen et al., 2014)	Koivupuro et al. (2012), Parfitt et al. (2010), Jörissen et al. (2015), Graham-Rowe, et al. (2014), Williams et al. (2012), Beretta et al. (2013), Principato et al. (2015), Parfitt et al. (2010), and Gille (2013)
Leftover knowledge	Fraction between 0 and 1	Knowledge related to the material elements of the foodstuffs and the likely contexts of their reuse. Forward thinking about the likely contexts of reuse of leftovers. Having no knowledge will result in in a knowledge level of 0. A full	Cappellini & Parsons, 2012	

		knowledge will result in a value of 1.		

The *Amount of leftovers stored* is affected by the following variables: *Amount of edible food leftover, Amount of leftovers discarded,* and *Amount of leftovers consumed.* Regarding the *Amount of edible food leftover*, there is a positive causal relation; more food left over increases the probability that these leftovers are stored. The *Amount of leftovers consumed* influences the *Amount of leftovers stored*. To consume leftovers, the leftovers should be taken from the storing. Therefore a negative causal relation exists between the variables *Amount of leftovers consumed* and *Amount of leftovers stored.* The *Amount of leftovers stored* is affected by *Amount of leftovers discarded.* Discarding more leftovers results in a lower *Amount of leftovers stored.* Therefore a negative causal relation is identified.

The Amount of leftovers consumed is affected by the *Desire to consume leftovers, Leftover knowledge,* and the *Amount of leftovers stored*. Household tend to not always eat leftovers. To consider this behaviour, the variable *Desire to consume leftovers* is added. If a household has a high desire, more leftovers are consumed, resulting in a positive causal relation. The *Leftover knowledge* is the counterpart that is needed since households are able to re-use and consume these leftovers. Having more knowledge results in more opportunities regarding the re-use of leftovers. This increases the *Amount of leftovers consumed.* The *Amount of leftovers consumed* is illustrated with a positive causal relation. Regarding the *Amount of leftovers stored*, the same variables exist as described during the storing and preparation phase; having a higher *Amount of leftovers stored* results in a higher *Amount of leftovers consumed and* therefore a positive causal relation exists.

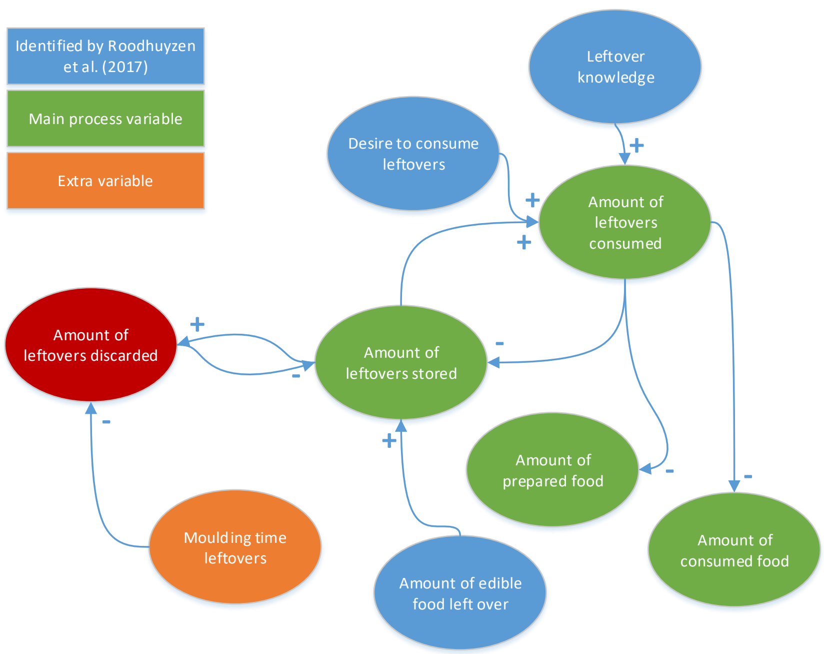


Figure 15: causal relation diagram for the leftover phase

The main process variable *Amount of leftovers consumed* affects two other main process variables from other phases; *Amount of prepared food* and the *Amount of consumed food*. The food that is consumed by eating leftovers should be taken considered while preparing new food. If not it results in extra made unneeded portions. Therefore, a negative causal relation between the *Amount of leftovers consumed* and the *Amount of prepared food* is present. Eating more leftovers leads to a lower *Amount of prepared food.* The *Amount of leftovers consumed* decreases the *Amount of consumed food*. Eating more leftovers results in eating lower *Amount of consumed food*, which is illustrated by a negative causal relation.

One variable food waste is present during this phase and that is the *Amount of leftovers discarded* that are thrown away after a too long *Storing time* of the leftovers. The variable *Moulding time leftover* is deduced from the storing phase. A longer *Moulding time leftovers* results in a lower *Amount of leftovers discarded*, which is illustrated with a negative causal relation.

2.4 Overall overview of the food waste system

This section elaborates on the important variables and causal relations that are considered during the general phase. Secondly, this section connects the causal relation diagrams identified in previous sub-sections into one causal relation diagram and incorporates these general variables. General variables are variables that cannot easily be connected towards one phase, but affect the food waste system on the level of a household in a general way. Based upon Roodhuyzen et al. (2017) 3 variables are identified; *Moral attitude, Knowledge on consequences food waste,* and *Household size.* The units, description, and scientific sources of these variables are described in table 7. 3 extra variables are added to complete the causal relation diagram; the *Average food needed per person, Average Kg/person,* and *Perceived amount of food waste.* The *Average Kg/person* is needed to estimate the *Amount of food needed for a household* combined with the *Household size.* The *Perceived amount of food waste* is a variable that represent the amount of waste from the households perspective. Based upon the *Perceived amount of food waste,* households may adapt their planning and preparing behaviour. In the general phase, 1 food waste variable is added: *Total food waste.* For the general phase, a total of 7 variables are added to the overall causal relation diagram. A more detailed overview of the factors considered during the qualitative analysis are elaborated on in **appendix A**. The result of this section is a causal relation diagram, which represents the food waste system on the level of a household. This causal relation diagram is visualised in figure 16**.** In next section, feedback loops are identified that are present in this causal relation diagram.

Table 7: variables that are taken into account during the general phase

Variable	Unit	Description	Based upon studied factors by:	Based upon derived factors by:
Household size	Number of members within a household	The number of members present within a household. *Household size* is expressed by the amount of people who do live together within a household.	studied Jörissen et al. (2015), Koivupuro et al. (2012), Quested et al. (2013), Parizeau et al. (2015), Williams et al. (2012), and Fonseca (2014).	Halloran et al. (2014) Parfitt et al. (2010), and Silvennoinen et al. (2014).
Moral attitude	Fraction between 0 and 1	The feelings of guilt when discarding food. The feeling of ethical wrongdoing. The *Moral attitude* is expressed by a fraction between 0 and 0. An attitude of 0 means total lack of concern regarding the waste of food. An attitude of 1 means fully feeling guilty when wasting food.	Stefan et al. (2013), Principato et al. (2015), (Blichfeldt et al., 2015), (Graham-Rowe, et al., 2014), (Parizeau et al., 2015), and (Graham-Rowe, et al., 2014)	n.a
Knowledge on consequences food waste	Fraction between 0 and 1	Knowing what food waste is and what the consequences are environmentally and for other people all over the world. Knowledge on consequences food waste is represented by a fraction. A fraction of 0 results in	Williams et al. (2012). (Gjerris & Gaiani, 2013). (Principato et al., 2015)	n.a

		no knowledge at all and a fraction of 1 is full knowledge regarding the waste of food.		

Adding the general variables
The following general variables are added to the causal relation diagram based upon the identified factors by Roodhuyzen et al. (2017): *Household size, Moral attitude, Knowledge on consequences food waste.* The *Household size* is affecting the *Average amount of food needed for a household.* More members leads to a higher household average, resulting in a positive causal relation between the variables. *Knowledge on consequences food waste* affects the *Moral attitude,* having more knowledge on the negative consequences of food waste leads to a higher *Moral attitude.* This relation is illustrated by a positive causal relation. The *Moral attitude* affects the *Perceived amount of food waste*. The *Perceived amount of food waste* is the waste perceived by the household. Having a higher *Moral attitude* leads to a higher *Perceived amount of food waste*, which is illustrated by a positive causal relation.

The following extra variables are added to the model; *Average food needed per person* and *Average Kg/person*. To estimate the *Average amount of food needed for a household*, the *Household size* is combined with the *Average Kg/person*. There is a positive causal relation between the *Average Kg/person* and the *Average amount of food needed for a household.* A higher amount of food needed per member within the household results in more food needed for a household.

The following food waste variables are added; *Total food waste,* which is an accumulation of all the food waste variables. All have a positive causal relation towards the *Total food waste.* The *Total food waste* has a positive causal relation towards the perceived *Amount of wasted food.* Wasting more food leads to a higher *Perceived amount of food waste*.

Connecting the multiple phases into one model
The re-using leftovers phase is connected via the *Amount of leftovers consumed* with the preparing phase via the *Amount of prepared food*. If the *Amount of leftovers consumed* increases, a lower *Amount of food prepared* results; less food is prepared to compensate the *Amount of leftovers consumed.* A negative causal relation illustrates the relation between the *Amount of leftovers consumed* and *Amount of food prepared*. A similar relation is present regarding the consuming phase. The *Amount of consumed food* and the *Amount of leftovers consumed* of the re-using leftover phase are connected. If the *Amount of leftovers* increase, the *Amount of consumed food* decreases. A negative causal relation is present between the *Amount of leftovers consumed* and the *Amount of consumed food.*

As mentioned before the phases are connected via the variables present between phases. The storing phase via the *Amount of stored food* and the re-using phase via the *Amount of stored leftovers* are directly connected with the planning phase via *Perceived amount of food inventory*. In both cases, more stored food or leftovers leads to a higher *Perceived amount of food inventory*, illustrated by two positive causal relations. These storing related relations are considered in more detail in section 2.5.1.

As mentioned before, households with a higher *Moral attitude* are more willing to reduce the food wasted within a household, they have a higher *Perceived food waste,* which is also dependent on the *Total food waste*. Households with a *Moral attitude* are positively correlated related with planning routines (Stefan et al., 2013; Parizeau et al., 2015). This mechanism is therefore incorporated within the qualitative model; households with a higher *Moral attitude* decreases the *Degree of over planning* via the *Perceived amount of food waste*. Also, the fine-tuning of the preparation of food in line with the needs within the households is correlated with the *Moral attitude* (Stefan et al., 2013). This mechanism is therefore incorporated within the qualitative model; a households with a higher *Moral attitude* decreases the *Provision factor* during the preparing phase. In both cases, there is a negative causal relation between the *Perceived amount of food waste* and the *Degree of over planning* and between the *Perceived amount of food waste* and the *Provision factor.*

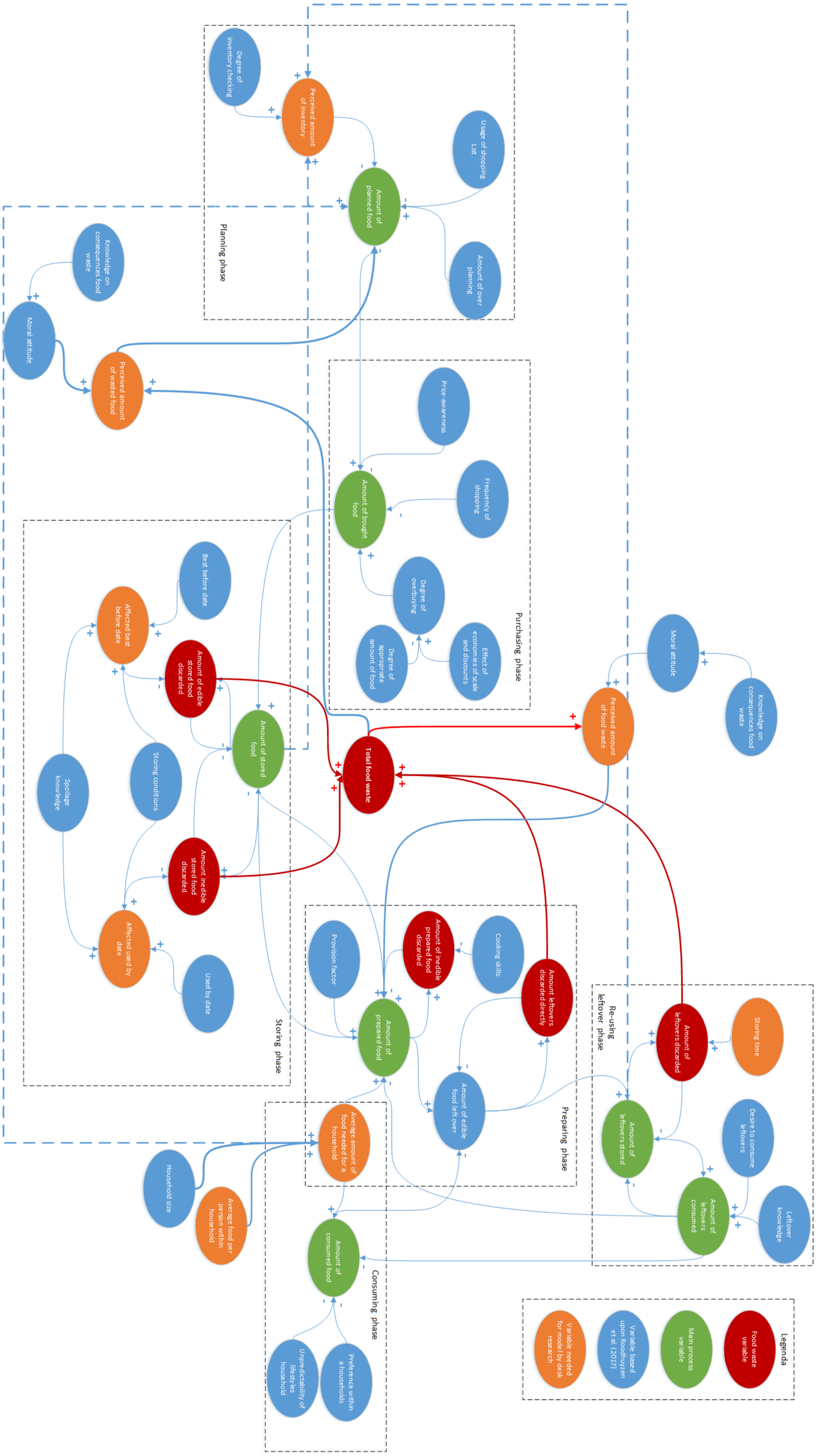


Figure 16: causal relation diagram of the total food waste system including the general variables

2.5 Demarcated overview of the system of interest

This section identifies the feedback loops that are present within the causal relation diagram. Multiple aggregated overviews of the model are created in this section. As mentioned in previous section, two main feedback mechanisms are identified. One feedback mechanism is identified via the storage of food and leftovers (2.5.1) and one feedback mechanism is identified via the waste of food (2.5.2). In sub-section 2.5.2, the food waste feedback mechanism identified in previous section is improved by making and describing the distinction between the planning related waste and preparing related waste feedback mechanisms. The storing and food wasting related feedback loops mechanisms are combined in the last sub-section (2.5.3), resulting in an aggregated overview of the total food waste system, based upon the analyses performed in this chapter.

2.5.1 Stored food & stored leftovers mechanisms

Considering the stored amounts affect the planning phase within a household. Regarding the stored food and leftover feedback paths present within the causal relation diagram, two main feedback loops are identified, which are illustrated in figure 17:

1) *Amount of stored food*: in this study it assumed that households who tend to store a lot of food automatically adapt their planning policy. Households change their planning behaviour, knowing that they have a lot of food. They consider a fraction of the food stored while planning to buy new food. A feedback loop is therefore identified, going from the *Amount of planned food*, to the *Amount of bought food*, to the *Amount of stored food*, via the *Perceived amount of inventory* finally back to the *Amount of planned food.* **This is a negative feedback loop; having more food stored results in a lower amount of planned food and in less stored food (i).**

2) *Amount of stored leftovers*: in this study it assumed that households who tend to store a lot of food automatically adapt their planning policy. Households change their planning behaviour, knowing that they have a lot of leftovers. A feedback loop is identified, going from the *Amount of planned food*, to the *Amount of bought food*, to the *Amount of stored food*, to the *Amount of prepared food,* to the *Amount of edible food leftover,* to the *Amount of leftovers stored,* back to the *Amount of planned food* via the *Perceived amount of inventory.* **This is a negative feedback loop; having more leftovers stored results in a lower amount of planned food and in fewer leftovers (ii).**

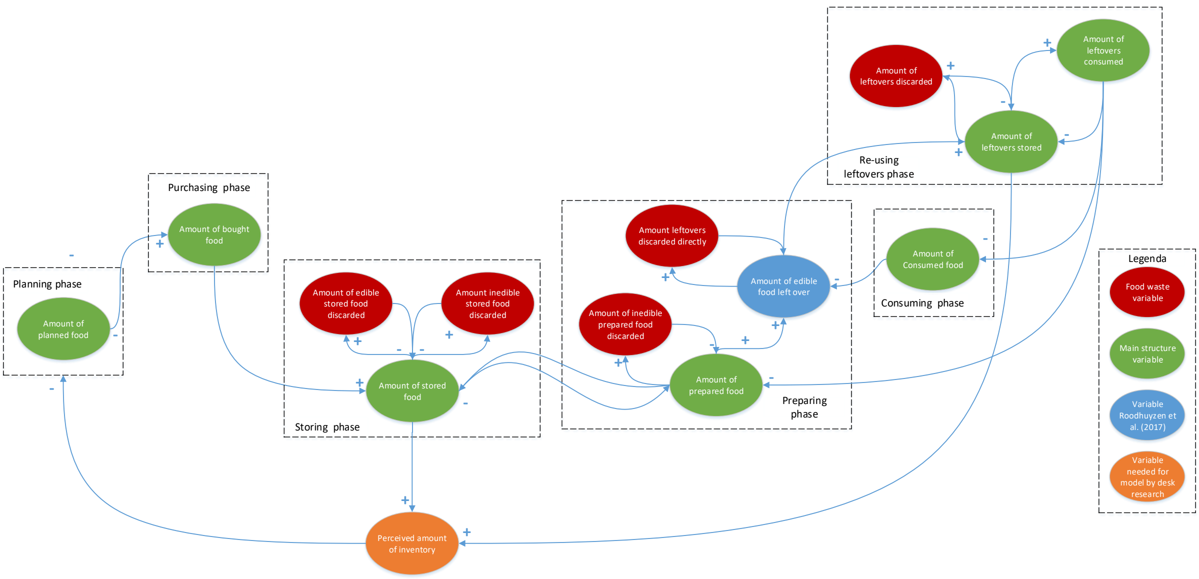


Figure 17: the stored food and leftovers feedback loops on the level of a household

2.5.2 Food waste mechanisms

As mentioned in section 2.4, the *Degree of over planning* and the *Provision factor* are connected to the *Perceived food waste*. In this sub-section, a distinction is made between the *Perceived amount of food waste planning* and *Perceived amount of food waste planning*. It is assumed that different amounts of food waste are applicable. The storing and re-using leftover related waste is applicable for the *Perceived amount of food waste planning.* For the *Perceived amount of food waste preparing*, only the food waste regarding the leftovers is considered; ruining food during the storing phase is assumed to not have an effect on the preparing behaviour. The food waste that is created during the preparing phase, the *Amount of inedible prepared food discarded* is not considered in both cases. It is assumed that ruining food due to lack of *Cooking skills* has no impact on the planning nor on the preparing behaviour. Regarding the food waste variables pathways present within the causal relation diagram, two main kind feedback loops are identified via the *Total food waste.* The *Total amount of food* waste is divided up into two food waste variables; *Total food waste regarding the planning loops* and *Total food waste regarding the preparing loops.*

- Via the *Amount of planned food:* it is assumed that households tend to adapt their planning behaviour if they throw food away. There are multiple pathways present within the causal relation diagram, which are illustrated in figure 18:

    1) *Amount of edible stored food discarded:* a feedback loop is identified going from the *Amount op planned food,* to the *Amount of bought food*, to the *Amount of stored,* to the *Amount of edible stored food discarded,* via the *Total food waste regarding the preparing loops,* back to the *Amount of planned food.* **This is a negative feedback; throwing edible food away during the storing phase within a household results in a lower of amount of planned food (i).**

    2) *Amount of inedible stored food discarded*: a feedback loop is identified going from the *Amount op planned food,* to the *Amount of bought food,* to the *Amount of stored,* to the *Amount of inedible stored food discarded,* via the *Total food waste regarding the planning loops,* back to the *Amount of planned food.* **This is a negative feedback; throwing inedible food away during the storing phase within a household results in a lower amount of planned food (ii).**

    3) *Amount of leftovers discarded directly*: a feedback loop is identified going from the *Amount op planned food,* to the *Amount of bought food, to the Amount of stored, food,* to the *Amount of prepared food,* to the *Amount of edible food leftover,* to the *Amount of leftovers discarded directly,* via *Total food waste regarding the planning loops,* back to the *Amount of planned food.* **This is a negative feedback; throwing more leftovers away directly after a meal within a household results in a lower amount of planned food (iii).**

    4) *Amount of leftovers discarded:* a feedback loop is identified going from the *Amount op planned food,* to the *Amount of bought food,* to the *Amount of stored,* to the *Amount of prepared food,* to the *Amount of edible food leftover,* to the *Amount of leftovers stored,* to the *Amount of leftovers discarded,* via the *Total food waste regarding the planning loops,* back to the *Amount of planned food.* **This is a negative feedback; throwing more leftovers away within a household results in a lower amount of planned food (iv).**

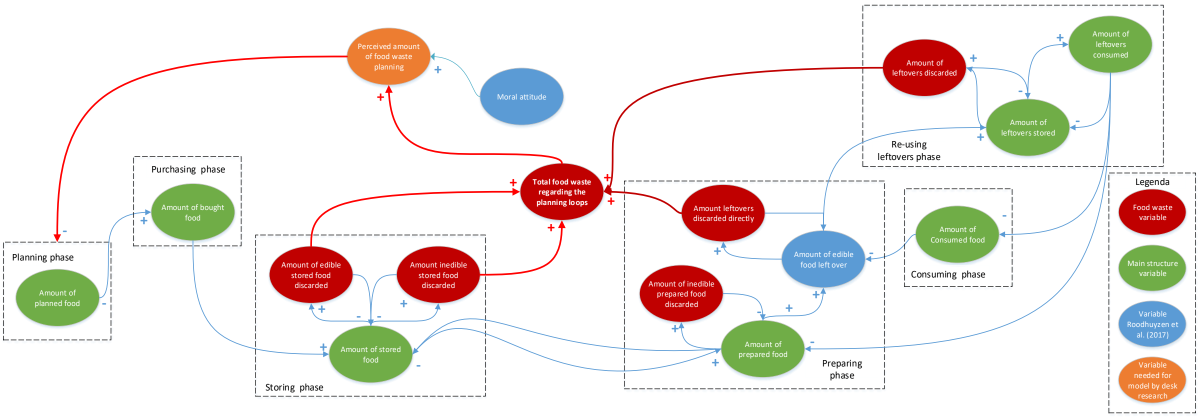


Figure 18: the planning food waste feedback loops on the level of a household

Via the *Amount of prepared food*: it is assumed that households tend to adapt their preparing behaviour if they tend to throw a lot food away. There are multiple pathways present within the causal relation diagram, which are illustrated in figure 19:

1) *Amount of leftovers discarded directly*: a feedback loop is identified going from the *Amount of prepared food,* to the *Amount of edible food leftover*, to the *Amount of leftovers discarded directly,* via the *Total food waste regarding the preparing loops,* back to the *Amount of prepared food.* **This is a negative feedback; throwing more leftovers away directly after a meal within a household results in a lower amount of prepared food (i).**

2) *Amount of leftovers discarded:* a feedback loop is identified going from the *Amount of prepared food, to the Amount of edible food leftover, to the Amount of leftovers stored, to the Amount of leftovers discarded,* via the *Total food waste regarding the preparing loops, back to the Amount of prepared food.* **This is a negative feedback; throwing more leftovers away within a household results in a lower amount of prepared food (ii).**

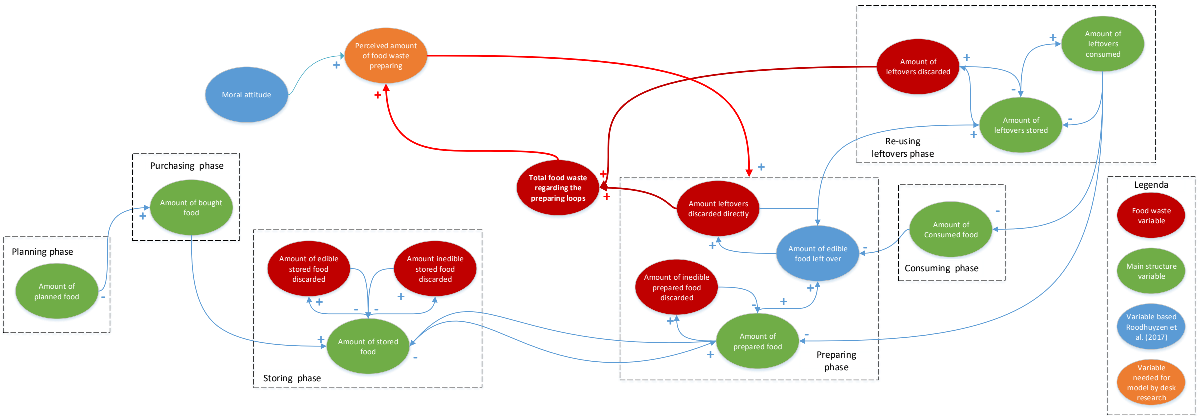


Figure 19: the preparing food waste feedback loops on the level of a household

2.5.3 An aggregated overview

In previous two sub-sections, 8 feedback loops are identified. 2 Feedback loops regarding the storing aspects of the food waste system and 6 feedback loops regarding the food waste mechanisms. 4 feedback loops via the planning loops and 2 via the preparing loops. All the identified loops have a negative nature, resulting in multiple balancing loops. The negative nature of the loop is deducted by following the causality of the loop from the beginning variable going back to this variable. These feedback loops are further considered during the model building in chapter 4, where they are implemented within a simulation model. An aggregated overview of the model is given in figure 20**.** In this figure the storage feedback loops are depicted by loop 1 and 2**,** the feedback loops regarding the waste of food and the planning behaviour via the *Degree of over planning* are depicted by loop a, b, c, and d. The feedbacks loops regarding the waste of food and the preparing behaviour via the *Provision factor* are depicted by loop i and ii. The rounded arrow depicts the direction of the loop, which are all counter wise in this aggregated overview. In this aggregated overview no difference is made between the *Total food waste regarding the preparing loops* and the *Total food waste regarding the preparing loops.* These variables are taken together in the variable *Food waste* in this aggregated overview.

Based upon the identified loops, it is concluded that the qualitative model defined in this chapter contains multiple negative feedback loops, also known as balancing loops.

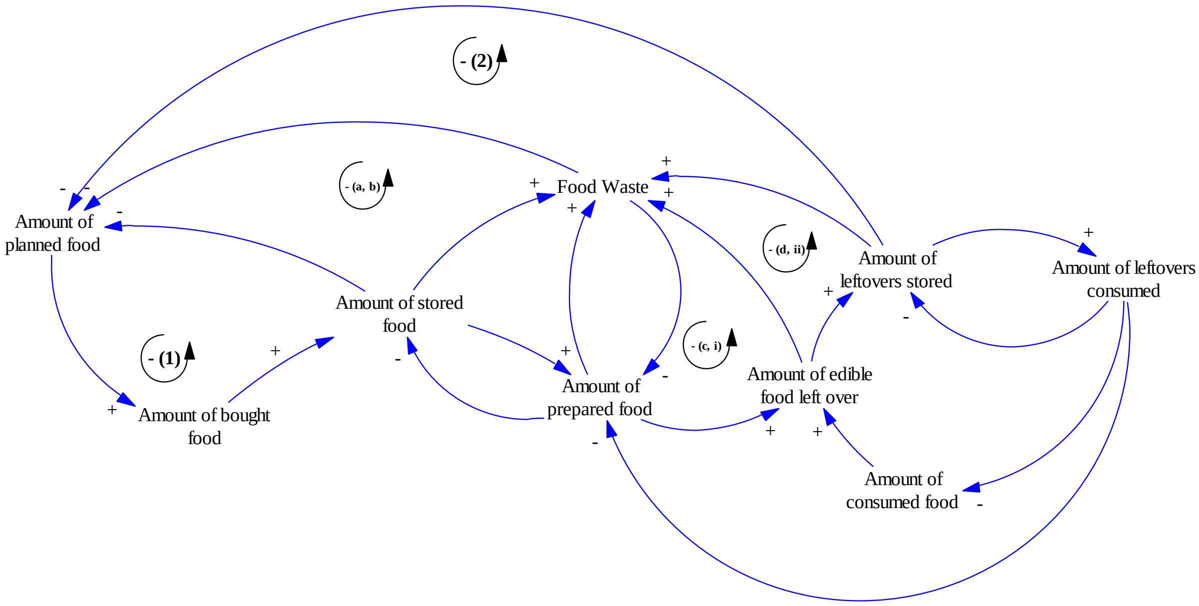


Figure 20; aggregated overview of the food waste system

2.6 Conclusions

This chapter describes a qualitative model that represents the food waste system of the research problem defined in the previous chapter. In this chapter the system of food waste is conceptualised by means of designing a causal relation diagram. This causal relation diagram represents the food waste system on the level of a household. The causal relation diagram consists of multiple causal relation diagrams, each representing a phase. Within the food waste system, the following phases are considered; the planning, the purchasing, the storing, the preparing, the consuming, and the re-using leftovers phase. For each phase, important factors are identified that are responsible for generating the phase related behaviour. The causal relation diagrams are combined and extra non-phase related variables are added. This results in the causal relation diagram that represents the food waste system on the level of a household. Relevant factors are identified by reviewing scientific literature, desk research, and expert interviews.

Based upon the factors that are considered within the causal relation diagrams, the following behaviour regarding the food waste within a household can be identified: households tend to plan to buy more food than actually needed during the planning phase. While making a planning, a household partly considers the food and leftovers that are stored. During the purchasing phase households tend to buy even more food than they initially planned to do. The bought food is stored during the storing phase. However, more food will be stored than needed for the preparation. This will result in food that is stored for longer periods. Storing food for longer periods may result in food waste due to the moulding process. Besides, food may be discarded because it has reached the use by or best before date. Furthermore, households tend to make more food than actually needed. During the consumption phase, the actual food that is consumed differs from the food that is prepared. This is caused by the preferences and hectic lifestyles that are present within households and as mentioned before because more food is prepared than actually needed. This difference between the food prepared and consumed results in edible food leftover, of which a part is thrown away directly after a meal and ends up as food waste. The resulting edible food leftover is stored during the re-using leftover phase, after which it is partly eaten and partly thrown away, ending up as wasted food due to the moulding process of the leftovers.

Based upon the qualitative model, multiple feedback mechanisms are identified. A difference is made between feedback mechanisms regarding the storage of food and leftovers and feedback mechanisms regarding the waste of food. The stored food and leftovers are partly considered while a household plans the food that needs to be bought. Households with a high moral attitude regarding the waste of food are more willing to change their planning and preparing behaviour. This behavioural change results in less planned and prepared food. All the feedback mechanisms are assumed to be negative. The combined effect of these mechanisms is assumed to have a balancing effect on the food waste system; an equilibrium of the generated waste of food is approached.

This study tried to capture all the relevant factors that are needed to represent the waste of food generated on the level of a household. However, multiple definitions of food waste are used in the scientific field of food waste on the level of a household. The use of multiple definitions results in different ways of measuring and presenting food waste, which troubles the creation of the causal relation diagram. Assumptions and simplifications are inevitable, which results in a high aggregation level of the causal relation diagram. No difference is made between multiple types of food and household. This implies that simulating interventions based upon this causal relation diagrams generates general effects of the interventions on the food waste on the level of a household.

The resulting causal relation diagram of the food waste system is used to identify possible interventions in chapter 3. These interventions are identified based upon parameters that can be affected by relevant stakeholders . In chapter 4, the quantitative model is created and the gathered is gathered based upon the causal relation diagram defined in this chapter.

3 Interventions

This chapter identifies interventions for reducing the food waste generated by a household. These interventions are connected to the qualitative system defined in previous chapter. A definition of an intervention is given in section 3.1. The approach on how to identify the interventions is given in section 3.2. The most relevant actors in regards to the interventions are elaborated on in section 3.3. Based upon the actors and the changeable parameters identified in previous chapter, possible interventions are identified per phase in section 3.4. A set of interventions is described in more detail in section 3.5. The most important insights are summarized in section 3.6. The result of this chapter is a set of interventions that is considered during the model use in chapter 6.

3.1 Defining an intervention

This section defines an intervention used in this study to scope the research. Due to the scope defined in previous section for the food waste system, interventions on reducing the food waste are focussed on households. Therefore, other stages of the food supply chain are not considered during this study (production, postharvest, processing, and distribution stage). The focus is on measures that are used for reducing all the foods that are discarded, which are avoidable on the level of a household. Multiple kinds of measures can be taken from multiple actor perspectives. Also, the food waste system can be influenced by multiple phases as defined in previous chapter (planning, purchasing, storing, preparing, consuming, and re-using leftover phases).

To scope the research the following definition of an intervention is used:

"Measures that are used for reducing the food waste that occur the preparation of food, and the food and leftovers that are discarded, either before or after it spoils, by the human members within a household."

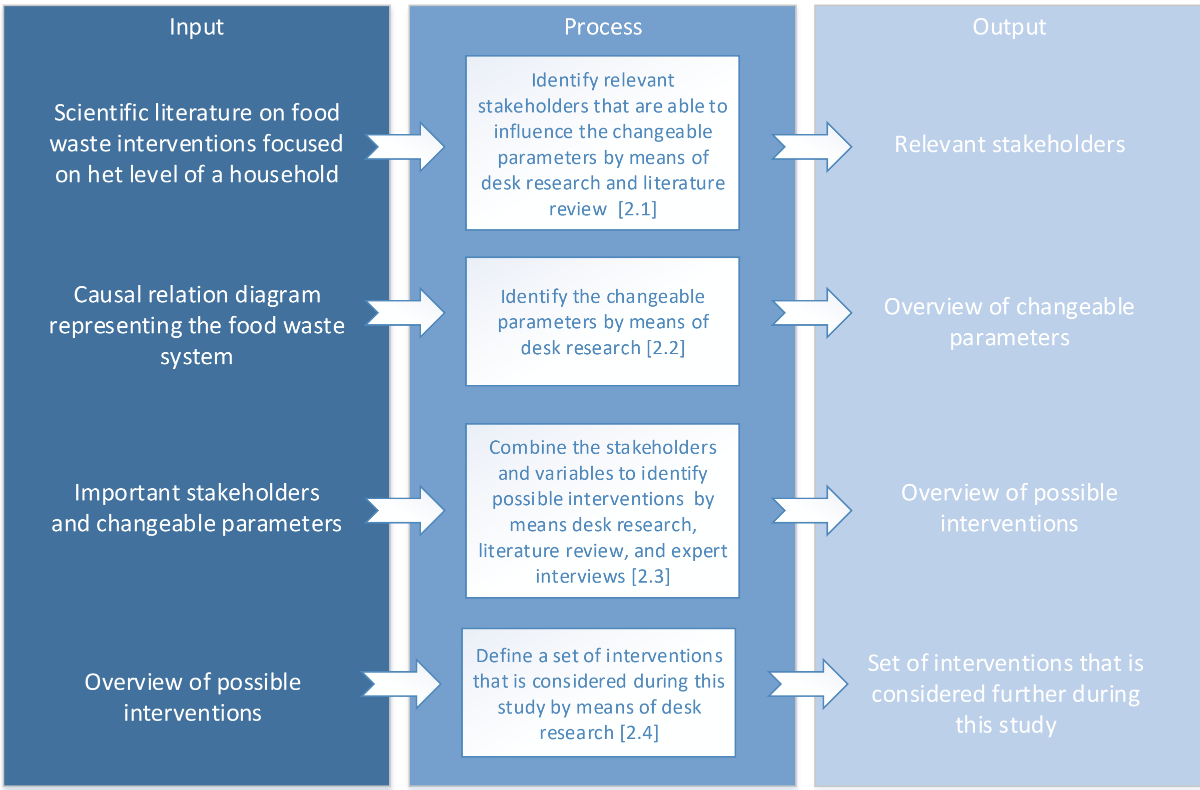


Figure 21: overview research design intervention analysis

3.2 Intervention analysis approach

This section describes the research steps are required to identify interventions that are considered further during this study. A visualisation of the research approach for this chapter is given in figure 21**.** Based upon these research steps, the interventions are identified, of which a set is considered during the model use in chapter 6.

Step 1: identify important stakeholders that may be able to affect the previous variables
Multiple interventions are possible from multiple actors' perspectives. Important actors are derived from scientific literature. These actors are used to categorize possible interventions for reducing the waste on the level of a household, which are identified during the third research step. The actors that are considered are described in section 3.3.

Step 2: identify the possible variables that can be affected
To simulate the different interventions, anchor points are needed. An intervention should affect a parameter within the causal relation diagram representing the food waste system on the level of a household defined in previous chapter. Based upon this causal relation diagram, per phase, multiple changeable parameters are identified and presented. The changeable parameters are given in section 3.4.

Step 3: combine the possible variables and actors and add possible interventions
An overview of the possibilities regarding the interventions is made by this research step. The changeable variables defined during the third research step and actors identified during the second research step are combined per phase. This is done to provide an overview of the possibilities regarding the interventions. Possible interventions are added by means of literature review. If possible, interventions are added to the overview. The results of this research step are presented and described in section 3.4.

Step 4: define a set of interventions
Given the interventions defined in previous research step, a review takes place based upon the kind of intervention (technical and social interventions) and the phase, which it affects. In this study, the focus is on a limited number of interventions that are considered further in this study. Based upon this review, a set of interventions is chosen in section 3.5.

3.3 Multiple-actor perspective

This section identifies the actors that are used for identifying possible interventions. Given the food waste system of a household, a wide variety of stakeholders are able to influence the behaviour of households, however based upon the available literature; the most important stakeholders are the government, the supermarkets, and the companies. In this section, the stakeholders considered in this study are described. The result of this section is an overview of relevant stakeholders, which are used for identifying and categorizing possible interventions in section 3.4.

1. *Government:* The government is able to influence the food waste system from multiple levels (Delley & Brunner, 2017). The government has mainly financial resources that can be used for realising interventions. The main kind of interventions that the government has realised is focused on the increasing the knowledge of the members present in a household and increase skill levels of household directly or via other institutions.
2. *Supermarkets:* As mentioned in chapter 2, supermarkets influence households; they stimulate to buy more food than needed due to economies of scale and discounts. This stakeholder can easily influence the waste of food on the level of a household. This stakeholder can take many actions like for example design new discounts forms (Delley & Brunner, 2017), Self- dispensing systems (Hebrok & Boks, 2017), information providing (Young et al., 2015), and packaging (Verghese et al., 2015).

3. *Companies:* All the companies that that are able to influence the qualitative model identified in previous chapter fall under this stakeholder in this study. Companies that make products or services that can be used by households to reduce the food wasted. There is a lot potential regarding the decrease of food waste on the level of a household, for example by improving the packaging of food products (Verghese et al., 2015; Hebrok & Boks, 2017). Fridges combined with smart applications for example can be used for decreasing the waste of food (Bucci et al., 2010; Hebrok & Boks, 2017; Ganglbauer et al, 2013).

3.4 Combining a multiple-phase and multiple actors perspective

This section provides an overview of possible interventions that can be used for decreasing the waste of food on the level of a household. Combining the stakeholders defined in section 3.3 and the changeable parameters of the causal relation diagram identified in previous chapter creates an overview of possible combinations for interventions. These interventions are added to the overview by means of literature research. The possible interventions are identified and discussed per phase in section 3.4.1-3.4.5. Interventions for the preparing and consuming phase are not considered in this study. It is assumed that the changeable parameters are not effectible in these two phases. The result of this section is an overview of possible interventions that reduce the food waste of which a set of is considered in next section.

3.4.1 Planning

Multiple variables can be used for affecting the *Amount of planned food* within the planning phase (2.3.1). These changeable parameters can be adjusted by interventions that are identified based upon scientific literature and are presented in table 8**.**

Table 8: overview interventions planning phase

Variable	Government	Supermarket	Companies
Degree of using shopping lists	- Introduce topics in home economics courses by Delley & Brunner (2017)	n.a	- Raise food supply awareness using a cam fridge by Farr-Wharton et al. (2014) & Ganglbauer et al. (2013 - ZmartFRI by Bucci et al. (2010) and Hebrok & Boks (2017)
Degree of inventory checking	- Introduce topics in home economics courses by Delley & Brunner (2017).	n.a.	- Raise food supply awareness using a cam fridge by Farr-Wharton et al. (2014) & Ganglbauer et al. (2013). - ZmartFRI by Bucci et al. (2010) and Hebrok & Boks (2017)

The planning behaviour can be adjusted mainly by two different kinds of interventions: awareness creation from a governmental perspective and a fridge with application that stimulates households to use shopping list and to increase the inventory awareness. A difference is found between the natures of these two kinds of interventions. The awareness interventions have a social character and the fridge has a technical character. The ZmartFRI is a fridge concept that includes an expiration date alert and the ability to print a grocery list and send it to the household members on demand. A FridgeCam is camera within the fridge, which is able of displaying its content and to send it to the households if demanded. Topics in home economics can be seen from a governmental perspective. Topics like awareness campaigns or courses, which provides information on how to cope with the *Degree of using shopping list* and the *Degree of checking the inventory.* Supermarkets are also able to introduce these topics, but none are identified based on scientific literature.

3.4.2 Purchasing

Multiple variables that can be used for affecting the *Amount of bought food* within the purchasing phase (2.3.2). These changeable parameters can be adjusted by interventions that are identified based upon scientific literature and are presented in table 9**.**

Table 9: overview of interventions purchasing phase

Variable	Government	Supermarket	Companies
Degree of appropriate amount of food	n.a.	- Self- dispensing systems by Hebrok & Boks (2017).	- Change pack sizes by Hebrok & Boks (2017) - Design for smaller households by Verghese et al. (2015). - Subdivided packages (Verghese, 2015).
Effect of economies of scale and discounts	n.a	- Design new discounts methods instead of quantity discounts by Delley & Brunner (2017).	n.a
Frequency of shopping	n.a	n.a	n.a
Price-awareness	- Introduce topics in home economics courses by Delley & Brunner (2017)	n.a.	n.a

Topics in home economics from a governmental perspective are awareness campaigns or courses focussed on the *Price-awareness*. Making households aware of the costs they could save may result in a lower *Amount of bought food*. These are social interventions. From the supermarket perspective, the *Degree of overbuying* can be adjusted by using a self-dispensing system and a new discount form. The self-dispensing systems disable the economies of scale effect and enables a household to get the exact amount of food needed. The new discount form entails a situation in which no promotions are offered like buy two products for the price for one. These interventions are both considered as technical interventions in this study. From an company perspective mainly packaging interventions are available. This type of intervention is also considered as a technical interventions.

3.4.3 Storing

There are multiple variables that can be used for affecting the food waste that occurs during storing phase (2.3.3). These changeable parameters can be adjusted by interventions, which are identified based upon scientific literature. These interventions are presented in table 10**.** It is assumed that the variables *Use by date* and the *Best before date* of products cannot be changed directly, since they are dependent on the type of food product.

Table 10: overview of interventions storing phase

Variable	Government	Supermarket	Companies
Spoilage knowledge	- Harmonise data definition and labelling by Delley & Brunner (2017), Hebrok & Boks (2017), Verhese et al. (2015), and Thyberg & Tonjes (2016) - Education to promote behavior changes by Thyberg & Tonjes (2016)	- Asda magazine by Young et al. (2017) - Asda e-newsletter by Young et al. (2017) - The Bump Mark by Hebrok & Boks (2017) - Harmonise data definition and labelling by Delley & Brunner (2017), Hebrok & Boks (2017), Verhese et al. (2015), and Thyberg & Tonjes (2016) - Asda Facebook by Young et al. (2017)	n.a.

Storing conditions	- Awareness campaigns by Delley & Brunner (2017) - Education to promote behaviour changes by Thyberg & Tonjes (2016) - Raise location awareness by The Colour Code Project by Farr-Wharton et al. (2014).	- Storage guidance by Hebrok & Boks (2017) - Asda e-newsletter by Young et al. (2017) - Asda magazine by Young et al. (2017) - Asda Facebook by Young et al. (2017)	- ZmartFRI by Bucci et al. (2010) and Hebrok & Boks (2017) & Ganglbauer et al. (2013). - Ethylene scavengers: - Oxygen scavengers: - Edible coatings: - Moisture absorbers - Aseptic packaging by Verghese et al. (2015). - Storage guidance by Hebrok & Boks (2017) - Improve packaging by Thyberg & Tonjes (2016) - Multi-layer-packaging: - Modified atmosphere packaging (MAP) by Verghese et al. (2015).

From a governmental perspective, the interventions have a social nature. The main topics of these interventions are awareness creation, education, and information providing. By these, the government is able to affect all the changeable parameters within the storing phase. Only the intervention: harmonisation of the data definition and labelling by Delley & Brunner (2017) only affects one parameter, which is the *Spoilage knowledge*. The supermarket is also able to provide the same information but via other communicational ways via magazines and newsletters. All these interventions have a social nature. A specific intervention is applied from a governmental perspective where the location awareness is increased by applying a Colour Code Project. Increasing the awareness of the location where food storage occurs is assumed to result in behavioural change. This project contained a colour system per type of food making households aware what kind of food is available in their storage. This project mainly increases the easiness of the search towards food. The outcomes of the project saw food waste reduced quite significantly. The companies are also able to affect the *Amount of stored food* by affecting the *Storing conditions*. A lot of different packaging techniques are possible. New packaging systems are active, smart or intelligent packaging. Active packaging includes components of packaging systems that are capable of scavenging oxygen, absorbing carbon dioxide, moisture ethylene and maintaining temperatures control and compensating for temperature changes. All are used to increase the *Storing conditions* within a household. A ZmartFRI is able to provide information on the *Use by date* and *Best before date* of products, which is a technical intervention. The companies could also increase the storing guidance to increase the *Storing conditions*, which is a social intervention.

3.4.4 Re-using leftovers

The food that is left over after a meal is thrown away directly or stored as leftovers. There are multiple variables that can be used for affecting the food waste that occurs during re-using leftover phase (2.3.6). Based upon scientific literature, these changeable parameters can be adjusted by interventions, which are presented in table 11**.**

Table 11: overview of interventions re-using phase

Variable	Government	Supermarket	Companies
Leftover knowledge	- Awareness campaigns by Delley & Brunner (2017) - Hold workshop associations by Delley & Brunner (2017) - Education to promote behavior changes by Thyberg & Tonjes (2016)	- Asda e-newsletter by Young et al. (2017) - Asda Facebook by Young et al. (2017) - Asda magazine by Young et al. (2017)	n.a.

Desire to consume leftovers	- Home economics courses by Delley & Brunner (2017).	n.a	n.a.
Moulding time leftovers	n.a	n.a.	n.a.

No interventions are documented to decrease the *Moulding time leftovers*. However, the same interventions that increase the *Storing conditions* can be used. From a governmental perspective, mainly social interventions are possible ranging from awareness campaigns, workshops, education and courses. Supermarkets are also able to adjust the *Leftover knowledge* and desire to consume leftovers of households but then again via other communicational ways, via newsletters, Facebook, and e-newsletters.

3.4.5 General

There are multiple variables that can be used for affecting general phase (2.4). Based on scientific literature, these changeable parameters can be adjusted by interventions, which are presented in table 12**.** The variables *Average Kg/person* and *Household size* assumed to be non-changeable. It is assumed that people do not want to change the their food consumed per week and it is assumed that changing the number of inhabitants per household on average is not possible within the timeframe of this study. Therefore these variables fall outside the scope of this study and are not considered during the intervention analysis.

Table 12: overview of interventions general phase

Variable	Government	Supermarket	Companies
Knowledge on consequences food waste	- Awareness campaigns by Delley & Brunner (2017), Whitehair et al. (2013), and Jagau & Vyrastekova (2017). - Develop new social norms by Delley & Brunner (2017) - Food calculator by Ganglbauer et al. (2013) - Make the connections between moments of consumption and their possible implications for later food waste more visible by Ganglbauer et al. (2013). - Design an interactive and mobile exhibition: simulation of negative consequences by Delley & Brunner (2017) - Thyberg & Tonjes (2016) introduced: Education to promote the importance of food waste prevention in terms of environmental, social, and economic impacts	- Asda e-newsletter by Young et al. (2017) - Asda Facebook by Young et al. (2017) - Asda magazine by Young et al. (2017)	n.a

In general, the government according to scientific literature can mainly adjust *the Knowledge on consequences of food wasted* in the general phase. To do so, many different alternative interventions are possible. The main idea behind is providing information on the consequences of food waste. The nature of these interventions is social. The supermarkets are also able to contribute to this knowledge by the use of social media and magazines according to scientific literature. All these interventions are of social nature. Even though the companies may be able to provide knowledge on the consequences, none are documented in scientific literature and therefore not considered.

3.5 Choosing a particular set of interventions for the further analysis

This section defines a set of interventions that is further considered during this study. The interventions that are considered are chosen based upon the phase they affect and their social or technical nature. In this study, two social interventions and two technical interventions are considered. The interventions that are taken into account affect the planning behaviour by using a Fridgecam (3.5.1), affect the purchasing behaviour by introducing a new discount type and no economies of scale in supermarkets (3.5.2), affect the storing behaviour by means of an awareness campaign focused on increasing the *Spoilage knowledge* (3.5.4), and affect the *Moral attitude* by influencing the *Knowledge on consequences food waste* via the Knowledge on consequences food waste (3.5.4). Based on the aggregated causal relation diagram defined in previous section, the effects of these interventions are illustrated in figure 22**.** The potential effects of the resulting interventions are simulated in chapter 6.

3.5.1 FridgeCam

The 'FridgeCam' is an application installed on a mobile device and the secured on the inside of a fridge. This application is able to take several photos, which are approachable, online by the members of a household (Farr-Wharton et al., 2014). A 'FridgeCam' enables households to better consider what they have at home while doing groceries. In this study it is assumed that one function of the ZmartFRi is added to the application: the shopping assistant suggesting (and sending) the grocery/shopping list (Bucci et al., 2010). This technical application from an company perspective affects the planning phase via the variables the *Degree of using a shopping list* and the *Degree of inventory checking*. Both degrees increase while applying the 'FridgeCam', resulting in a lower *Amount of planned food*. This lower *Amount of planned food* is assumed to result in a lower *Amount bought food* and thereby in a lower *Amount of stored food* resulting in a lower *Total amount of stored food discarded* during the storing phase.

3.5.2 No discount and economies of scale

The new discount form entails the design of a new discounts form where no quantity discounts are present by Delley & Brunner (2017). This intervention is assumed to decrease the economies of scale for an household. Households buy quantities more in line with their actual needs for the same price per kilogram, resulting in less food bought. Besides, other promotions like buy one and get two are also not available regarding this intervention. This technical intervention from a supermarkets perspective affects the purchasing phase. The new discount form combined with the self-dispensing system is assumed to affect the variable *Effect of economies of scale and discounts*. This variable is assumed to decrease using this intervention, resulting in a lower *Degree of overbuying* and thereby into a lower *Amount of food bought*, resulting in a lower *Amount of food stored* and thereby results in a lower *Total amount of stored food discarded* during the storing phase.

3.5.3 Spoilage knowledge campaign

This campaign provides information to increase the overall *Spoilage knowledge* within a household. It entails information of the difference between the "best before" date, the "use by", and the "sell by" date (Delley & Brunner, 2017). It is also assumed that increasing the *Spoilage knowledge* increases the ability of a household to determine the edibility of food, even when it has surpassed the *Best before date*. A more uniform and better understandable date label system could better communicate appropriate information to households, contributing to a reduction of food waste (Vittuari et al. 2015). Increasing the *Spoilage knowledge* is assumed to decrease of the *Amount of stored food*. This social intervention from a governmental perspective affects the storing phase. The campaign is assumed to affect the *Affected use by date* and the *Affected best* *before date*, resulting in longer storing times and less discarded stored food. The *Amount of edible stored food* and the *Amount of edible stored food* is affected by means of this intervention.

3.5.4 Awareness campaign on consequences food waste

In scientific literature many suggestions are made on how to increase the variable *Moral attitude*. In this study, it is assumed that the *Moral attitude* is dependent on the variable *Knowledge on the consequences of food waste*. Therefore an general awareness campaign is considered further on in this study that focuses on increasing the *Knowledge on the consequences of food waste* by providing information and education (Whitehair et al., 2013; Thyberg & Tonjes, 2016; Delley & Brunner, 2017; Jagau & Vyrastekova, 2017). Even though this campaign can be realised by multiple stakeholders, the government is considered as the relevant stakeholder. The government has the most resources to realise the campaign, by itself or via other institutions that are specialised in providing these kinds of information. This social intervention from a governmental perspective affects the general phase. The *Knowledge on the consequences food waste* is assumed to increase, and thereby also the *Moral attitude*. Increasing the *Moral attitude* is assumed to increase the *Perceived amount of food waste* and thereby to decrease the variables *Degree of over planning* during the planning phase and the *Provision factor* during the preparing phase. By lowering these two variables, the *Amount of bought food* and the *Amount of prepared food* are assumed to decrease, resulting in a lower *Amount of stored food* and a lower *Amount of food leftover.* Following this, the *Amount of edible stored food discarded* and the *Amount of inedible food discarded* are decreased during the storing phase and the *Amount of leftovers discarded directly* and the *Amount of inedible leftovers* are reducing during the preparing and re-using leftover phase.

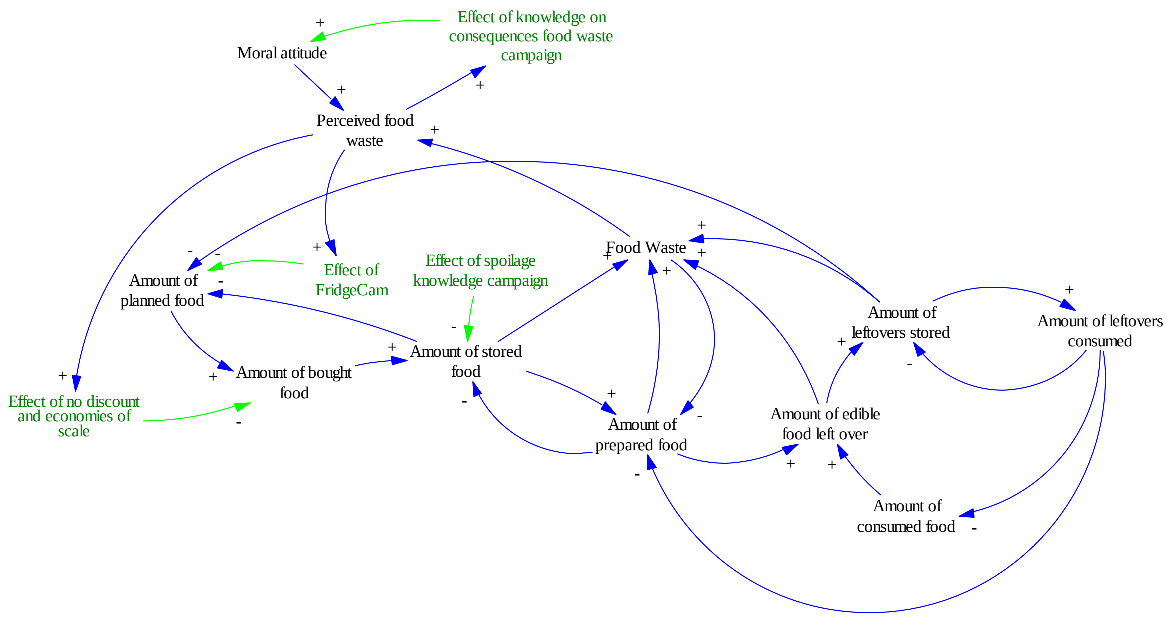


Figure 22 aggregated overview food waste system with effects interventions included

Intervention feedback mechanisms

In the current combined System Dynamics model it is assumed that the variable *Perceived amount of food waste* influences the effect of an intervention. This effect is illustrated in figure 22**.** As mentioned before, the *Perceived amount of food waste* is a product of the *Total amount of food waste* and the *Moral attitude*. Households with a low *Moral attitude* do not care about wasting food are not willing to reduce the food that is wasted, or at least are less likely to try to (Stefan et al., 2013; Graham-Rowe, et al., 2014; Principato et al., 2015). Households that are concerned about wasting food are more willing to adapt their behaviour, resulting in less wasted food (Stefan et al., 2013). It is also possible that households cannot reduce the waste of food due to the absence of this waste. A household cannot reduce food waste if there is none. Therefore is the variable *Total food waste* needed*.* This study captures the willingness of households combined with the amounts of food wasted via the *Perceived amount of food waste.* The *Perceived amount of food waste* is used to determine the potential effect of any given intervention. Through this mechanism, temporary feedback loops are created while applying an intervention. All interventions affect the *Total food waste* and thereby *Perceived amount of food waste*. Decreasing this *Perceived amount of food waste* results in a decrease of the effect of the intervention applied. All these temporary feedback loops have a negative nature, resulting in more balancing loops present within the qualitative model identified in previous chapter. This effect is quantified during the model use in section 6.3.1.

3.6 Simulation method

This section selects a simulation method that is used in this study to simulate the interventions that are identified in this chapter, based upon the qualitative model designed in previous chapter. First, the modelling technique is chosen (3.6.1) after which it is elaborated more upon in detail (3.6.2). Based upon the modelling method, possible simulation software is reviewed (3.6.3). The result of this section is a modelling method and software that is used during this study.

3.6.1 Suitable simulation method

There are multiple suitable modelling methods possible. A simulation method is chosen in this sub-section based upon the goals of this study, the characteristics of the qualitative model and interventions and the demarcation of the problem. The most common methods for modelling dynamic systems are Agent-Based Modelling (Bonabeau, 2002), the Discrete Event simulation (Schriber et al., 2012), and System Dynamics (Forrester, 1992). These modelling methods are used for different problems with different goals.

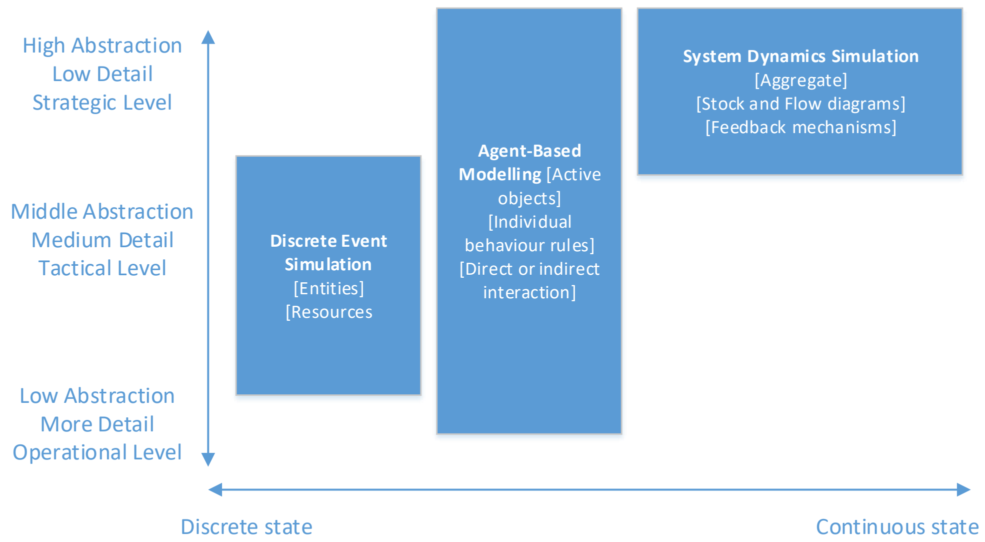


Figure 23: overview characteristics modelling methods (adapted from Borshchev & Filippov (2004))

As argued by Borshchev & Filippov (2004) the following distinctions are made considering the kind of problems regarding the modelling methods: its level of abstraction (i) and its event (discrete) or time (continuous) based characteristics**.** This distinction is illustrated in figure 23. Based upon the qualitative system identified in the second chapter and the interventions identified in this chapter, the following is concluded; given the current literature, the causal pathways between the different variables present within the food waste system are not investigated and therefore uncertain. Regarding the interventions, the following is concluded: little research is done towards interventions that are focused on reducing the food waste within a household. Most interventions are merely suggestions and the potential effects of these interventions on the food waste system or on the waste of food are most of the time not investigated or documented. These uncertainties result in a high abstraction problem with low detail. The high level of abstraction of the qualitative model identified in chapter 2 combined with the goal where the interest is on exploring the possible behaviour of the system and not on specific outcome values of interventions demands a modelling method like Agent-Based Modelling or System Dynamics, which have a more explorative character. In chapter 2, the qualitative model is based on a flow of food over time within a household. An average household is considered, resulting in one aggregated household with a time based structure of the model that represents the all the households present within the Netherlands. Due to this continuous based model, the System Dynamics simulation method is preferred over the Agent-Based Modelling method.

In this study, the System Dynamics approach seems to be a suitable method for simulating the interventions identified in previous section based on the causal relation model identified in previous chapter. These effects are inherent complex; there is a continuous level of interaction, and the impacts of interventions over time are from a strategic level.

3.6.2 System Dynamics approach

System Dynamics is a method for analysing dynamic systems to support policy analysis and decision-making. In this study this is the analysis of the food waste system in a household given multiple interventions, which also can be seen as policies. A System Dynamics model is created to provide insights into the behaviour of the system through its structure (Forrester, 1992). Many systems are modelled by means of System Dynamics, however, in current scientific literature, no attempts are found to simulate the food waste on the level of a household from a System Dynamics perspective. It is rather a new approach for simulating the waste of food within households.

System Dynamics models are comprised of stock-flow structures and feedback loops. Within the model arrows that represent causal relations connect variables. Feedback concepts are important in System Dynamics models. A feedback loop is a system structure that causes output from one variable to eventually influence input to that same variable. Feedback loops can have a positive influence on the system, which has a reinforcing effect. Negative feedback loops, as present within the qualitative model defined is chapter 2 have a balancing effect on the behaviour of the system. In a model with multiple different feedback loops, or interacting mechanisms, it is hard to anticipate system behaviour.

The following elements are present within System Dynamics models: variables, stocks, inflow variables, and outflow variables. Dynamic behaviour rises in System Dynamics due to the Principle of Accumulation (Yamaguchi, 2003). According to this principle, dynamic behaviour of the system arises due to the flows into, and out of, the stock. Regarding these flows, there are three possibilities; if the inflow exceeds the outflow, then the value of the stock increases. If the outflow exceeds the inflow, then the value of the stock decreases. Lastly, if the outflow equals the inflow, then the value of the stock remain the same. This last possibility describes a state of dynamic equilibrium in a system dynamics model. In the causal relation model defined in previous chapter, the *Amount of stored food* and the *Amount of leftover stored* are stocks. A certain amount of food is present within a household, which increases due to the *Amount of bought food* and decreases due to the *Amount of prepared* food and the amounts of stored food discarded.

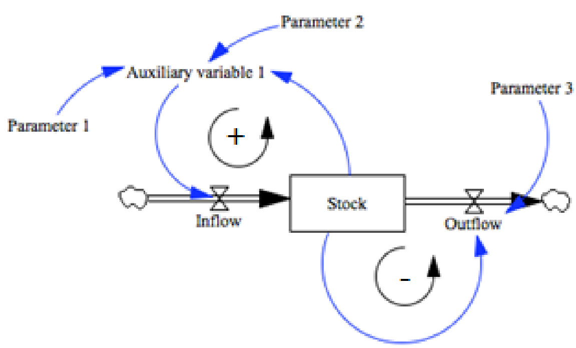


Figure 24: example of a basic System Dynamics structure

Auxiliary variables can influence these in and outflows of stocks. A difference is made between variables that do not change during the simulation, which are parameters or constants, and variables that are influenced by other variables. The latter are auxiliary variables that are influenced by other variables. An illustration of the different types of variables is given in figure 24**.** A System Dynamics model per phase and a System Dynamics model in which these phases are connected are given and discussed in next chapter.

As mentioned, a feedback loop occurs when a change in something ultimately comes back to cause a further change in the same variable. If the further change is in the same direction it's a positive or reinforcing loop. This reinforcing loop is illustrated by in figure 24 by a clockwise arrow with a positive sign. If it's in the opposite direction it's a negative or balancing loop, also called a goal-seeking loop. The balancing loop is illustrated in figure 24 by a clockwise arrow with a negative sign. Analysis of the system is possible when the variables and relations are quantified.

Connecting the stock-flow structures with the present feedback loops results in an appropriate system description of the food waste system. System Dynamics generates the output of the model by computing all the integral equations based upon a numerical integration method. In the modelling program Vensim PRO x32, which is used for this study, Euler and Range-Kutta methods can be used. Based upon, interaction and effects over time can be identified by means of the System Dynamics model. The interactions within the model are important to consider since it provides insights on the possible effects that are expected. Unexpected negative and positive effects of interventions are also important to consider; these effects may provide interesting insights. The integration method, combined with other model settings and the System Dynamics software used in this study are discussed in section 4.4. Examples of outputs of the System Dynamics model are provided in chapter 6.

3.6.3 System Dynamics software

For this study the software Vensim PRO x32 is used to represent the model and to simulate the food waste and the effects of the interventions on the food waste. Multiple other software packages are possible within the field of System Dynamics. The most used packages for System Dynamics modelling are the packages of AnyLogic, IThink, Powersim, and Vensim. These different packages have many common features and the differences are minor. Regarding the design and the purpose of the model, no major difference between the different modelling packages can be found for this study, therefore the Vensim software is used in this study.

3.7 Conclusions of this chapter

This chapter identifies interventions for reducing the food waste generated by a household. To structure the research, an overview per phase is created. This overview is based upon the relevant stakeholders and the parameters that can be affected, identified by means of the causal relation diagram defined in chapter 2. Where possible, interventions are added to this overview by means of reviewing scientific literature.

Based upon reviewing scientific literature, three relevant actors are identified that are able to influence the causal relation diagram defined in previous chapter. The following actors are incorporated: the government, the supermarkets, and the companies. These actors are able to influence the behaviour of the households.

The interventions that are documented in scientific literature is limited. Besides, the effects of these interventions are often not considered and estimated. Most of the interventions that are given are mere suggestions. Due to the absence of the potential causal effects of interventions regarding the causal relation diagram from previous chapter, assumptions are inevitable. In this chapter, the potential effects of the interventions are identified based on estimated causal effects towards the changeable parameters of the causal relation diagram.

In this chapter a set of interventions is chosen based upon the phase that is affected by the intervention itself, the technical or social nature of the interventions, and the responsible stakeholder. The following interventions are considered during this study:

- *FridgeCam*; this technical intervention from an company perspective affects the planning phase. It increases the degree that a household can check their inventory while making a planning. Besides, this intervention affects the degree of using a shopping list. Applying this intervention enables a household to estimate the food needed better while determining the planned food.
- *No discount and economies of scale*; this technical intervention from a supermarkets perspective affects the purchasing phase. If supermarkets remove their products with an economic of scale discount and not offer other type of discounts decreases the extra unnecessary food bought by a household.
- *Spoilage knowledge campaign*; this social intervention from a governmental perspective affects the storing phase. Increasing the knowledge regarding the spoilage within a household encourages people to trust their own instincts rather than the best before and use by date. Thereby food may be stored and used within a longer time frames, which makes it more likely that the stored food will not be thrown away.
- *Awareness consequences food waste campaign*; this is a social intervention from a governmental perspective. Increasing the knowledge regarding the consequences of wasting food is assumed to increase the moral attitude within a household. Increasing the moral attitude results in an behavioural change of the planning and preparing behaviour within a household. Less food is planned to be bought and less food is prepared, both resulting in less food thrown away.

Based upon the relation between the interventions and the causal relation diagram, a new causal mechanism is identified. Applying an intervention results in a temporary feedback loop. An intervention affects the waste of food within a household, which results in a lower perceived food waste by the household. This lower perceived food waste decreases the effect of the intervention, resulting in a negative feedback loop. This temporary feedback loop has a negative nature, resulting in a balancing loops.

Based upon the aggregation level of the causal relation diagram defined in previous chapter, the uncertainties surrounding the potential effects of the interventions, and the general character of the interventions, the System Dynamics simulation method is noted as a suitable method. Therefore, the System Dynamics approach is used to simulate the potential effects of the interventions.

The interventions identified in this chapter are simulated in during the model use. In chapter 6, the interventions are quantified after which they are simulated to determine the potential effects on the waste of food within a household.

4 Available data & Model building

This chapter transforms the causal relation diagram defined in chapter 2 into a System Dynamics model. Besides, data is gathered that is necessary to generate the food waste behaviour on the level of a household. The approach on how to create the System Dynamics model and how to gather the needed data is given in section 4.1. Per phase, an overview is given by means of System Dynamics sub-models in section 4.2. These sub-models illustrate the parameters and the relations between the variables present. Besides, uncertain data regarding the parameters and relations are discussed in this section**.** The System Dynamics sub-models are connected into a combined System Dynamics model, which is discussed in section 4.3. Based upon the resulting model, the integration method and time step are tested and discussed in section 4.4. These settings are used throughout this study. The most important insights based upon the discussions are concluded in the last section. The resulting System Dynamics model is tested in next chapter. A set of uncertain parameters that are defined in this chapter are further considered during the robustness analysis in chapter 6. A more detailed overview of the values of the parameters and the mathematical relation present in the resulting System Dynamics model of this chapter is given in **appendix B.**

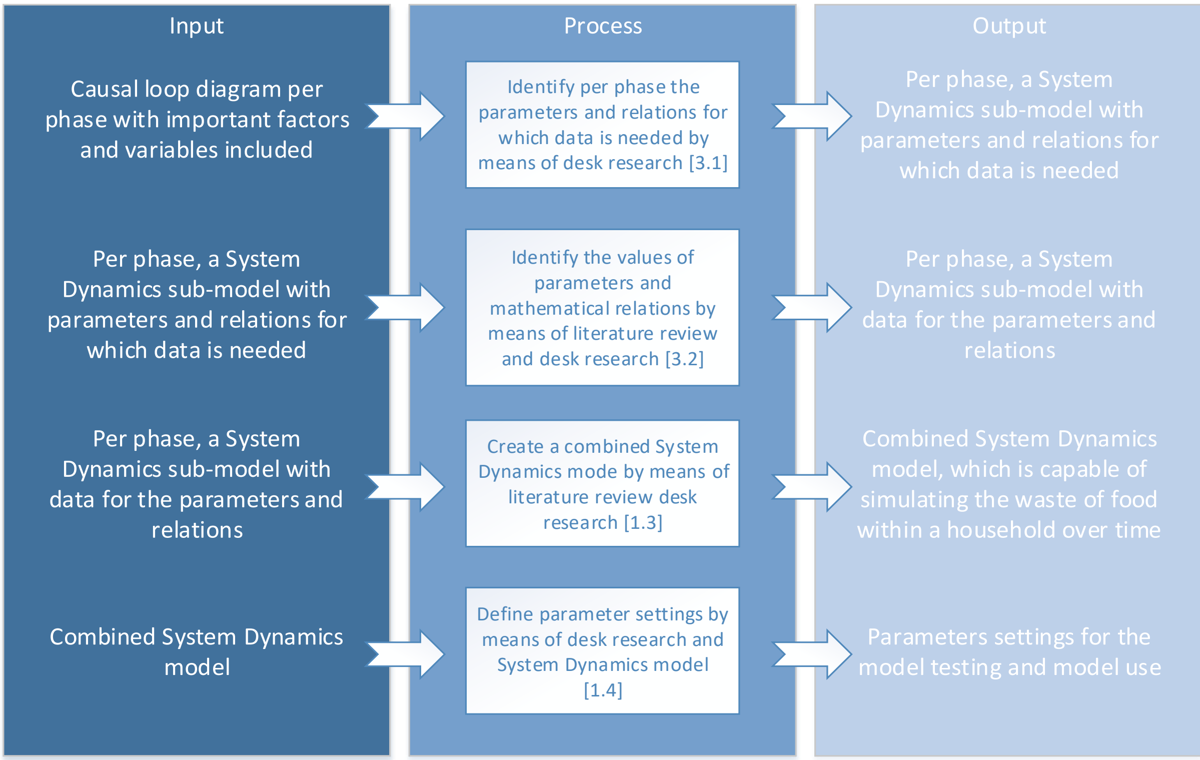


Figure 25: overview research design data-gathering and model building

4.1 Data-gathering approach

This section describes the research steps are required to create the System Dynamics model and to gather the available data. An overview of the research approach is given in figure 25. The results of these research steps are given in more detail in **appendix B.**

Step 1: identify the parameters and relations for which data is needed

Based upon the causal relation diagrams identified in section 2.3, per phase a System Dynamics sub-model is created. Per sub-model, parameters and relations are identified for which data is required. An overview of the parameters and relations present per phase is given in section 4.2. The parameters and relations considered in this study are elaborated on in **appendix B.**

Step 2: identify the values of the parameters and the mathematical relations
Data is gathered for the parameters and relations that are identified during previous step. Data is gathered by means of reviewing to scientific literature and studies. Based upon the available data, the most uncertain parameters and relations are discussed in section 4.2. Based upon this discussion, the most important uncertain parameters are identified per phase. These important uncertain parameters are considered during the robustness analysis in section 6.6. A more detailed overview of the available data elaborated on in **appendix B.**

Step 3: create a System Dynamics model
The identified parameters and relations combined with the available data are connected and transformed into multiple System Dynamics sub-models. These sub-models, each representing a phase, are connected, resulting in a System Dynamics model that is capable of simulating the waste of food on the level of a household**.** The resulting System Dynamics model is presented in section 4.3. In this section, the most uncertain parameters and relations are discussed. The most important parameters are considered during the robustness analysis in section 6.6. A more detailed overview of the parameters, relations and the available data are elaborated on in **appendix B.**

Step 4: Define the model settings regarding the simulation run
Based upon the resulting combined System Dynamics model, the model settings are identified that are needed to generate the behaviour of the System Dynamics model. These model settings are tested and discussed during this research step. The duration of the simulation run, the integration method, and the time step are identified that are used during this study. These settings are discussed in section 4.4

4.2 Data-gathering and specification of the food waste system

This section provides an overview of the System Dynamics sub-models that represents the causal relation diagrams identified in section 2.3. The parameters and relations between the variables are illustrated in this section. Besides, the uncertain data is discussed regarding these parameters and relations. The planning phase is considered in section 4.2.1, the purchasing phase in section 4.2.2, the storing phase in section 4.2.3, the preparing phase in section 4.2.4, the consuming phase in section 4.2.5, and the reusing the leftover phase in section 4.2.6. A difference is made between variables identified during the conceptualisation in chapter 2 (depicted blue) and extra variables that are needed and not explicitly mentioned during the qualitative model in chapter 2 (depicted green). The extra variables that are not explicitly mentioned. These variables are needed to keep the System Dynamics model simple and these variables are needed to represent a lookup effect. The food storage feedback mechanism identified in section 2.5.1 is discussed during the planning phase. The feedback mechanisms regarding the food waste variables identified in section 2.5.2 are discussed during the preparing phase. The resulting System Dynamics sub-models per phase are connected in section 2.4, resulting in a System Dynamics simulation model that is capable simulating the generation of the waste of food within a household. Besides, the most important uncertain variables are identified, which are considered during the robustness analysis in section 6.6. A more detailed overview of the variables, relations and data needed per sub-model are elaborated on in **appendix B.**

4.2.1 Planning

The data that is needed to generate the planning behaviour is considered in this sub-section. As mentioned before, the behaviour of interest for this phase is that households tend to plan to buy more food than actually needed. This implies that within the model the *Adjusted amount of planned food* needs to be greater than the *Average amount of food needed for a household*. The causal relation diagram of the planning phase combined with the available data is transformed into a Vensim sub-model, which is illustrated in figure 26. The storage feedback mechanism is described at the end of this section. A more detailed elaboration on the parameters, relations, and available data for the planning phase is given in **appendix B**.

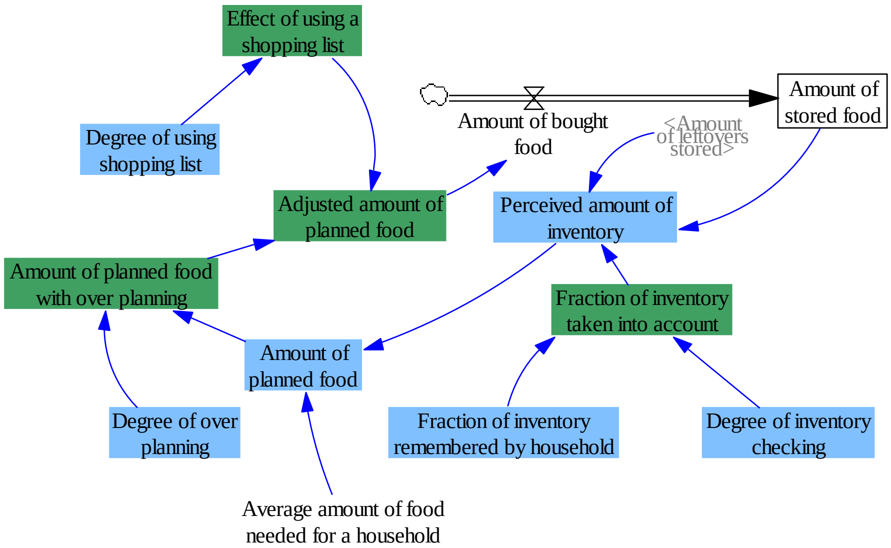


Figure 26: planning phase sub-model

Regarding the data that is available for the planning phase, the following parameters are most uncertain: *Degree of over planning, Degree of inventory checking,* and *Fraction remembered by household.* It is difficult to estimate a value on what households tend to over plan in regards to what they actually need. Even though the variable *Degree of over planning* is mentioned in scientific literature, it is investigated to what degree. Therefore is an assumption inevitable; a degree of 10% is considered during this study. The fractions variables are hard to estimate due to the fact that these are household dependant and no scientific estimations are available. In this study it is assumed that households remember 80% of the *Amount of food stored* and the *Amount of stored leftovers* on average. The resulting 20% that is not remembered by the household is checked 50% of the time. A *Degree of inventory checking* of 50% is assumed, resulting in a total percentage of 90% of the stored amounts that is considered during the planning phase.

Regarding the relations, the *Effect of using a shopping list* is uncertain and assumptions are inevitable. It is assumed that not using a shopping list increases the *Adjusted amount of planned food* according to the graph presented in figure 27**.** The y-axis represents the additional fraction added to the *Amount of planned food with over planning.* The x-axis represents the input variable; *Degree of using shopping list.* Using no shopping lists results in an additional 10% planned food regarding the *Amount of planned food with over planning.*

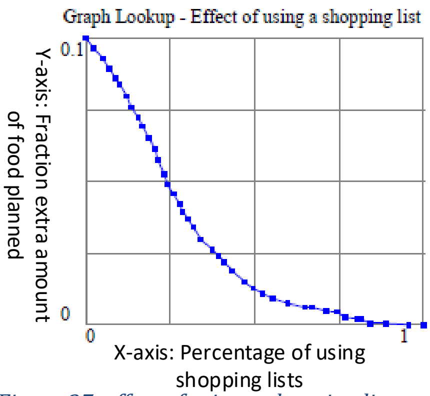


Figure 27: effect of using a shopping list

From the planning phase, the parameter *Degree of over planning* is considered during the robustness analysis, which is discussed in section 6.6. The parameters *Degree of inventory checking* and *Fraction remembered by household* is not considered because the *Amount of stored food* is assumed to be small and the effects of changing these fractions are assumed to be limited. The *Effect on using shopping list* is not considered during the robustness analysis due to its assumed small effect on the *Adjusted amount of planned food.* On average, it is assumed that households use a shopping list 70% of the time (Jörissen et al., 2015). Increasing or decreasing this amount does not have a big impact, which is illustrated in figure 27**.**

Storage feedback mechanism
The storage feedback mechanisms described in section 2.5.1 are incorporated by adding the variables *Degree of inventory checking,* and *Fraction remembered by household.* These two variables added together result in the variable F*raction of inventory taken into account.* This variable is connected with the *Amount of stored food* and the *Amount of leftovers stored* by means of the variable *Perceived amount of inventory*. These relations are illustrated in figure 26. The *Perceived amount of inventory* is the *Fraction inventory into account* multiplied with the *Amount of stored food* and the *Amount of leftovers stored*. The resulting perceived amount is considered while determining the new *Amount of planned food*, finally resulting in an incorporated feedback loop into the System Dynamics model.

4.2.2 Purchasing

The data that is needed to generate the buying behaviour is considered in this sub-section. The behaviour of interest for this phase is that people tend to buy even more food than actually planned, which was already more than actually needed, ending up with too much food available for consumption. The *Amount of bough food* should be greater than the *Amount of prepared food* and the *Amount of edible stored food discarded* and the *Amount of inedible food discarded.* The causal relation diagram of the purchasing phase combined with the available data is transformed into a Vensim sub-model, which is illustrated in figure 28. A more detailed elaboration on the parameters, relations, and available data for the purchasing phase is given in **appendix B**.

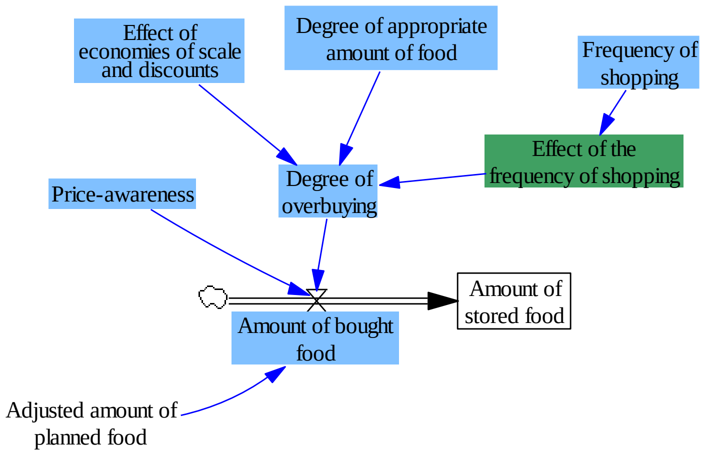


Figure 28: purchasing phase sub-model

Regarding the data that is available for the purchasing phase, the following parameters are most uncertain: *Price-awareness* and *Effect of economies of scale and discounts*. The food extra bought due to discounts is uncertain since it not measured or at least documented in scientific literature. The effect is unknown. Therefore an assumption is inevitable; on average households buy 10% too much food due to discounts and economies of scale. It is assumed that the *Price-awareness* is not that high in a developed country like the Netherlands. It is assumed that households do not tend to waste food due to financial problems. Most households within the Netherlands live above the long-term low-income limit. An average value is chosen of 5% in this study. It is assumed that 5% of the fraction of the *Degree of overbuying* is compensated by the *Price-awareness* in the System Dynamics model. In other words, 95% of the actual *Degree of overbuying* is used.

From the purchasing phase, the parameter *Effect of economies of scale and discounts* is taken into account during the robustness analysis in section 6.6. The parameter *Price-awareness* is not considered, due to its expected small impact; the *Degree of overbuying* is only affected by a small fraction while changing the variable *Price-awareness*.

4.2.3 Storing

The data that is needed to generate the storing behaviour is discussed in this sub-section. The behaviour of interest for this phase is that households store the food that they have bought, which is not prepared. Besides, two types of food waste results due to the fact that households have too much food stored and are not able to prepare it on time. An *Amount of edible stored food discarded* and an *Amount of inedible stored food discarded* results during this phase. The causal relation diagram of the storing phase combined with the available data is transformed into a Vensim sub-model, which is illustrated in figure 29. A more detailed elaboration on the parameters, relations, and available data for the storing phase is given in **appendix B**.

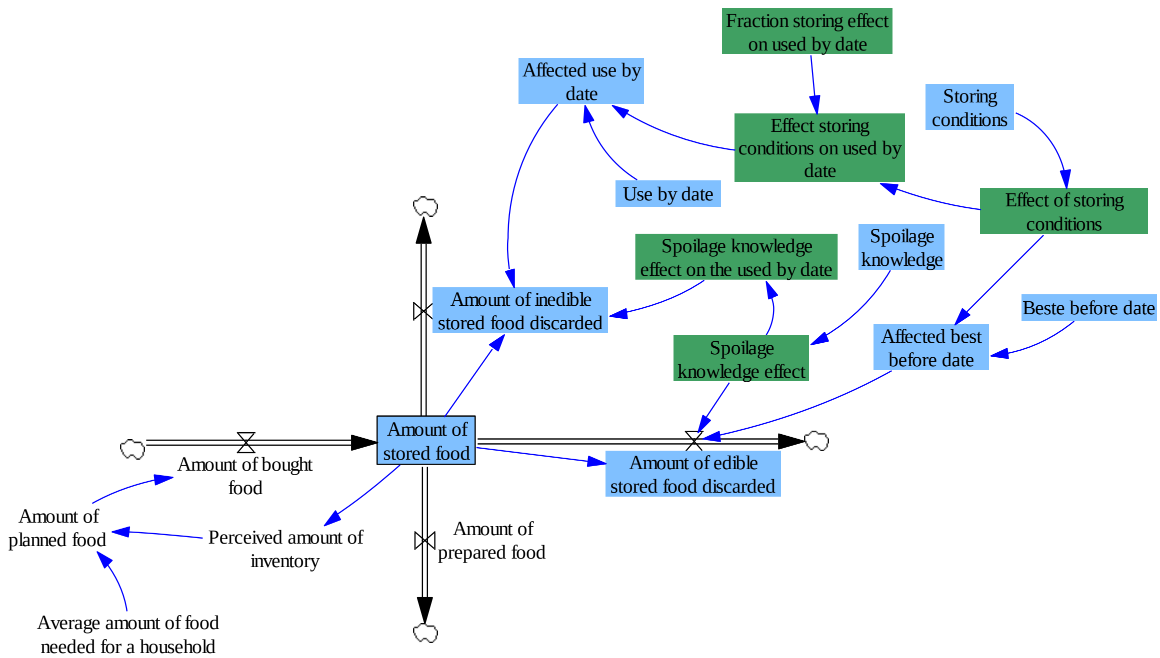


Figure 29: storing phase sub-model

Regarding the data that is available for the storing phase, the following parameters are most uncertain: *Use by date, Best before date, Spoilage knowledge* and *Storing conditions*. Regarding the data of the *Best before date* and *Use by date* no average is given due to the difference between the dates per many types of food. The *Best before date* is longer for canned products than for example dairy produce. Therefore the following rule is applied: the *Best before date* is three times as much as the *Use by date* in the System Dynamics model. Respectively, a time is chosen of 1 week and 3 weeks in the System Dynamics model for the *Use by date* and *Best before date*. The *Storing conditions* and *Spoilage knowledge are* not investigated, measured, or documented in scientific literature. Therefore educated guesses are necessary. It is assumed that households have a degree of 70% regarding the *Storing conditions.* All households have a fridge and most households know how to store food, however, improvements are still possible. Putting the fridge on 4 degrees of Celsius instead of 7 degrees of Celsius would for example result in an increase of the *Storing conditions*. Within the Netherlands, it is assumed that a household has *Spoilage knowledge* of 50% on average. Households do not always know the difference between use by and best before dates. It is assumed that households are not that good in determining if food is still edible or not. Increasing the *Spoilage knowledge* results in households that can store food for longer periods.

Regarding the relations present within the storing phase, the *Spoilage knowledge effect* is an uncertain relation with a relative high impact. For this relations, no scientific data is available and assumptions are inescapable. Therefore a relations is assumed according to figure 30**.** The x-axis of the *Spoilage knowledge effect* represents the input of the variable *Spoilage knowledge.* The resulting y-axis represents the effect on the division of food thrown away in this phase. Having a

Spoilage knowledge effect of 0.6 results in an average time it takes for food to be thrown away 60% based upon the *Best before date* and 40% based upon the *Use by date*.

A higher *Spoilage knowledge* results in a higher dependence on the *Best before date* rather on the *Use by date*. Relying more on the *Best before date* results in an increase of the average time before food is discarded during the storing phase because the *Best before date* is 3 weeks and the *Use by date* is 1 week. Being more dependent on the *Best before date* represents the ability to determine if food is still edible, even when it surpassed the *Best before date.*

From the storing phase, the parameters *Use by date, Best before date, Spoilage knowledge* and *Storing conditions* are considered during the robustness analysis in section 6.6. The *Spoilage knowledge effect* and the *Effect of storing conditions* are not considered due to its expected small impact on the food waste system. Changing the values of the inputs for these look-up functions are assumed to have a small impact on the system as a whole and are therefore not considered.

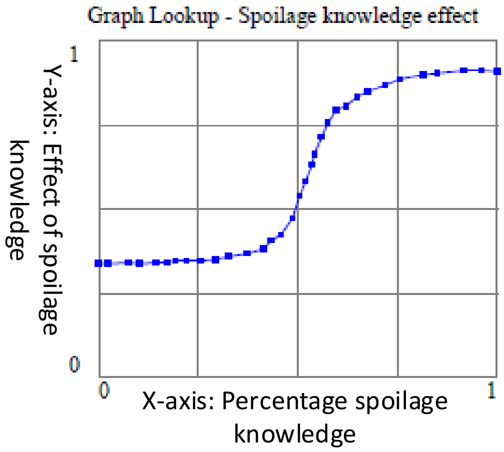


Figure 30: effect of Spoilage knowledge effect

4.2.4 Preparing

The data that is needed to generate the preparing of food behaviour is discussed in this sub-section. The behaviour of interest for this phase is that households prepare the food that is stored. During this phase, one food waste variable results, which is ruining food due a lack of cooking skill. The causal relation model of the preparing phase combined with the available data is transformed into a Vensim sub-model, which is illustrated in figure 31**.** A more detailed elaboration on the parameters, relations, and available data for the preparing phase is given in **appendix B**.

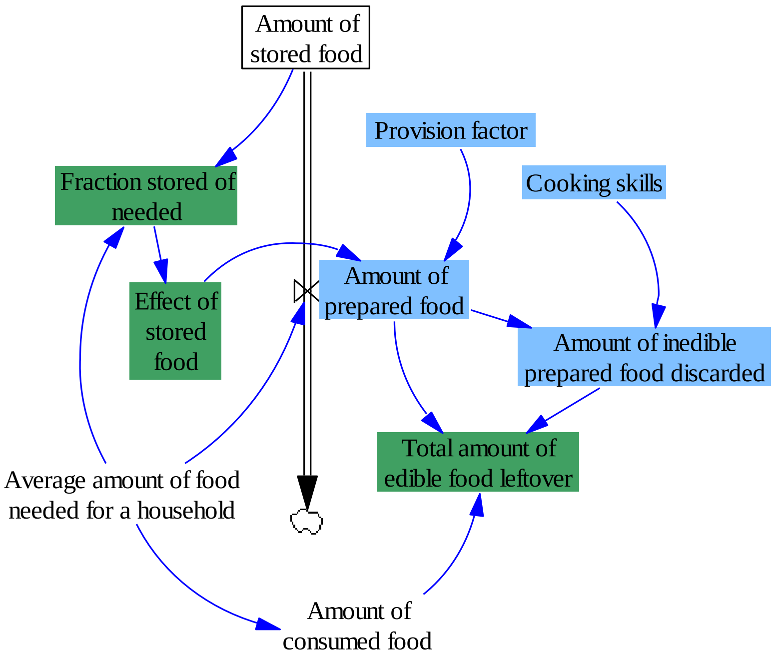


Figure 31: preparing phase sub-model

Regarding the data that is available for the preparing phase, the following parameters are most uncertain: *Provision factor* and *Cooking skills.* Both variables are noted as important to determine the preparing behaviour but no data is available on these two variables. It is assumed that in the Netherlands the average household has a high *Cooking skills;* a skill level of 97.5 is chosen. This results in a 2,5% of the *Amount of prepared food* turns into an *Amount of inedible prepared food discarded.* The *Provision factor* is uncertain. No attempts are made in scientific literature to measure the food a household prepares extra. Also, estimating this fraction is hard since members within a household might decide to eat more than they actually need. In this study it is assumed that on average, a household prepares an additional 5% on top of the *Average amount of food needed for a household,* which is not consumed by the household.

From the preparing phase, the *Provision factor* is taken into account during the robustness analysis in section 6.6. The *Cooking skills* within a household is not considered. In this study it is assumed that this parameter is non-changeable and falls therefore outside the scope.

4.2.5 Consuming

The data that is needed to generate the consuming behaviour is considered in this sub-section. The behaviour of interest is that households consume the prepared food. However, if too much food is prepared, leftovers result. This may result into food waste; *Amount of leftovers discarded directly*. The causal relation diagram of the consuming phase combined with the available data for is transformed into a Vensim sub-model, which is illustrated in figure 32. A more detailed elaboration on the parameters, relations, and available data for the consuming phase is given in **appendix B**.

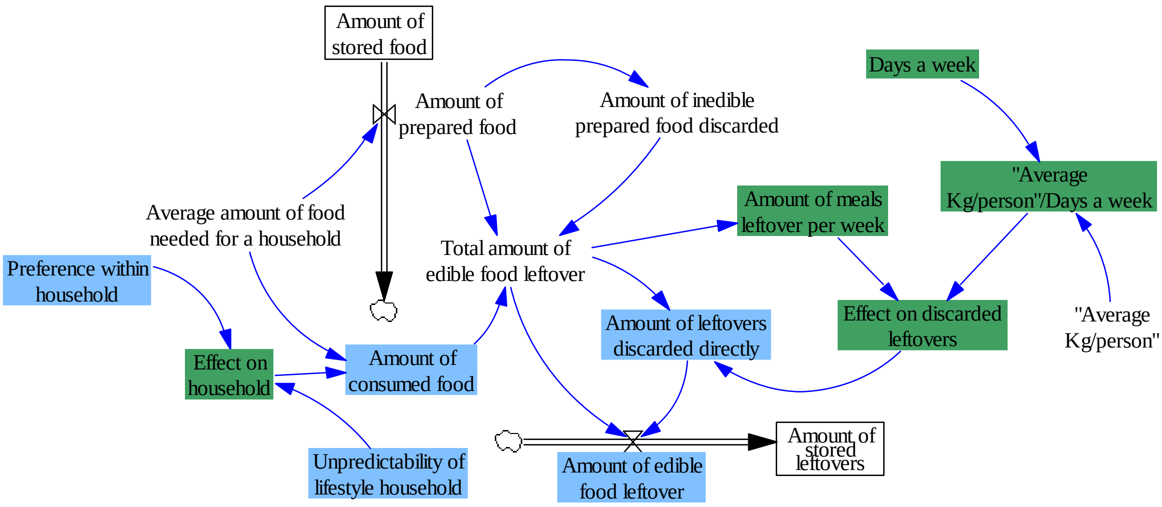


Figure 32: consuming phase sub-model

Regarding the data that is available for the consuming phase, the following parameters are most uncertain: *Preference within household* and *Unpredictability lifestyle households.* Both variables are noted as important but no data is available on these two variables. It is assumed that households in the Netherlands have unpredictable lives and preferences. A combined effect 3% is considered during this study. The product of the *Preference within household* and *Unpredictability lifestyle household* is 3%. Only a fraction is less consumed due to the absence of people within a household in this study. It is assumed that the absence of people within the household do not necessarily result in a bigger *Total amount of edible leftover*. It is assumed that other people might join and some members within the household decide to eat more if someone else dislikes it.

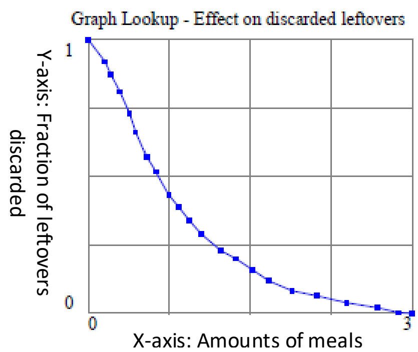


Figure 33: Effect on discarded leftovers

Regarding the relations present within the storing phase, there is one uncertain relations; the *Effect on discarded leftovers*. For this relation, no scientific data is available and an assumption is inescapable. The *Effect on* *discarded leftovers* s needed to determine the *Amount of leftovers discarded directly.* The *Effect on discarded leftovers* is dependent on the *Amount of meals leftover per week*, which is the *Total amount of edible food leftover/Average Kg food per day per person.* This amount is used as input for the look-up function, as illustrated in figure 33. The *Amount of meals leftover per week* is presented on the x-axis. The y-axis represents the fraction of the leftovers that are discarded directly. It is assumed that having 3 meals a week leftover results in no *Amount of leftovers discarded directly.*

From the consuming phase, the combined effect of the *Preference within household* and *Unpredictability lifestyle household is* taken into account during the robustness analysis in section 6.6. The *Effect on discarded leftovers* is assumed to be very small, since not a lot of leftovers are generated within the System Dynamics model and is therefore not considered during the robustness analysis.

4.2.6 Re-using leftovers

The data that is needed to generate the re-using leftovers behaviour is discussed in this sub-section. The behaviour of interest for this phase is that households may consume the leftovers, or may not which could result in food waste. The causal relation diagram of the re-using leftover phase combined with the available data is transformed into a Vensim sub-model, which is illustrated in figure 34. A more detailed elaboration on the parameters, relations, and available data for the re-using leftovers phase is given in **appendix B**.

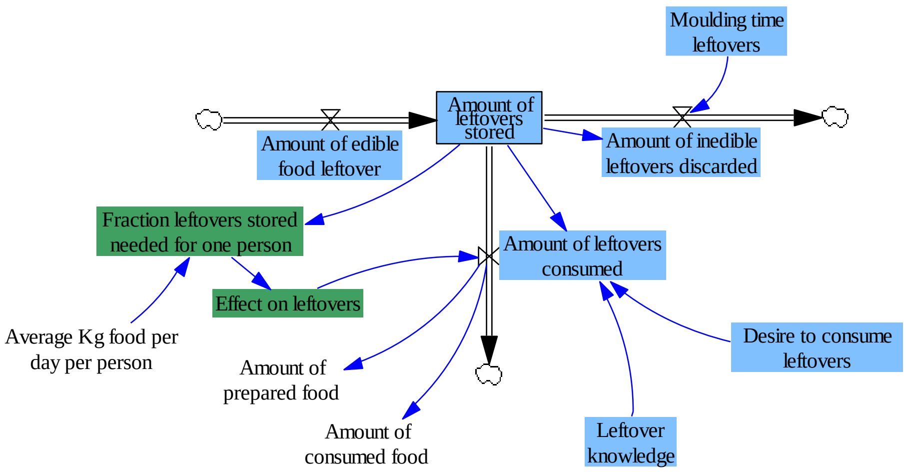


Figure 34: re-suing leftovers phase sub-model

Regarding the data that is available for the re-using leftover phase, the following parameters are most uncertain: *Leftover knowledge, Desire to consume leftovers,* and *Moulding time leftovers.* Regarding the desire and knowledge: no scientific data is available to what extend households are willing to eat leftovers and to what extent they know how to prepare those leftovers. In this study, it is assumed that households know how to re-use leftovers quit well: a *Leftover knowledge* is chosen of 0.8. The *Desire to consume leftovers* is assumed to be lower. Leftovers are not always eaten while they could be, and therefore a value of 0.5 is chosen in this study. Regarding the *Moulding time leftovers,* it is assumed in this study that on average, it takes 3 days before a leftover is moulded. There is no average data available, since a lot of different values are applicable for different kinds of leftovers.

From the re-using leftover phase, the *Leftover knowledge* and *Desire to consume leftovers* are taken into account during the robustness analysis in section 6.6. It is assumed that these variables are most uncertain and have a big impact on the system as a whole.

4.3 General variables data gathering

This section provides an overview of the System Dynamics model that represents the causal relation model identified in section 2.4. All the parameters and relations present in this System Dynamics model are illustrated in **figure 37.** In this section, the most uncertain variables and relations are elaborated on. Besides, two major feedback loops are described, as identified in section 2.5. A more detailed elaboration on the parameters, relations, and available data regarding the combined System Dynamics is given in **appendix B**. The resulting combined System Dynamics model is used to identify the model settings, which are considered in next section.

Regarding the data that is available for the general variables, the following parameters are most uncertain: *Knowledge on consequences on food waste* and *Average Kg/person.* The *Average Kg/person* is uncertain since it is dependent on the definition of food waste on the level of a household and the way it is measured. I is argued that per household of 2.4 people purchased around 27 kg of food and drink per week in 2011 in the United Kingdom (WRAP, 2013). Therefore, a value of 11.25 kilogram per person is used. In this study it is assumed that the average households has knowledge of 70%. Households are assumed to be well educated on this subject; it is assumed that households know on an average what the consequences are of wasting food, however, improvements are still possible. It is assumed that extra information can be obtained by households, if it reached out to them regarding the subject.

Regarding the relations in this phase, the following relations are uncertain. The M*oral attitude* is elaborated on in this section*.* The *Moral attitude* is a look-up function presented in figure 35**.** The input is the *Knowledge on consequences food waste,* which is represented on the x-axis. Based upon an output is generated, which is presented on the y-axis. Increasing the *Knowledge on consequences food waste* increases the *Moral attitude*, however, increases from a knowledge level of 60% and higher have bigger impact on the *Moral attitude*. The *Perceived amount of food waste planning* and the *Perceived amount of food waste preparing* are products of the variables *Moral attitude,*

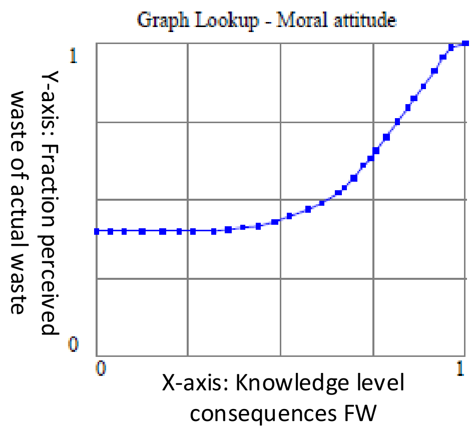
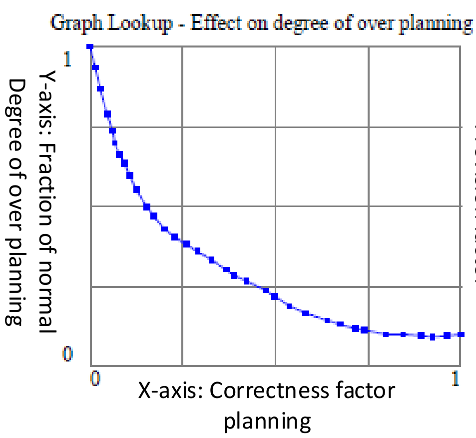


Figure 35: Effect on discarded leftovers

From the general phase, only the variable *Knowledge on consequences food waste* is taken into account during the robustness analysis in section 6.6. As mentioned before, the *Degree of over planning* and *Provision factor* are mentioned as uncertain. However, these are replaced by the variables *Normal degree of over planning* and the *Normal provision factor.* The latter two are thereby considered during the robustness analysis. The parameters *KG/person* is considered during the output validation in section 5.3.3.



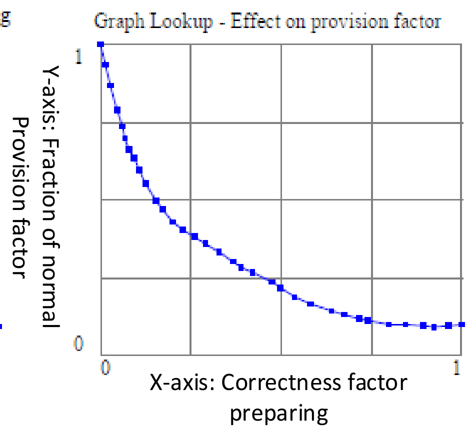


Figure 36: look-up functions Effect of on provision factor and Effect on degree of over planning

Food waste feedback mechanisms

As mentioned in section 2.5.2, in the System Dynamics model a difference is made between the preparing and planning food waste mechanisms. Both mechanisms have a negative feedback character. The feedback loop regarding the waste is considered via the *Amount of planned food* and the *Amount of prepared food*. Wasting food during the storing, consuming, and re-using leftover phase results in a *Total food waste regarding the planning loops*. Wasting food during the consuming and re-using leftover phase results in a *Total food waste regarding the preparing loops*. These amount are transformed into a *Perceived amount food waste planning* and into a *Perceived amount food waste preparing* by multiplying the amount by the *Moral attitude.* The *Correctness factor planning* is calculated by dividing the *Perceived amount of food waste planning* by the *Average amount of food needed for a household,* and *Correctness factor preparing* is calculated by dividing *Perceived amount of food waste prepared* by *Average amount of food needed for a household.* These values are used for inputs for the *Effect on degree of over planning* and the *Effect on provision factor*, which are illustrated in figure 36**.** Having high correctness factors result in a *lower Degree of over planning* and lower *Provision factor*. For example, a *Correctness factor planning* of 1 results in a *Degree of over planning* of 1% instead of 10%. Based upon the aforementioned affects, their values of the *Degree of over planning* and the *Provision factor* are adapted, resulting in two negative feedback loops that are incorporated into the System Dynamics model.

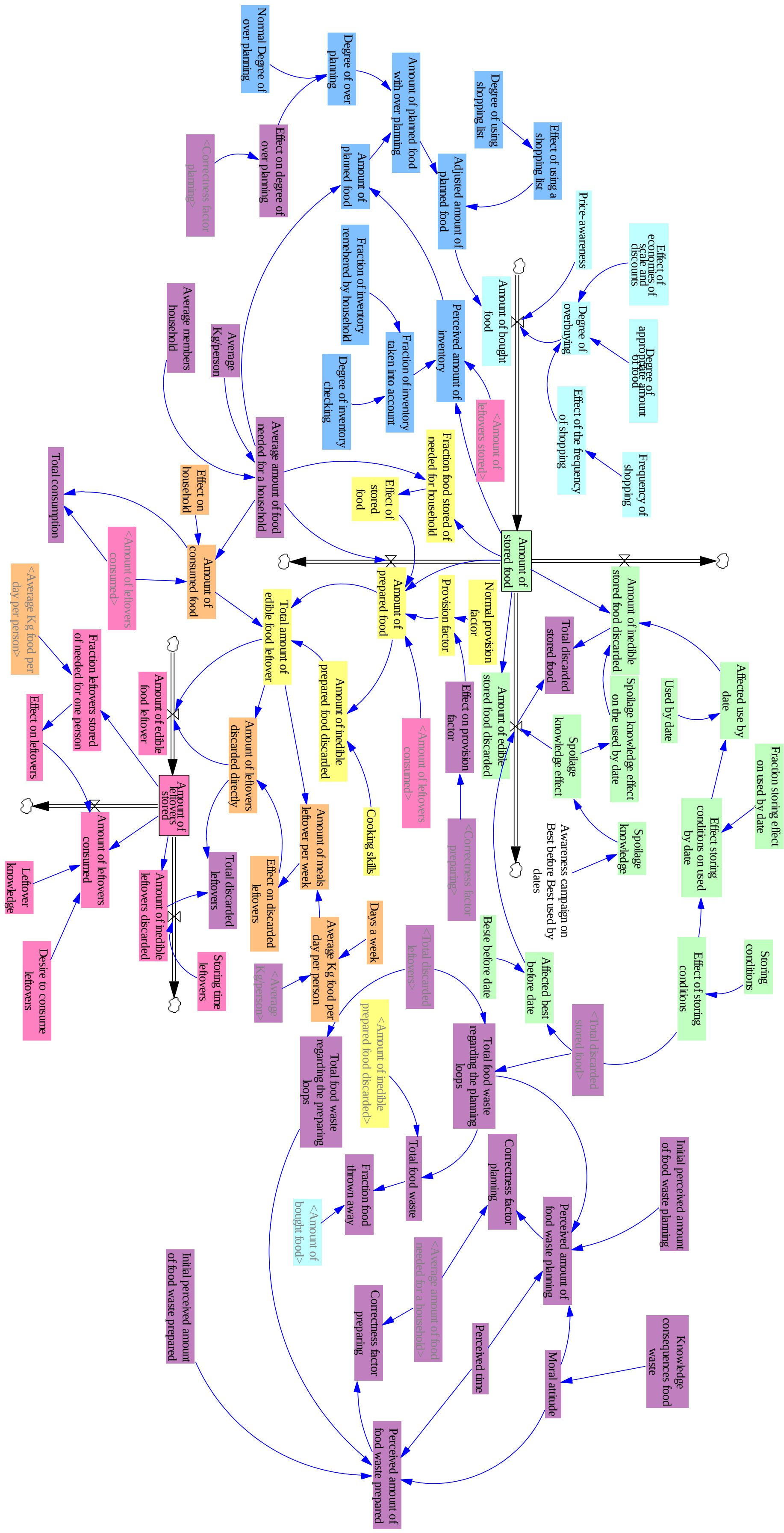


Figure 37: System Dynamics model

4.4 Specification of simulation run

This section described and discusses the simulation duration, the time step, and the integration method used during this study. As stated in previous chapter, the combined System Dynamics approach combined with the Vensim simulation software used to design the combined System Dynamics model. Based upon, various model settings are tested to identify the correct settings in this section. The resulting settings are used during the testing of the model in next chapter, and during the simulation in chapter 6.

Simulation run

Simulate the waste of food within households a timeframe is chosen of 1.5 years, which corresponds with 78 weeks. There are no specific goals set at the moment regarding the waste of food on the level of a household in the Netherlands. The simulation range may differ while testing the model in next chapter and preforming the base-run in chapter 6.

Integration method

The numerical integration method depends on the construction of the food waste system designed in this chapter. Given the possibilities within Vensim, there are three different types of integration methods: the Euler method and the Runge-Kutta methods (2, 4, and auto). The Euler method should be used if the model contains some kind of integer value, since the Runge-Kutta cannot handle these. To test these methods, both are used while simulating the food waste and compared. The results of this comparison are visualised by figure 38**.** No major difference can be found between the methods; the same behaviour resulted illustrated by one blue line. The other graphs are underneath it. Due to the absence of the integer values in the previous defined model, the Runge-Kutta auto method is chosen throughout this study.

Time step & time constant

The time step is also very important to consider given the integration method. Choosing a time step is a compromise between the calculation time and the rounding errors and/or the accuracy of the results. More accuracy is reached by using a smaller time step. To determine the correct time step, multiple time step values are tested. The four smallest possible time steps inside this software package are 0.0625; 0.0313; 0.0156 and 0.0078. A simulation time of 20 weeks is used to compare the different settings. Running the simulations resulted in small differences, which is illustrated in figure 38. Therefore, the smallest possible time step is chosen during this study.

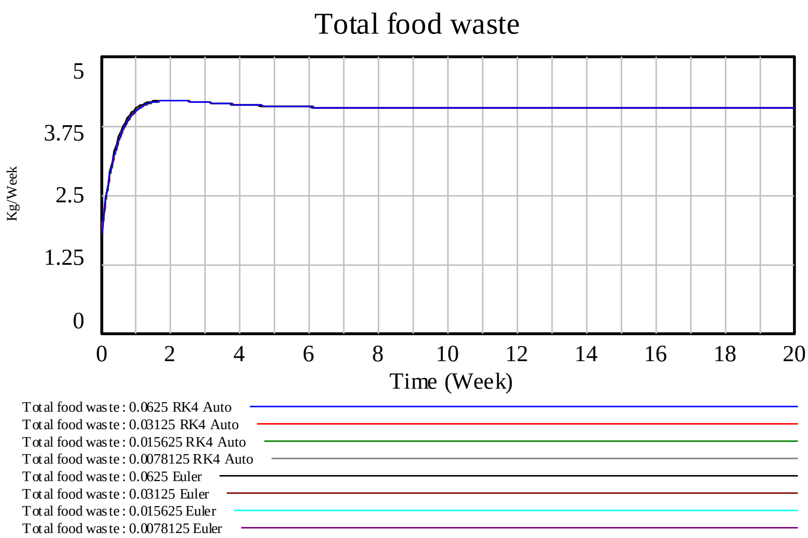


Figure 38: results of simulating the model with varying model settings

4.5 Conclusion of this chapter

This chapter transforms the causal relation diagram representing the food waste system on the level of a household defined in chapter 2, as argued in chapter 3, into a System Dynamics model. Based upon the causal relation diagrams, parameter and relations are identified that are present within the System Dynamics model. Data is gathered for these parameters and relations. System Dynamics sub-models are created per phase and connected to each other resulting in a System Dynamics model that represents the causal relation diagrams defined in section 2.3 and thereby the food waste system on the level of a household. The available data is gathered by means of literature review and desk research.

The needed data was not always available for the System Dynamics sub-models, resulting in uncertain parameter values, uncertain mathematical relations, and eventually in simplifications. Assumptions are therefore inevitable. To cope with these assumptions, multiple important uncertain variables are identified. The *Degree of over planning* is considered as an uncertain variable during the planning phase. From the purchasing phase, the parameter *Effect of economies of scale and discounts* is taken further into account. From the storing phase, the parameters *Use by date, Best before date, Spoilage knowledge* and *Storing conditions* are considered during the uncertainty analysis. From the preparing phase, the *Provision factor* is taken further into account. From the consuming phase, the combined effect of the *Preference within household* and *Unpredictability lifestyle households is* considered during the uncertainty analysis. From the re-using leftover phase, the *Leftover knowledge* and *Desire to consume leftovers* are taken further into account. From the general phase, the variable *Knowledge on consequences food waste* is considered.

The System Dynamics sub-models are connected and general variables are added, resulting in a System Dynamics model that represents the food waste system on the level of a household. Based upon the results of simulating the System Dynamics model with the available data, model settings are specified, which are used throughout this study.

The resulting combined System Dynamics model is tested and improved in chapter 5. The resulting uncertain parameters are considered during the robustness analysis considered in section 6.6.

5 Model testing

This chapter tests and improves the System Dynamics model that represents the food waste system on the level of a household defined in previous chapter. Testing the model is necessary to understand the models behaviour and limitations. A distinction is made between static and dynamic testing, as described section 5.1. The results of both are discussed in Section 5.2 and 5.3 respectively. Based upon the discussion, the model is adapted and its limitations are identified in section 5.4. In chapter 6, this resulting improved System Dynamics model is used to simulate the interventions identified in chapter 3. A more detailed overview of the results of the test performed in this chapter are given in **appendix D, E, F, and G.**

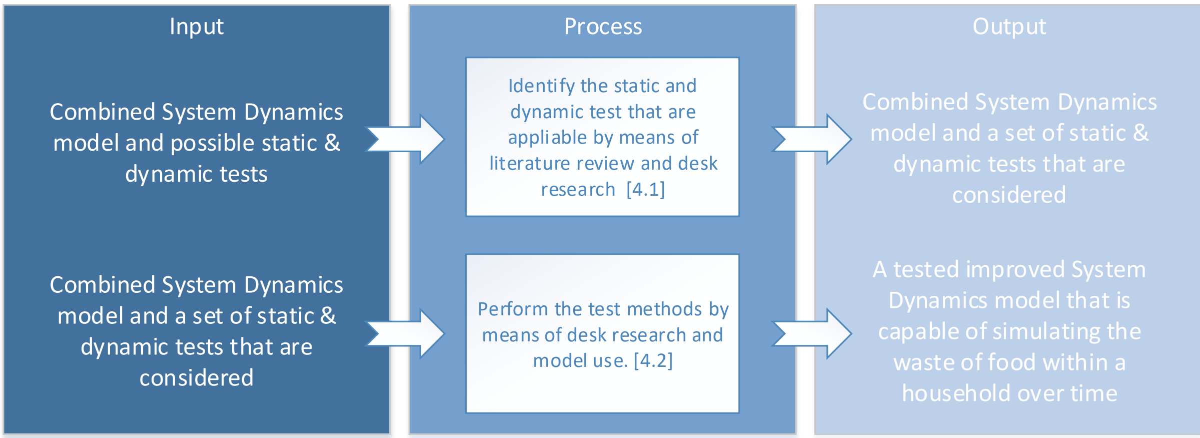


Figure 39: overview research model testing

5.1 Model-testing approach

This section describes the research steps required to deliver the improved System Dynamics model. A visualisation of the research approach is given in figure 39**.** Based upon these steps, the static and dynamics testing of the model are elaborated on in this chapter. A more detailed elaboration of the results of the research steps can be found in **appendix D, E, F, and G.**

Step 1: identify static and dynamic test

There is a wide variety of possible methods that can be used for testing the model statically and dynamically. Based upon the approach identified by Sterman (2000, ch. 21), a set of methods is chosen for testing the model statically and dynamically. The purpose of and the tests itself are described in sub-section 5.2.1 – 5.2.3 (static tests) and 5.3.1 – 5.3.5 (dynamic tests).

Step 2: perform test methods

The identified methods from the previous research steps need to be executed. Based upon the results of the static and dynamics tests, insights are drawn regarding the usability and limitations of the model. If possible, the model is adapted accordingly or important limitations are drawn. These limitations are taken carefully into account during next chapters. The results are discussed per test in sub-section 5.2.1-5.2.3 (static tests) and 5.3.1 – 5.3.5 (dynamic tests). The results of the static tests are given in **appendix D** and the results of the dynamic test are given in **appendix E, F, and G.**

5.2 Static testing of the model

This section elaborates on the static tests and it discusses the results of these tests. For the static testing of the model, a set of tests is identified. Static testing is type of testing in which the code is not executed. According to the approach given by Sterman (2000, ch. 21), the following static tests are identified: Boundary Adequacy (5.2.1), Dimension Consistency (5.2.2), and a Structure Assessment (5.2.3). A Parameter Assessment is not performed since the available data for these parameters are, in the degree in which it is possible, described in previous chapter. Per test, a short elaboration on the test is given after which the results of the test are discussed.

5.2.1 Boundary Adequacy

The purpose of this test is to verify if the combined food waste System Dynamics model, identified in previous chapter represents the real-world food waste system on the level of a household (Sterman, 2000, ch. 21). During this test, it is checked whether the food waste generation described in the introduction is captured endogenously within the model. The main goal of the model is to simulate the generation of food waste on the level of a household within the Netherlands. The first two types of food waste occur during the storing phase; *Inedible stored food discarded* (i) and the *Edible stored food discarded* (ii). *Inedible prepared food discarded* occurs during the preparation phase (iii). The *Leftovers discarded directly* (iv) occurs during the consumption phase, and the last waste of food takes place within the last phase; *Inedible leftovers discarded* (v) occurs within the leftover phase. These types of food waste influence the planning behaviour of a household by affecting the *Degree of over planning* and the preparing behaviour of a household by affecting the *Provision factor*. In this section it is discussed whether the generation of food waste is taken endogenously into account. This is done by analysing the constants that are present in the model, which could also be represented properly by a variable that changes over time. Besides, the absence of potentially important feedback structures is discussed.

Given the constants that are present in the model and which are not affected by interventions identified in chapter 3, the following are considerable as variables: the *Price-awareness* related to the purchasing phase*,* *Cooking skills* related to the preparing phase, *Preference within household* and *Predictability lifestyle household* within the consuming phase, and *household size* within a household within the general phase. *Price-awareness* and the *Preference within household* and *Unpredictability lifestyle household* may change over time but are not included as variables since the value can differ a lot per household and the value over time may vary a lot for different households, therefore constants are chosen instead of variables. The average *Cooking skill* within a household may change over time, but its effect may differ a lot per household and it is assumed that the impact on the waste of food is not big. Therefore a constant is used to represent the *Cooking skill*. The *Household size* is also changeable over time, but considering the time scope, which is 1.5 year maximum during the model use, it is assumed that changes regarding the *Household size* falls outside the scope and is not considered as a variable in this study.

Regarding the potential important feedback structures that are omitted from the model, the following are identified: multiple types of food (i), seasonality loops (ii), the kind of meal (iii), types of households (iv), and the food supply chain as a whole (v). Different kinds of food have are not included due to a lack of data. Many factors have to change or taken on multiple values if multiple types of food are considered. Making a difference between multiple types of food would increase the quality of the insights regarding the effects of interventions; it is decided to take not into account due to the scope. In this study the interest is on the general impacts on the waste of food, not on the food waste type specific. Seasonality is not taken into account due to the absence of adequate data. Seasonality may have an impact on the waste of food. Other types of food are eaten more in specific periods, however, no distinctions are made between different types of food and therefore seasonality is not included. The focus in this study is more on the consumption of supper rather than on the all the food that is consumed within a household. This is due to the available data, which is also focussed more on supper. Making a distinction between food wasted during breakfast, lunch, snacks, and supper would increase the quality of the model. Different kinds of households are not considered due to a lack of data. Adding more types of households would increase the quality of the model, especially the quality of the effects of the interventions. Interventions can be designed more specific for multiple types of households. The scope of the study has implications regarding the feedback loops. In this study, only the consumers' stage of the food supply chain is included. Possible feedback loops between the different stages present within the food supply chain are therefore not considered. These loops may have an impact on the behaviour of the system of interest in this study.

The model has all the important concepts and feedback situations incorporated, however, some concepts that are too ambiguous or fall outside the model scope are excluded. Some concepts are not present within the model due to the absence of data or due to the restriction of resources available for the study. However, given the scope and goal of this research, which is to gain insights regarding the effects of interventions of food waste on the level of a household in general, these concepts are not needed to provide the main impacts of interventions on the food waste on the level of a household within the Netherlands.

5.2.2 Dimension Consistency

The purpose of this test is to check whether the units used during the model building and data gathering in chapter 4 are correct and correspond with the units defined in the qualitative model in chapter 2. The units are checked on consistency throughout the model (i) and on the existence of the dimension in the real world (ii) (Sterman, 2000, ch. 21). An overview of the parameters, relations, and their dimension is presented in **Appendix D**. Important is the difference between parameters that are expressed in measurable true values with a clear real world dimension and values that aren't expressed in true values or measured due to its lack of a clear real world dimension and are addressed as dimensionless. In this study there are multiple kinds of dimensionless variables: variables that are a fraction, percentage or a degree (i), variables that represent knowledge which is not measurable (ii), variables that have a real world counterpart, these variables are needed to represent look-up effects (iii).

To test the consistency of the dimensions used in the combined System Dynamics model, a tool that is provided by Vensim Pro x32 is used: the unit checking tool, resulting in the following: mainly warnings and no errors are present within the System Dynamics model. These warning are predictable due to the number of the number of loop-up effects, fractions, degrees, and knowledge variables that are present within this System Dynamics model. Based upon this, it is concluded that only minor inconsistencies were found.

5.2.3 Structure Assessment

Structure assessment approach described by Sterman (2000, ch. 21) is used. According to this approach the combined System Dynamics model described in previous chapter is reviewed by considering the consistency with the descriptive knowledge of the system (i), the level of aggregation (ii), the conformation to the basic physical laws (iii), and the capturing of the behaviour of the actors in the system (iv).

It is assumed that the model structure is consistent with relevant descriptive knowledge of the system. The qualitative model is based upon scientific data that is reviewed during the first part of the conceptualisation, during the qualitative analysis of the food waste system on the level of a household. Factors and relations are derived during this conceptualisation, resulting in a causal relation diagram. Data is gathered to add values to these parameters and to create mathematical relations between these parameters, resulting in the System Dynamics model, which is defined previous chapter. Using this approach results in the assumption that the model is created according to the relevant knowledge that is available and thereby is assumed that the structure of the model is consistent with the relevant available data.

The level of aggregation aims to represent the households within the Netherlands. In theory the combined System Dynamics model can also be used for simulating the waste of food on the level of households for other countries. However, these countries need to have the same characteristics as the Dutch households. Adjusting parameters that represent the characteristics of such a household in another country may result in a System Dynamics model, which is capable of simulating food waste for another country that does not share the same characteristics as the Netherlands, but these adjustments should be investigated first.

Regarding the conformation to physical laws and the behaviour of the actors within the system the following topic is interesting: the most important aspect is that the *Amount of stored food* and the *Amount of stored leftovers* should not become negative, which currently may happen in the System Dynamics model. If households tend to make more food than is available, too much food is drawn from the storage. This results in a negative *Amount of stored food*, which cannot happen in reality. To restrict this behaviour from happening, the decision of the households is adapted. Having no food within the storage leads to the behaviour in which no food at all is prepared or the *Amount of stored food* that is present. Therefore an IFTHENELSE function is applied for variable *Amount of prepared food*, which is elaborated on in **appendix B.** Another function that is reconsidered is the *Total amount of edible food leftover*, ruining a lot of food within a household combined with a lower *Provision factor* may lead to an *Amount of prepared food* that is lower than the *Amount of consumed food*, resulting in a negative *Amount of edible food leftover*, which is not possible in reality. Also here, an IFTHENELSE function is applied which is elaborated on in section **appendix B**. Besides, the *Amount of leftovers consumed* is also considered with a IFTHENELSE function. It is not possible to eat more leftovers than there are present within the stock *Amount of leftovers stored.* Therefore an IFTHENELSE function is applied, which is elaborated on in **appendix B.** Also the *Amount of planned food* is considered with an IFTHENELSE function. If the *Amount of stored food* and the *Amount of leftovers stored* are more than the *Average amount of food needed for a household*, then the *Amount of planned food* becomes negative. This function is described in more detail in **appendix B.**

5.3 Dynamic testing of the model

This section elaborates on the static tests and it discusses the results of these tests. A set of dynamic tests identified by Sterman (2000, ch. 21) is applied in this section. Dynamic testing is done when the code is in operation mode, after the static tests. When the code is executed with input with a value, the result or the output of the code is checked and compared with the expected output. The following tests are performed to check of the model dynamically: Extreme condition test (5.3.1), Sensitivity analysis (5.3.2), Output validation test (5.3.3), Face validation (5.3.4), and Equilibrium testing (5.3.5). Per test, first a short elaboration on the test is given, after which the results of the test are discussed.

To test the model dynamically, the following model settings are used: a runtime of 20 weeks, a time step 0.0078125, and the Runge-Kutta auto integration method. A longer runtime does not have an impact on the behaviour of the system. The smallest time step possible of 0.0078125 combined with the Runge-Kutta auto integration method is used during the dynamic testing. A more detailed overview of the results of the dynamic tests is given in **appendix E, F, and G**.

5.3.1 Extreme Condition Test

The purpose of the extreme condition test is to check whether the results of the simulations make sense when its parameters take on extreme values. The approach of Sterman (2000, ch. 21) is used. During the extreme condition test all the equations are subjected to large shocks and extreme conditions regarding their inputs.

The results of the tests are discussed in this sub-section. This is done by elaborating on the effects of combining opposite extreme conditions per phase. Two situations per phase are discussed; one in which a lot of food is assumed to waste and one situation in which a little amount of food is wasted. An overview of the results of the extreme condition is given **in appendix E.**

The extreme condition test resulted in the expected behaviour for all phases. Minor changes are made, which are adjusted in the combined System Dynamics model. After implementing the changes, all the behaviour is explainable and as expected. However, the preparing phase needs to be carefully taken into account. With this System Dynamics model, it is not possible to use a high *Provision factor.* A too high factor leads to a not able to reach the desired accuracy error. Changing the time step did not result in fewer errors. This error is explained by the fact that a to high *Provision factor* increases the *Amount of prepared food*. If the *Amount of prepared food* becomes too high, it will become higher than the *Amount of bought food* combined with the *Amount of stored food*, the *Amount of edible stored food discarded*, and the *Amount of inedible stored food discarded*, resulting in a negative Amount of stored food, which is not possible in reality. To prevent this from happen, a special function is needed to calculate the *Amount of* *prepared food,* which is given below. Introducing an IFTHENELSE function results in errors while using a *Provision factor* higher than 25%. Preparing more than 25% more than needed, can be simulated, however, using a higher *Provision factor* results in errors. It is also important to note that changing other parameters may influence the maximum *Provision factor* that can be used while simulating the model. Using a *Provision factor* that is above the 25% is not relevant in this study (but should be kept in mind).

5.3.2 Sensitivity Analysis

The purpose of the sensitivity analysis is to test the impacts of small changes of parameters on the system as a whole. The output of the simulations can be used to understand the behaviour of changing the parameters and to identify possible errors in the model. All parameters are tested with a plausible range of uncertainty. A range of +/-10% is used to vary the parameters. Univariate and multivariate parameter changes are applied. Based upon the results of the simulations, the effect on the system is analysed. It is checked whether the output is understandable. The approach identified by Sterman (2000, ch. 21) is used. In this sub-section, the results of the sensitivity analysis are discussed. All the parameters are varied, and the output of varying three parameters are given in **appendix F.**

The results of the univariate sensitivity analysis show that the model is relatively robust against parameter changes of +-10%. Only numerically sensitivity resulted to most of the alterations made. Regarding the multivariate sensitivity analysis; even with a combination of parameter changes, only numerical sensitivity takes place. The impact differences are not significant to consider.

Based upon the sensitivity test it is concluded that changing the parameter values with +/-10% resulted in the assumed behaviour; univariate and multivariate. The impacts changed per parameter, but given the effect on the system overall, no unexpected behaviour is encountered.

5.3.3 Output Validation

The purpose of the output validation is to check whether the output of the system corresponds with reality. This is done by comparing the output of the model with actual real world data. Within the model, mainly two important key performance indicators are identified. These are the *Total amount of food waste* and the *Fraction of food thrown away.* Based upon the comparison, the value of the parameter *Average Kg/person* is tested. An overview of the results of adjusting this parameter is illustrated in **appendix G.**

Given the data that is available within the Netherlands on food waste within households it is estimated that on average 65.9 kilogrammes food per person is wasted in 2010, 64.4 kilogrammes in 2013, and 62.2 kilogrammes in 2016 (CREM, 2017). Over the years between 2010 and 2016, the average fraction unavoidable food waste was 45%. According to results of the System Dynamic model, an amount of 99 kilogrammes food wasted per person per year. This amount is a lot more than estimated by CREM. The difference can be explained by the use of different definitions of food waste while developing the model. In **appendix B** it is argued that per household of 2.4 people purchased around 27 kg of food and drink per week in 2011 (WRAP, 2013). However, the source of CREM does not involve the waste of drinks. As mentioned in section 2.1, the focus is on the waste of food only. To compensate the amount of drinks and to decrease the amount of food wasted within the System Dynamics model, a lower value for the variable *Average Kg/person* is tested in **appendix G**.

Over the last years, the average person bought around the 370 kilogrammes of food per year in the Netherlands, drinks excluded (van Doornen, 2017). Based upon the data provided by CREM, it can be concluded that in 2016 the total waste of food was around 16.9% of the food that enters the household per person. Based upon this data, it is concluded that the System Dynamics model generates around the same *Fraction of food thrown away*, which is 15%. To compensate the difference between the waste generated by the model and the actual data, the variable *Average Kg/person* is adjusted, resulting in a System Dynamics model that generates less food waste. The *Fraction of food thrown away* does not change while changing the *Average Kg/person.*

To adjust the System Dynamics model according to the available data, the following assumptions are made: even though the unavoidable waste is not considered during this study, it seems that this amount is inherently included within the System Dynamics model. Therefore it is assumed that the amount of unavoidable food waste is present. Even though the unavoidable food waste is now included, it is still expected that affecting the waste of food within the System Dynamics model results in a decrease of the avoidable food waste only. The unavoidable waste remains the same. Over the years between 2010 and 2016, the average fraction unavoidable food waste of the total amount of food wasted was 45% (CREM, 2017).

The following adjustment to the model is made: testing multiple values for the variable *Average Kg/person* shows that a value of 7 kilogrammes resulted in a total amount around 130 kilogrammes annually, resulting in an amount of 62.9 kilogram per person. This amount approaches the actual value of 62,2 Kg in 2016. As mentioned before, the avoidable and unavoidable food waste are included and the waste of drinks are excluded (CREM, 2017). The result of using a value of 7 kilogrammes instead of 11.25 kilogrammes for the parameter *Average Kg/person* is illustrated in figure 40**.**

Using a value of 7 kilogrammes for the variable *Average Kg/person* results in a total food waste of 62,9 kilogram per person per year. Based upon this amount, it is assumed that 45% is unavoidable. This results in 28,3 kilogram of food waste that that cannot be avoided per person per year. The resulting 34,6 kilogram avoidable food waste can be affected by interventions. The difference between the avoidable and unavoidable food waste are considered in chapter 6 and 7, while interpreting the results.

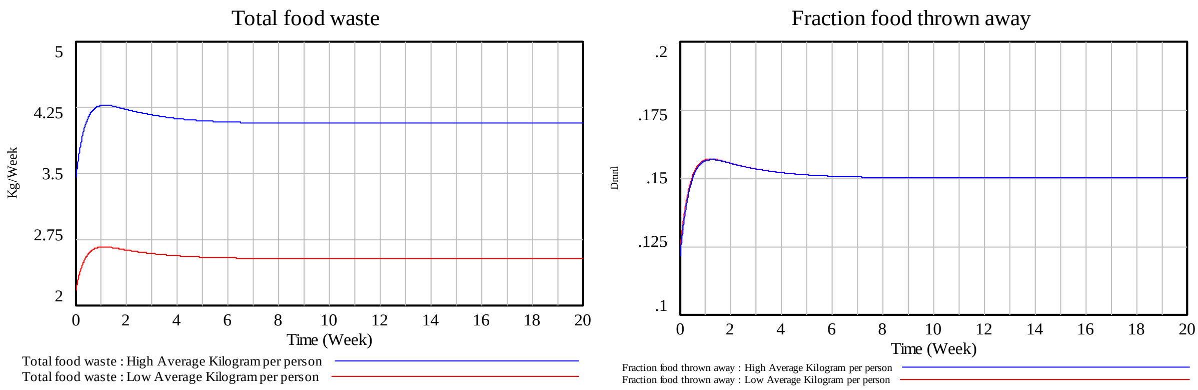


Figure 40: effect of using different values for the variable "Average Kg/person"

5.3.4 Face Validity

The purpose of the face validity test was to check whether the model structure is a recognisable representation of the real system. The feedback structures of the model and the essential characteristics of the System Dynamic model were validated with two academics in the field of domestic food consumption, food quality and waste from the Food Quality and Design group of Wageningen University.

The output of the System Dynamics model and the causal mechanisms were discussed by demonstrating the output of the simulations. More specifically, the storage feedback mechanisms (section 2.5.1), the food waste feedback mechanisms (section 2.5.3), and the temporary feedback mechanisms (section 3.5) were discussed. Based upon this discussion, it can be concluded that the mechanisms are likely to be present within the food waste system on the level of a household. However, the actual quantitative effects are not known and not yet investigated. Therefore, the actual output of the simulations cannot be verified due to its uncertain character.

Furthermore, it can be concluded that the model revealed the expected behaviour. Except the equilibrium of the stock *Amount of food stored,* which was lower than expected. In real life situations, it is possible that households do have more food stored than the model depicts.

However, the initial value of the *Amount of stored food* is a product of the model. Changing the value of the *Amount of stored food* does not influence the equilibrium in which it results. Based upon this difference between the *Amount of stored food* depicted by the System Dynamics model and reality. It may be that the during this study, the focus was on dinner instead of the consumption of food during the whole day. This is also stated in section 5.2.1. This aspect should be considered while drawing conclusions.

5.3.5 Initialisation

This section test the values of the stocks and the constants needed to get the behaviour of the system into equilibrium. As mentioned in chapter 4, the values for *the Amount of stored food* and the *Amount of leftovers stored* are uncertain and cannot be derived from literature. Besides the values for the *Initial perceived amount of wasted food regarding the planning* and *the Initial perceived amount of wasted food regarding the preparing* are also not known. Therefore, these values are chosen to be simulated in equilibrium during the model use in chapter 6**.** Based upon the result of the output validation, the following values are considered in this study: value of 1.6 kilogrammes for the *Amount of stored food*, 0.16 kilogrammes for the *Amount of leftovers stored*, an *Initial perceived amount of wasted food regarding the planning* of 1.24 kilogrammes, and an *Initial perceived amount of wasted food regarding the preparing* of 0.3971 kilogrammes. Simulating the System Dynamics model with these values results in starting in an equilibrium. These values are considered while simulating the potential effects of the interventions in next chapter.

5.4 Conclusions of this chapter

This chapter tests and improves the combined System Dynamics model defined in previous chapter. Tests are performed to identify the limitations of the model and to identify errors that are corrected. To test the System Dynamics model, a variety of static and dynamic tests are performed.

Based upon the static test it is concluded that the System Dynamics simulation model is usable for the intended purpose, which is to contribute to the overall understanding of the system in which food is being wasted and visualising the effects of interventions on this waste of food on the level of a household in the Netherlands. To simulate the waste of food within a household it is suggested that additional structures are applicable. Incorporating these additional structures makes the model more usable and realistic. However, given the goal of this study and the available data, the model is still of significant quality to provide helpful insights.

Based upon the results of the dynamic test, it is concluded that the model is capable of simulating the effects of interventions on the waste of food generated by households. No surprises are encountered during the extreme condition test. All parameters are varied over a realistic scale, resulting in the expected behaviour. No weird behaviour is identified during the sensitivity analysis; only logic and predictable behaviour resulted. Regarding the output validation, a major change is made within the model; the unavoidable waste is inherently considered during this study, therefore a difference is made between the avoidable and unavoidable food waste while interpreting the results of the simulations. Besides, due to a lack of data on the initial values of the *Amount of stored food*, *Amount of leftovers stored*, and the perceived food waste variables the initial values are investigated. Using the initial values on the equilibrium of the same behaviour results in an output of the System Dynamics model that starts in equilibrium. The underlying causal mechanisms regarding the stored amounts of food, the food waste, and the temporary feedback loops are discussed with experts, which agreed that these mechanisms are likely to be presents.

It is important to consider that even after all the test, the output of the System Dynamics model is still surrounded with uncertainties due to the lack of data during previous chapters. However, the underlying mechanisms are interesting to consider and even though the System Dynamics model may not give exact results, it provides an rough indication of possible effects.

The resulting tested and improved model is used in next chapter for simulating the effects of the interventions defined in chapter 3. Besides, the set of important uncertain parameters that resulted from the uncertainty analysis is considered test the robustness of an intervention in next chapter.

6 Model results

This chapter presents the results of the simulation of the interventions that are defined in chapter 3 by means of the improved System Dynamics model defined in chapter 5. The approach on how to simulate the effects of the interventions is elaborated on in section 6.1. Accordingly, a base run is performed and discussed in section 6.2 to determine the natural state of the model. Important aspects that are needed to simulate the interventions are discussed in section 6.3. The simulated effects of the interventions are discussed individually in section 6.4 and combined in section 6.5. The most promising combination of interventions is tested on its robustness in section 6.6. Based upon the results of the simulations, conclusions are drawn in section 6.7. The simulated results of this chapter are considered in a broader perspective in chapter 7. A more detailed overview of simulations performed in this chapter are elaborated on in **appendix H, I, and J.**

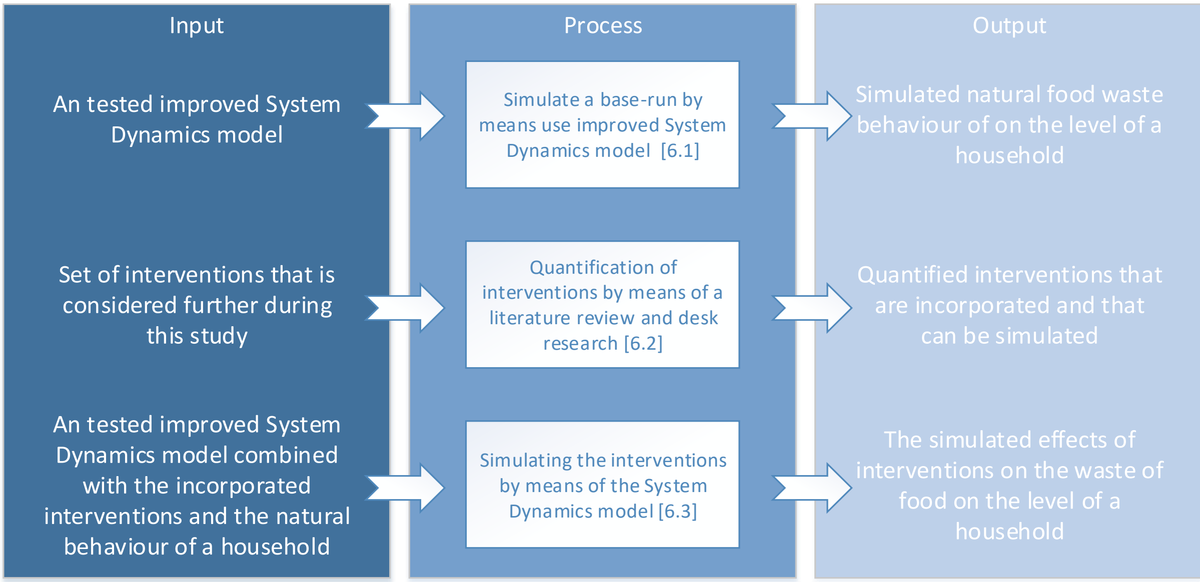


Figure 41: aggregated overview research design model results

6.1 Model use approach

This section describes the research steps required to simulate the effects of the interventions identified chapter 3. A visualisation of the research approach is given in figure 41. Based upon these steps, the results of the simulations of the interventions are presented and discussed in this chapter. A more detailed explanation of the research steps can be found in **appendix H, I, and J.**

Step 1: perform a base run

The parameter values of the natural state of the System Dynamics model are elaborated on in chapter 4 and improved in chapter 5. These values and the resulting System Dynamic model are used to simulate the potential effects of the interventions. To understand the potential effects of the interventions, it is important to understand the behaviour of the system in its natural state. The simulated results of the interventions are compared with the results of the base-run, which illustrates the possible effects. An overview of the results of the base-run simulation are given and discussed in section 6.2.

Step 2: quantify interventions

The effects of the interventions on the model need to be quantified before they can be simulated and compared with the results of the base-run identified in previous step. Extra relations are incorporated into the System Dynamics model. The effect of the *Moral attitude* within a household on the effect of an intervention in general is discussed in section 6.3.1. Besides, a possible adoption rate over time regarding knowledge provided by a campaign is discussed in section 6.3.2. The interventions identified in chapter 3 influence the values of parameters that are present within the System Dynamics model. The potential effects of these interventions on these parameters are estimated by means of available data and educated guesses, which are elaborated on in **appendix H**.

Step 3: run policy experiments
The quantified effects of the interventions defined in previous step are simulated during this research step. Changing the parameters over the range identified in previous research step simulates the effects of the interventions. The results of the simulations are compared with the results of the base run. An overview of the results of simulating the interventions individually is presented and discussed in section 6.4. A set of interventions is simulated combined in section 6.5. The the most promising combination of interventions is tested on its robustness in section 6.6. Important uncertain parameters and relations that are identified during the model building and data gathering in chapter 4 are adjusted over a plausible range while simulating the intervention strategy to test its robustness. The results of the individual simulations, combined simulations and the robustness test are elaborated on in **appendix H, I, and J**.

6.2 Base-run simulation

This section presents and discusses the results of the base-run simulation. Based upon the improved System Dynamics model from chapter 5, the food waste behaviour on the level of a household is simulated. In this section, the values in equilibrium are used while simulating the interventions, as described in section 5.3.5. The results of the base-run are illustrated in figure 42, figure 43, and figure 44. The resulting behaviour of the base-run is used to determine the simulated potential effects the interventions on the behaviour of the food waste system individually in section 6.4 and combined in section 6.5.

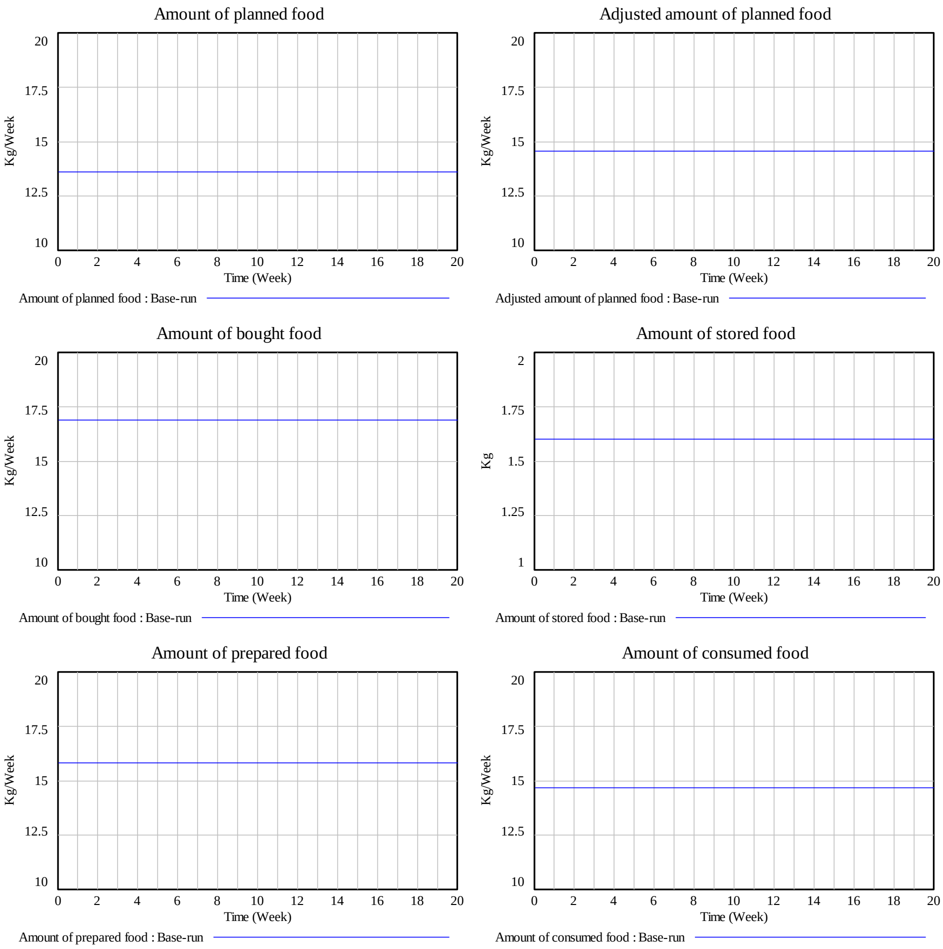


Figure 42: output simulation base-run (i/iii)

As illustrated in figure 42, the *Adjusted amount of planned food* is bigger than the *Amount of planned food* due to the *Degree of over planning* and *Effect of using a shopping list.* The *Amount of bought food* is again bigger than the *Adjusted amount of planned food* due to the *Degree of overbuying.* This amount of bought food is stored, resulting in an *Amount of stored food*. However, this stored food is partly used for preparation and partly discarded during the storing phase, resulting in a lower *Amount of stored food*. The difference between the *Amount of prepared food* and the *Amount of consumed food* is explained by the fact that more food is prepared than consumed during the base-run. During the preparation of food, an *Amount of inedible prepared food discarded* results from a lack of *Cooking skill*s. This amount is extracted from the *Amount of prepared food.* The *Amount of consumed food* is influenced by the variables *Preference within household* and *Unpredictability lifestyle households,* resulting in a lower *Amount of consumed food.* However, even taking the *Amount of inedible prepared food discarded* into account results still in a higher *Amount of prepared food* than the *Amount of consumed food* combined with the *Amount of inedible prepared food discarded.* This difference results in a *Total amount of edible food leftover*.

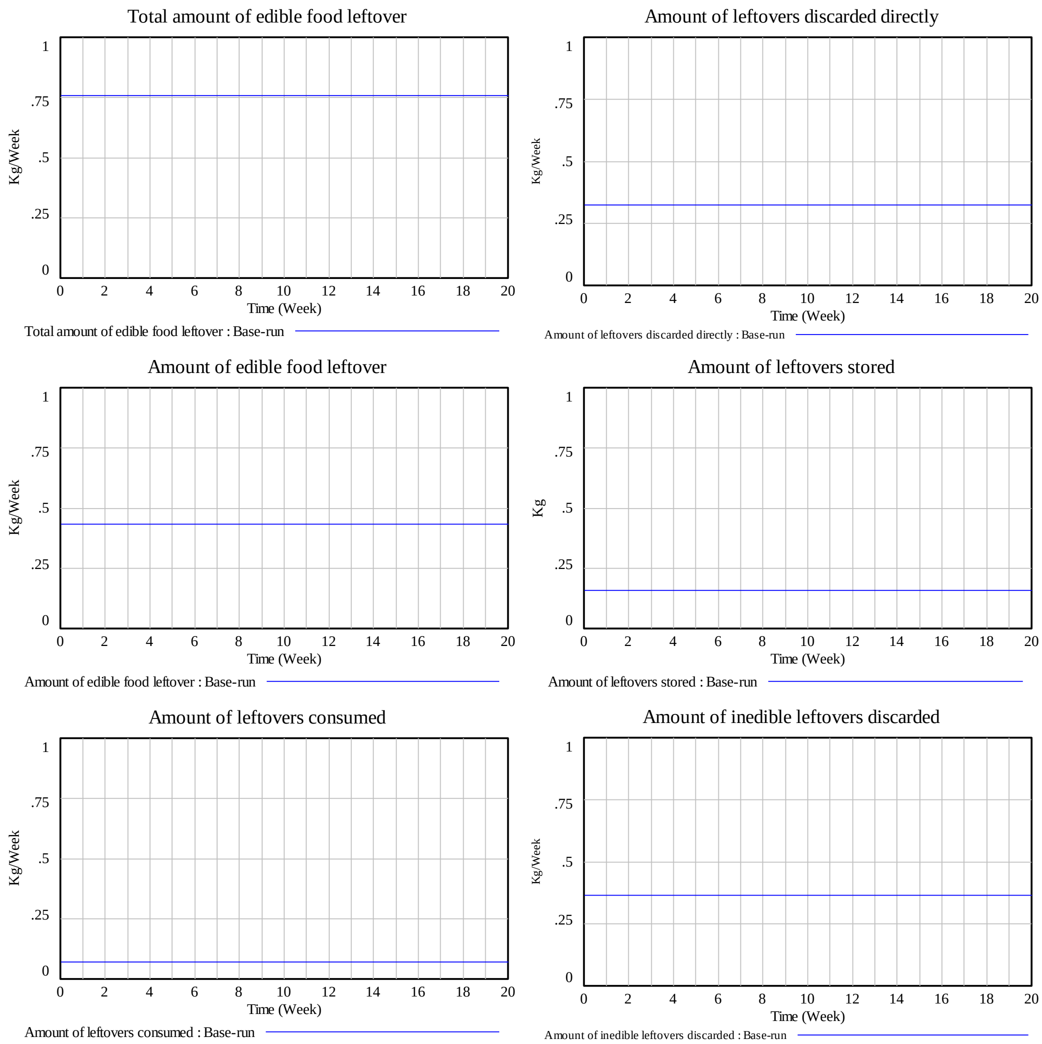


Figure 43: output simulation base-run (ii/iii)

As illustrated in figure 42 and 43, the *Total amount of edible food leftover* is the difference between the *Amount of prepared food* and the *Amount of consumed food* combined with the *Amount of inedible prepared food discarded*. The *Total amount of edible food leftover* is partly thrown away directly, represented by the variable *Amount of leftovers discarded directly*, and partly stored via the variable *Amount of edible food leftover*. The resulting leftovers stored, represented by the variable *Amount of leftover stored* is partly eaten, represented by the variable *Amount of leftovers* *consumed* and partly discarded due to the moulding process of these leftovers, represented by the *Amount of inedible leftovers discarded*.

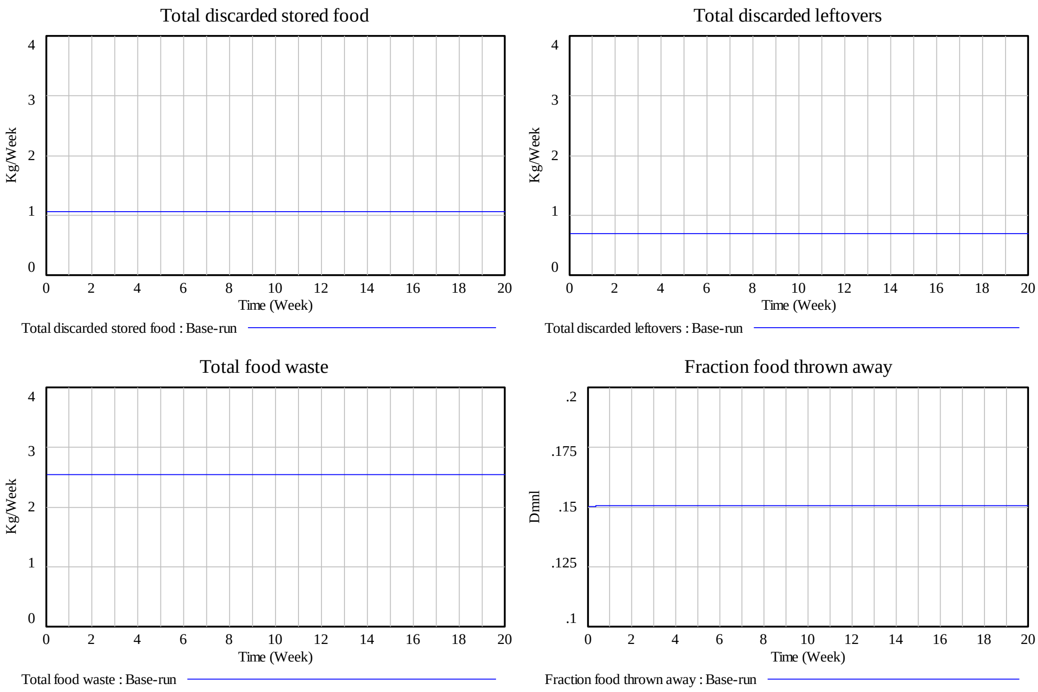


Figure 44: output simulation base-run (iii/iiii)

As illustrated in figure 44**,** more food is thrown away during the storing phase than during the consuming and the leftover phase. The *Total discarded stored food* is the accumulation of the *Amount of inedible stored food discarded* and the *Amount of edible stored food discarded*. The variable *Total discarded leftovers* is the accumulation of the variables *Amount of leftovers discarded* and *Amount of leftovers discarded directly*. The *Total food waste* is more than the *Total discarded stored food* and *Total discarded leftovers* due to the fact that also the *Amount of inedible prepared food discarded* is included while calculating the *Total food waste*. Regarding the *Fraction food thrown away* within a household; of all food that is bought by a household, 15% is discarded based on the results of the base-run. As mentioned in section 5.3.3, 45% of this waste is assumed to be unavoidable and 55% of this waste is assumed to be avoidable.

6.3 Enlarging effect on interventions and time-based effect

This section has two functions. The first part of this section elaborates on the enlarging effect of the *Moral attitude* on the *Effect of an intervention in general,* which is discussed in section 6.3.1. Secondly, to simulate the campaign interventions, there is also a time-based component needed, which is elaborated on in section 6.3.2. These components are added to the System Dynamics model. The result of this section is an improved System Dynamic model to which the effects of interventions can be added. This resulting System Dynamics model is used to simulate the potential effects of the interventions, defined in section 3.5. The interventions are simulated individually in section 6.4 and combined in section 6.5.

6.3.1 Considering the enlarging effect.

During the intervention analysis in section 3.5, a connection is identified between the *Perceived amount of food waste* and the effects of the interventions. Households with a higher *Perceived amount of food waste* are more willing to reduce the food waste within their household. This relation is specified by connecting the *Perceived amount of food waste planning* and the effects on the interventions. This connection is included in the System Dynamics model, resulting in an improved model that is capable of simulating the effects of the interventions including the effect of the *Perceived amount of food waste*. The assumed relation between the *Perceived amount of food waste planning* and the effect of an intervention is illustrated in figure 45.

Interventions have an individual effect on the waste of food, but the impact of its effect is dependent on the *Moral attitude* and the *Total food waste regarding the planning loops*, via the *Perceived amount of food waste planning*. Regarding the effect on the interventions, the planning oriented perceived food waste is considered and not the preparation perceived food waste. As mentioned in section 4.3, the *Total food waste regarding the planning loops* contains all the food waste that is generated within the household except the *Amount of inedible prepared food*. It is assumed that ruining food due to a lack of *Cooking skills* food does not result in a trigger for enlarging the effects of interventions in general. Having a higher *Perceived amount of food waste planning*, represented on the x-axis results in a higher effect of the intervention used at that moment, represented on the y-axis in figure 45.

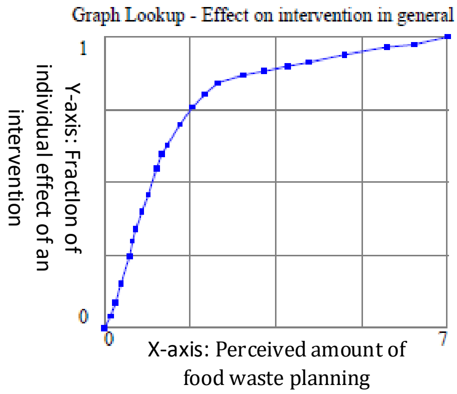


Figure 45: effect of perceived food waste on an intervention in general

In the System Dynamics, the resulting individual effect of an intervention is calculated by multiplying the individual effect of an intervention by the *Effect on intervention general*. The resulting fraction based on the *Perceived amount of food waste planning* illustrated in figure 45 is multiplied with the effect of an intervention in general. The result of this adjustment in the System Dynamics model is that interventions on reducing the waste of food have a bigger effect within households with a higher *Moral attitude*. This aspect illustrates that households who believe that wasting food is wrong, are more willing to reduce this waste and therefore, the effects of an intervention has a bigger effect in such a household.

No scientific data is available on regarding the potential effect of the *Moral attitude* and the effect of an intervention. Therefore, the relation presented in figure 45 is assumed and other relations may be possible. However, changing the relation is assumed to not affect the underlying causal mechanisms. Changing this relation does affect the actual effect of an intervention.

6.3.2 Time based effect of campaigns

There are two interventions identified in section 3.5 that are based upon providing information and knowledge via campaigns. To cope with the adoption of the knowledge provided by the campaigns, an extra variable with a time component is added to the model. It is assumed that on average it will take time before a households adopts this new knowledge and some of the knowledge is forgotten over time. To illustrate this effect, a look-up function is used, which is illustrated in figure 46**.** In this figure the x-axis represents the time in weeks and the output on the y-axis, is the average adoption rate of the household. In this study and during the simulations it is assumed that the knowledge is adopted linear over the first 40 weeks. It peaks around 85%, thus at the best 85% of the households have adopted the knowledge. However, not every household will remember the knowledge provided on the longer term. This results a decrease of the adoption of the knowledge after week 39. Households may forget and therefore not apply the knowledge to reduce the amount of waste given to them.

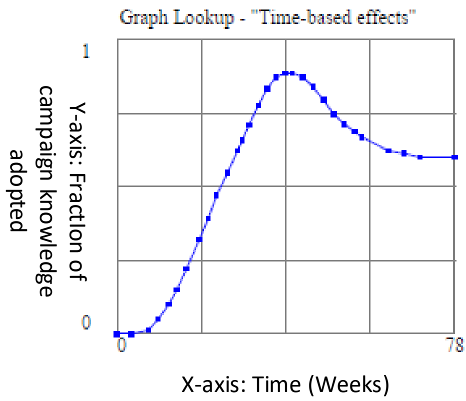


Figure 46: effect of a campaign over time

The relation illustrated is not certain. Therefore, the relation presented in figure 46 is assumed and other relations may be possible. However, changing the relation is assumed to not affect the underlying causal mechanisms, it mainly effects the campaign interventions.

6.4 Individual simulated effects on interventions

This section quantifies and simulates the interventions defined in section 3.5. These interventions are simulated by means of the System Dynamics. The effect of an intervention and the adoption relation of an intervention, discussed in section 6.3.1 and 6.3.2 are considered while estimating the effects of the interventions by means of the System Dynamics model. The simulation results are discussed per intervention (sub-section 6.4.1 – 6.4.4). In the last sub-section, the potential effects of the individual simulations are compared. A more detailed overview of the results of these simulations is presented in **appendix H.** Based upon the individual effects of the interventions, multiple combinations of the most promising interventions are further considered and simulated combined in the next section.

6.4.1 FridgeCam

This sub-section elaborates on the results of simulating the 'FridgeCam' alternative. As stated in section 3.5.1, this technical intervention affects planning phase through the *Degree of using shopping list*. Besides, the 'FridgeCam' allows a household to take a higher *Amount of stored food* and *Amount of leftovers stored* into account; the 'FridgeCam' affects the *Degree of inventory checking.* How these variables are affected the results of simulating the 'FridgeCam' intervention is elaborated on in **appendix H.** The results of the simulation are illustrated in figure 47, figure 48, and figure 49. A low potential effect of this intervention is given during the base-run, which is no effect at all. A big potential effect is of the 'FridgeCam' is given where the variables *Degree of using shopping list* and the *Degree of inventory checking* are affected by the 'FridgeCam' according to **appendix H**. The resulting difference between the base-run and the simulated effects of the intervention illustrate the potential individual effect of the 'FridgeCam' intervention.

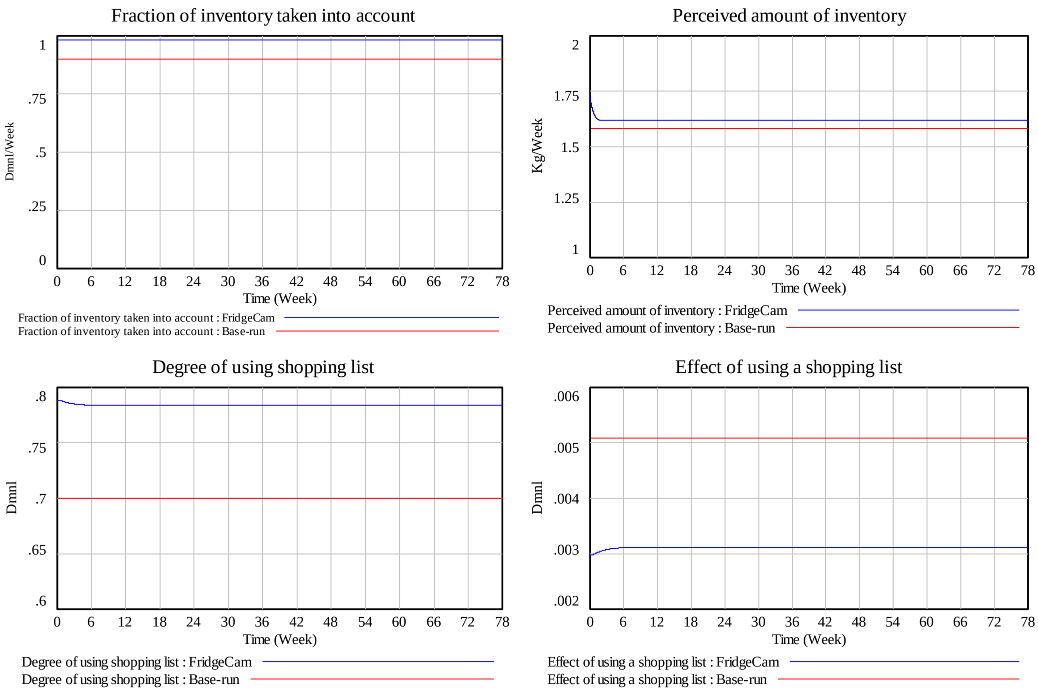


Figure 47: results of the CamFridge (i/iii)

According to the results of the simulation, this intervention affects the over planning aspect during the planning phase. As illustrated **in figure 47,** it is concluded that using a CamFridge has an effect on the *Fraction inventory taken into account* and on the *Degree of using a shopping list.* Using a 'FridgeCam' increases the *Fraction of inventory taken into account* and thereby also in a higher P*erceived amount of inventory.* Also the *Degree of using a shopping list* increases while using the 'FridgeCam'. The *Fraction of inventory taken into account* increases around the 8% and the *Effect of using a shopping list decreases* from 0,5% to 0,3%.

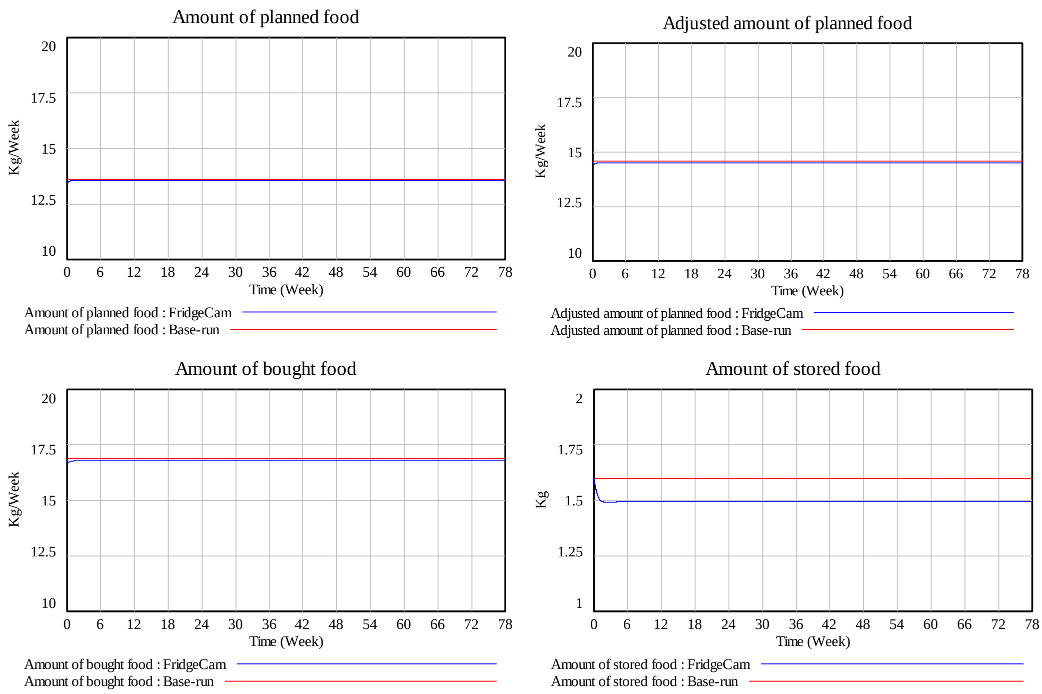


Figure 48: results of the CamFridge (ii/iii)

As illustrated in figure 48, the increase of the *Perceived amount of inventory* results in a lower *Amount of planned food* while using the 'FridgeCam'. However, as illustrated, this effect is little. No different lines can be identified. The results on this variable almost the same. Combining this with decreasing effect of the variable *Effect of using a shopping list* also decreases the *Adjusted amount of planned food*. Then again, its effect is very little. Small differences can be identified between the different coloured outputs. The decrease of the *Adjusted amount of planned food* results in a decrease of the *Amount of bought food*. Following this, a lower *Amount of stored food* is present within the households. As illustrated in **appendix H**, no effects are considerable after the storing phase, and therefore not elaborated on in this section.

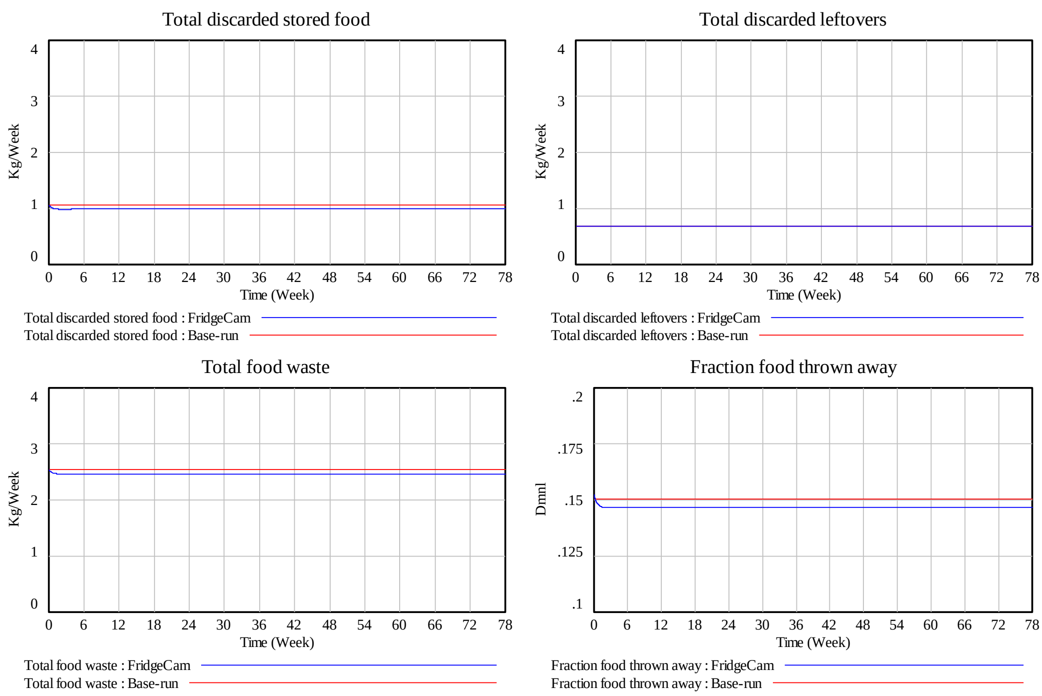


Figure 49: results of the CamFridge (iii/iii)

A decrease of the *Amount of stored food* results in a decrease of the *Total stored food discarded* and thereby of the *Total food waste*, which is illustrated in figure 49. As mentioned before, the behaviour of the System Dynamics model is not affected after the preparing phase. The results of the base-run and the 'FridgeCam' regarding the *Total leftovers discarded* is identical. The *Fraction food thrown away* decreases according to the results of the simulation presented in figure 49. Based upon the results, a decrease around the 0.5% of the *Fraction food thrown away* is identified while individually simulating the 'FridgeCam' intervention.

6.4.2 No discount and economies of scale

As stated in section 3.5.4, this technical intervention from a supermarket perspective affects the purchasing phase through the variable *Effect of economies of scale and discounts*. Thereby, the intervention affects the *Degree of overbuying.* How these variables are affected and the effect of this change is elaborated on in in **appendix H.** The results of the simulation are illustrated in figure 51, and figure 52. A low effect of this intervention is given during the base-run, which is no effect at all. A big potential effect of the 'No discount and economies of scale intervention' is given by the simulation where the *Effect of economies of scale and discounts* are affected according to **appendix H**. The difference between the results of the base run and the simulated intervention illustrate the potential individual effects of the 'No discount and economies of scale intervention'.

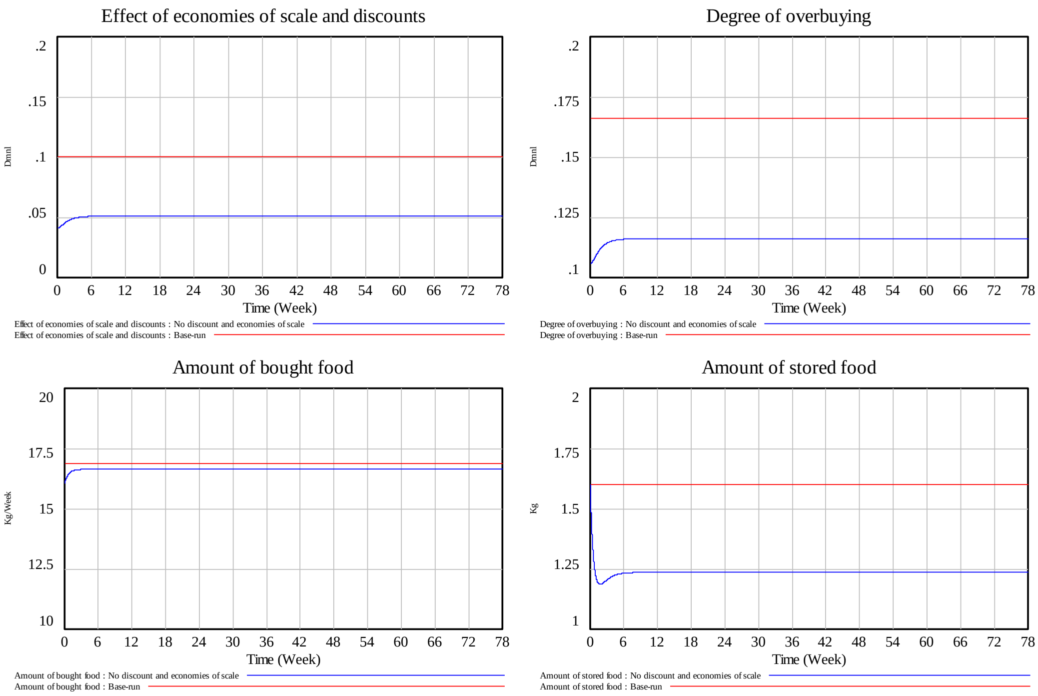


Figure 50: results of no discount & economies of scale intervention (i/ii)

According to the results of the simulation, this intervention affects the overbuying aspect during the purchasing phase. As illustrated in figure 50, by applying the 'No discount and economies of scale intervention', the *Effect of economies of scale and discounts* is reduced. Following this, the *Degree of overbuying* also decreases, resulting in in a lower *Amount of bought food* and thereby in a lower *Amount of stored food*. Also during this intervention, no phases are affected after the storing phase, which is illustrated in **appendix H**.

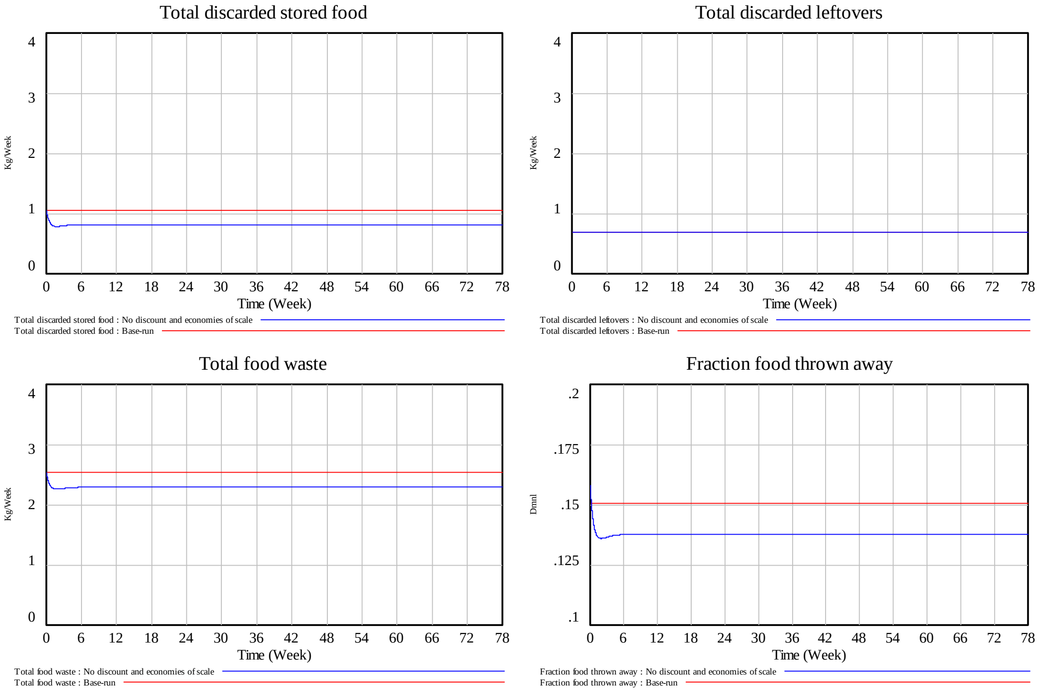


Figure 51: overview effect of no discount & economies of scale (ii/ii)

As illustrated in figure 51**,** having less food stored results in a *lower Amount of inedible stored food discarded* and a lower *Amount of edible stored food discarded*. This decrease is represented by a resulting decrease of *the Total discarded stored food* and thereby in a decreased amount of *Total food wasted.* Based upon the results, a decrease around the 1.25% of the *Fraction food thrown away* is identified while individually simulating the 'No discount and economies of scale intervention'.

6.4.3 Spoilage knowledge campaign

As stated in section 3.5.3, this social intervention from a governmental perspective affects the storing phase via the *Spoilage knowledge.* Thereby, this intervention affects the *Amount of edible stored food discarded* and the *Amount of inedible stored food discarded*. Having a higher *Spoilage knowledge* results in a shift from relying more on the *Best before date* rather than on the *Use by date*. In the System Dynamics model, the *Best before date* is assumed to be 3 weeks and the *Use by date* 1 week. In this study, it is assumed that relying more on the *Best before date* represents the ability to determine better if food is still edible even when it has surpassed the *Best before date*. The effects of changing the Spoilage knowledge within the System Dynamics model are presented in figure 53 and figure 54. How these variables are affected and the effect of this change is elaborated on in in **appendix H**. A low effect of this intervention is given during the base-run, which is no effect at all. A big effect is given by the intervention where the *Spoilage knowledge* of the members within a household *is* affected by the 'Spoilage knowledge campaign' according to **appendix H**. The resulting difference between the simulations represents the potential effect of the 'Spoilage knowledge campaign'.

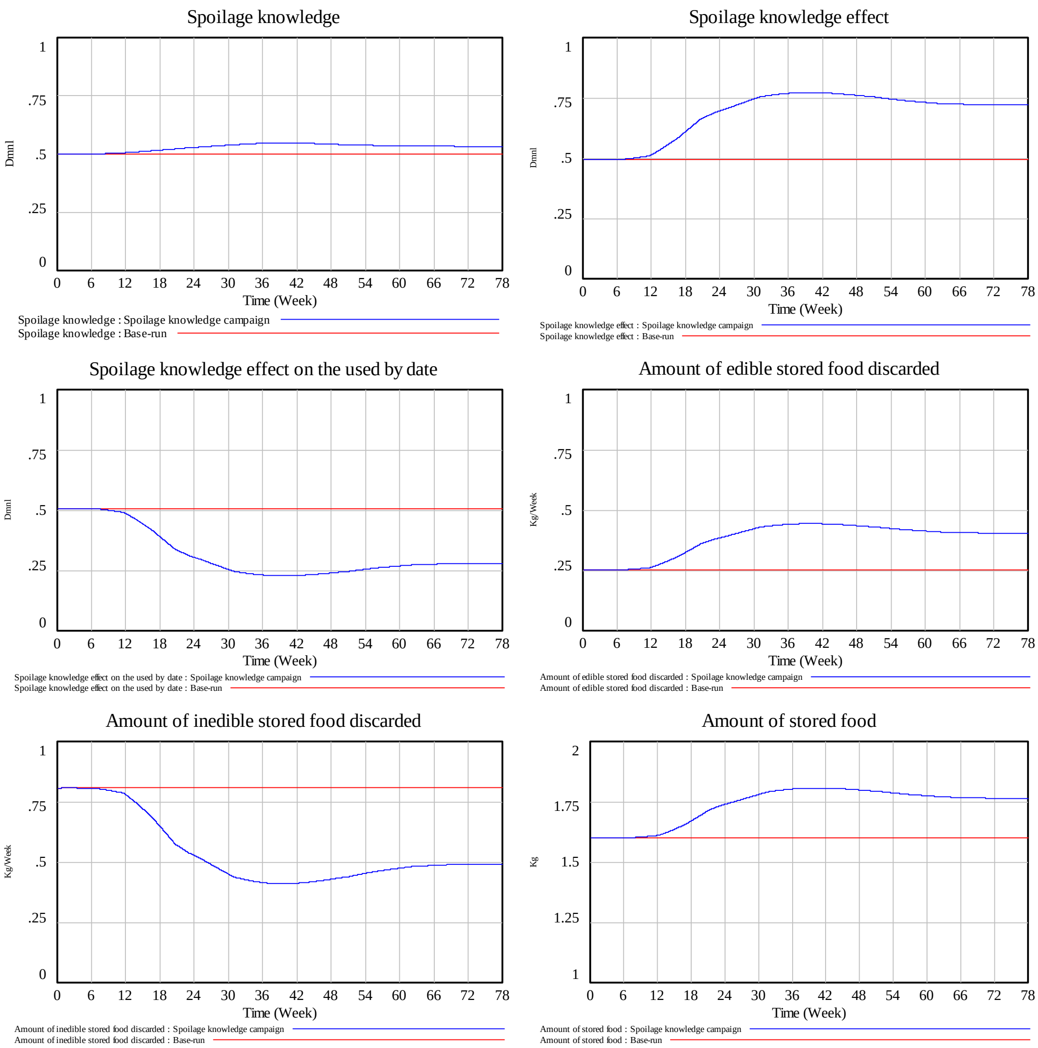


Figure 52: overview effect of campaign on increasing Spoilage knowledge (i/ii)

According to the results of the simulation, this intervention affects the overbuying aspect during the purchasing phase. As illustrated in figure 52, increasing the *Spoilage knowledge* has an effect on the *Spoilage knowledge effect.* Having more knowledge results in a bigger *Spoilage knowledge effect*. A bigger *Spoilage knowledge effect* results in a shift of relying more on the *Best before date* than on the *Use by date*. During the base-run the *Spoilage knowledge* effect is 0.5, which results in an equal part of the food that is thrown away based upon the *Best before* and *Use by date*. Applying the 'Spoilage knowledge campaign', the value of the *Spoilage knowledge effect* increases. This increase results in a bigger share of relying on the *Best before date,* which is around the 75%. A smaller share results of relying on the *Use by date*, which is 25%. By increasing the *Spoilage knowledge effect* more food is thrown away based upon the *Best before date*. This shift affects the *Amount of edible food discarded* and the *Amount of inedible food discarded*. The *Amount of inedible stored food discarded* decreases more than the *Amount of edible food discarded increases*. This is expectable since the *Best before date* is longer than the *Use by date* resulting in longer time before food is discarded on average, which gives the household a better change to prepare the food on time. An increase of the *Amount of stored food* results due to the increase of the average time it takes before the household discards food. No phases are affected after the storing phase, which is illustrated in **appendix H.**

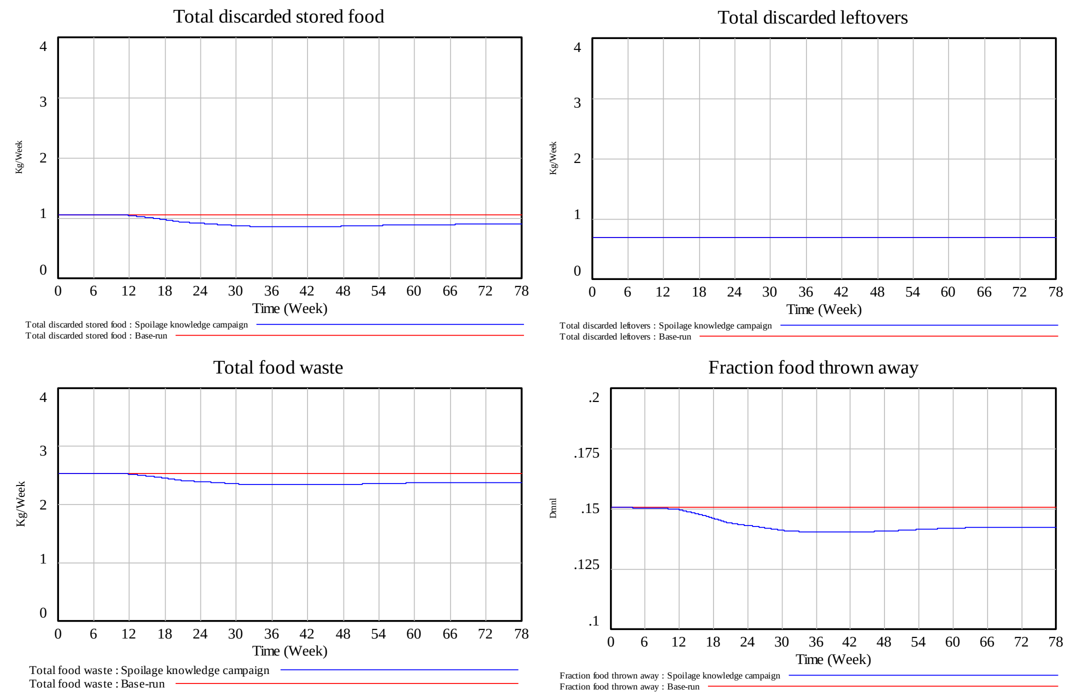


Figure 53: overview effect of campaign on increasing Spoilage knowledge (ii/ii)

Based upon the results of the simulation, as illustrated in figure 53**,** a decrease of the *Total food waste* results via the decrease of *Total discarded stored food*. Based upon the results, a decrease around the 0.8% of the *Fraction food thrown away* is identified while individually simulating the 'Spoilage knowledge campaign'.

6.4.4 Knowledge on consequences food waste campaign

As stated in section 3.5.2, this social intervention from a governmental perspective affects the food waste system during the general phase via the *Knowledge on consequences food waste.* Affecting this variable results in a change of the value of the *Moral attitude.* Following this, the *Perceived food waste planning* and *Perceived food waste prepared* are affected. Finally, the planning and preparing phase are affected; the *Degree of over planning* and the *Provision factor* are adjusted, resulting in a decrease of the amount food wasted. The results of the simulation are presented in figure 54, figure 55 and figure 56. How these variables are affected and the effect of this change is elaborated on in in **appendix H**. A low effect of this intervention is given during the base-run, which is no effect at all. A big effect is given by the intervention where the *Knowledge on consequences food waste* of the members within a household is affected by the 'Spoilage knowledge campaign'.

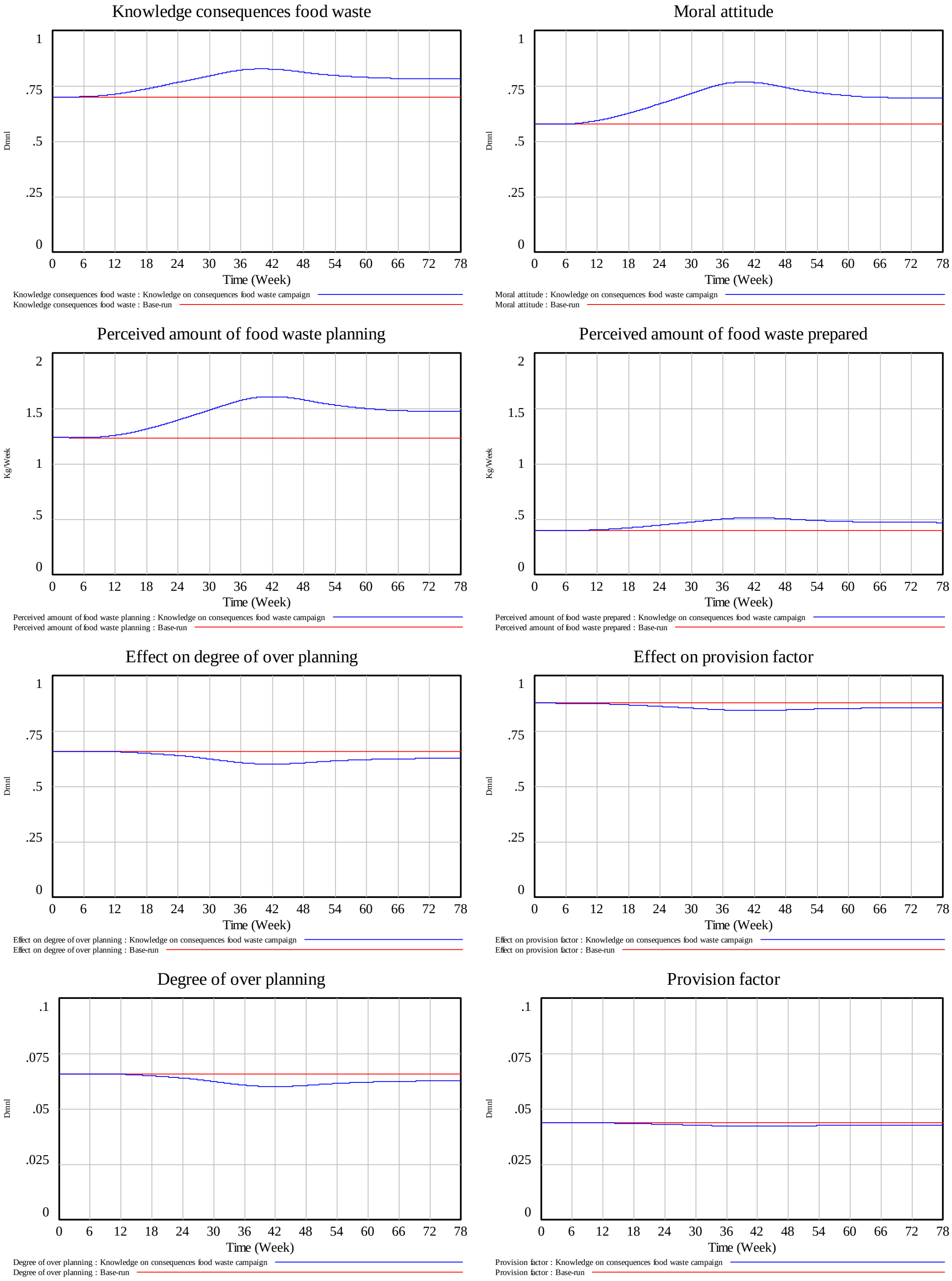


Figure 54: overview effect of campaign on increasing knowledge consequences food waste (i/iii)

Based upon the results of the simulation, as illustrated in figure 54, two major aspects are influenced by increasing the *Knowledge on consequences food waste.* As stated in section 2.5, the model is affected via the feedback loop regarding the planning oriented behaviour and via the feedback loop regarding the prepared oriented behaviour. Increasing the *Knowledge on consequences food waste* has an effect on the *Moral attitude.* Increasing the *Moral attitude* increases the *Perceived amount of food waste planning,* and thereby the *Correctness factor planning*. This finally results in an adjustment of the *Degree of over planning* via the changing *Effect of degree of over planning.* Besides, increasing the *Perceived amount of food waste prepared increases* the *Correctness factor prepared*. This finally results in an adjustment of the *Provision factor* via the changing *Effect on provision factor.*

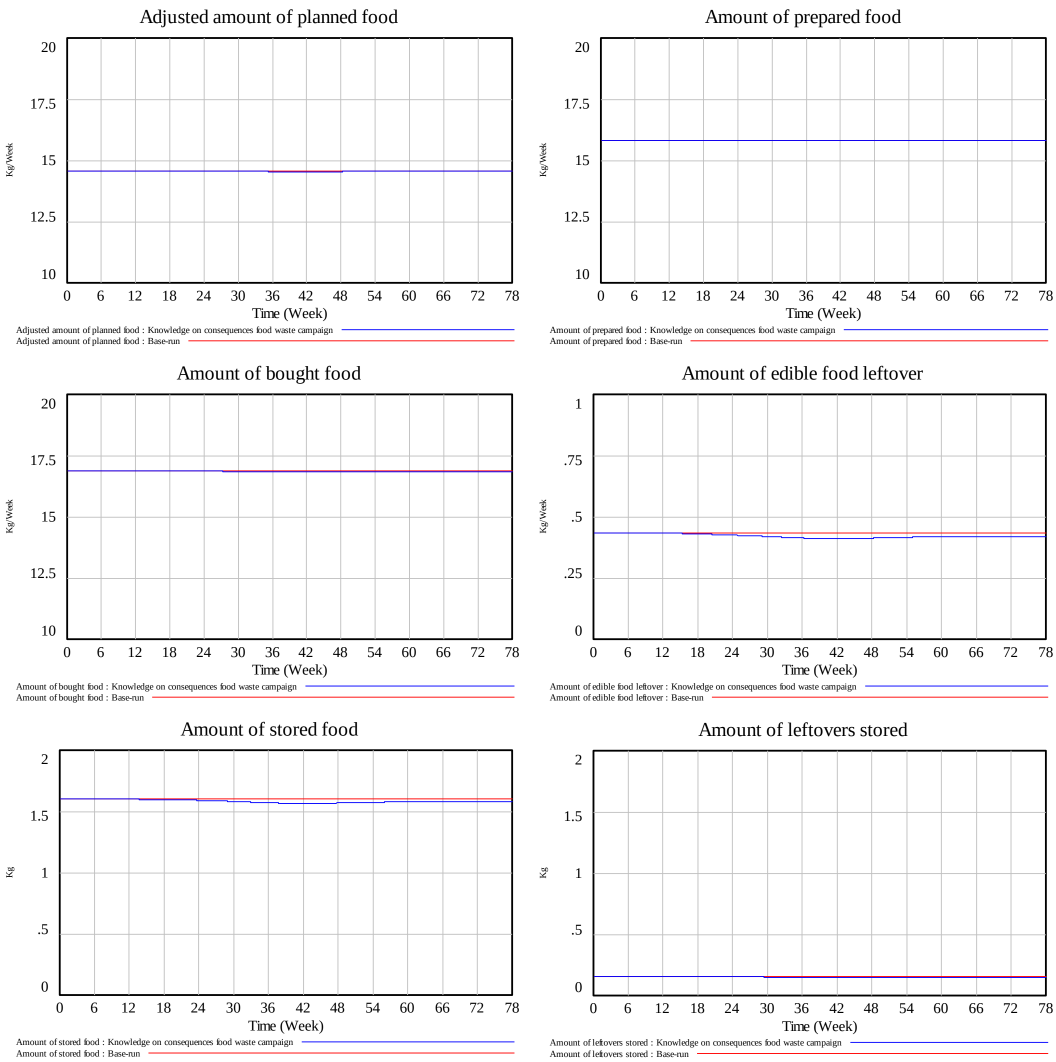


Figure 55: overview effect of campaign on increasing knowledge consequences food waste (ii/iii)

Based upon the simulation, as illustrated in figure 55, changing the *Degree of over planning* decreases the *Adjusted amount of planned food* resulting in a lower *Amount of stored food.* The change in the *Provision factor* decreases the *Amount of prepared food* resulting in a lower *Amount of edible food leftover,* which eventually results in a lower *Amount of leftovers stored.* By applying the 'Knowledge on consequences food waste', small decreases are identified regarding the stored amounts of food and leftovers.

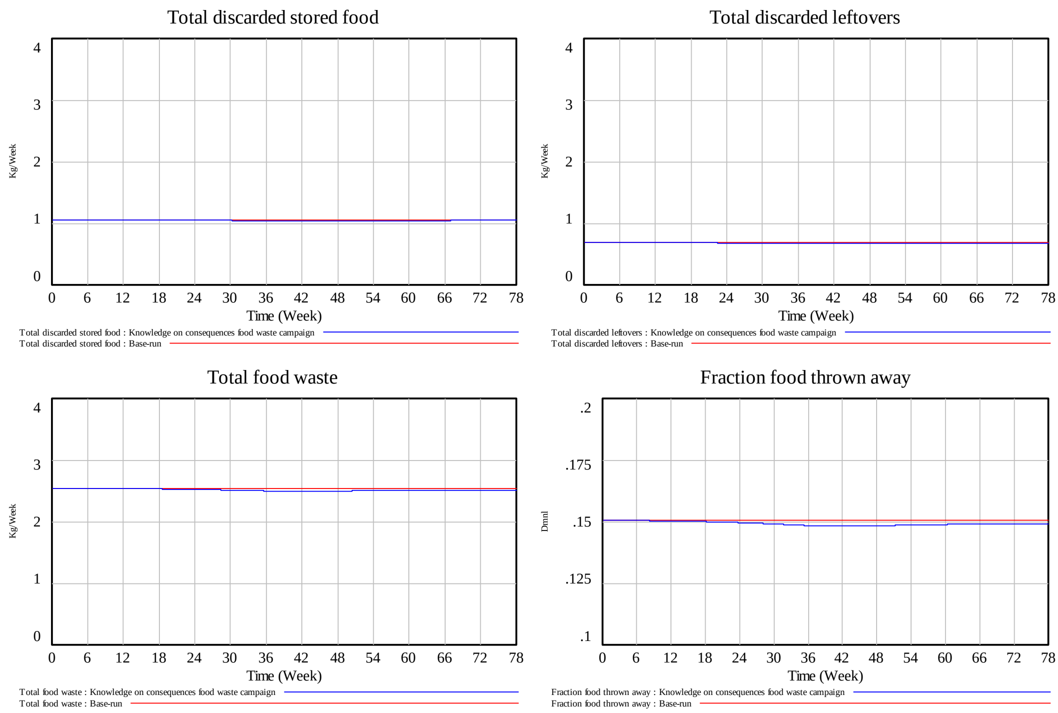


Figure 56: overview effect of campaign on increasing knowledge consequences food waste (iii/iii)

Based on the simulation, as illustrated in figure 56, the decrease of the *Amount of stored food* and the *Amount of stored leftovers* results in a decrease of the *Total discarded stored food* and *Total discarded stored leftovers*. In both cases, a small impact on the stored related waste variables can be identified. Based upon the results, a decrease around the 0.1% of the *Fraction food thrown away* is identified while individually simulating the 'Knowledge on consequences food waste campaign'.

6.4.5 Comparing the effects of the interventions individually

This sub-section compares and discusses the effects of the interventions that are simulated individually. The effects of the interventions on *Fraction food thrown away* are illustrated in table 13 and in figure 57. Based upon the results, insights are derived in this sub-section.

As simulated during the base-run in section 6.2, a household wastes around 15% of all the food that is bought. The *Fraction food thrown away* is reduced by a percentage ranging between 0.1% and 1.2% by simulating the interventions individual. The potential effects based upon the simulations are presented in table 13**.** As mentioned in section 5.3.3, a distinction is made between avoidable and unavoidable food waste. Also, it is assumed that the interventions affect the avoidable waste of food. 55% of the *Total food waste* is assumed to be avoidable. Considering only the avoidable food waste, a maximal reduction of 15.8% of this waste can be realised by applying the 'No discount and economies of scale intervention'. Based upon the results of the simulation, it can be concluded that reducing the waste of food within a specific phase has a relative small impact on reducing the *Total food wasted*. Thereby it can be concluded that the generation of food waste is a segmented process; interventions should focus on multiple phases in to effectively reduce the waste of food on the level of a household.

Table 13: overview individual potential impact of the interventions on the Fraction of food thrown away

Intervention (t=week 78)	Fraction food thrown away total (%)	Fraction food thrown away avoidable (%)	Relative improvement of an avoidable (%)
None	+/- 15.0%	+/- 8.25%	n.a
Knowledge consequences FW campaign	+/- 14.9%	+/- 8.15%	+/- 1.2%
CamFridge	+/- 14,7%	+/- 7.95%	+/- 3,6%
Spoilage knowledge campaign	+/- 14.2%	+/- 7.45%	+/- 9.7%
No discounts and economies of scale	+/- 13.8%	+/- 7.05%	+/- 15.8%

The intervention Knowledge on the consequences food waste campaign resulted in the lowest decrease of the *Fraction food thrown away*. However, it was the only intervention that affected the storing and leftover phase. The Knowledge on the consequences food waste campaign is interesting to consider due to its expected enlarging effect on other interventions. As described in section 6.3.1, the *Effect on an intervention* is based on effect is dependent on the *Moral attitude* and the *Total food waste regarding the planning loops*, via the *Perceived amount of food waste planning*. The Knowledge on consequences food waste intervention is the only intervention that affects the *Moral attitude*. Increasing the *Moral attitude* increases the effect of another intervention. Therefore, this intervention is combined with the two best performing interventions according to results summarized in table 13. An overview of the effects of the interventions on the *Fraction food thrown away* is illustrated in figure 57. The 'No discount and economies of scale intervention' and the 'Spoilage knowledge campaign' are combined with the No discounts and economies of scale intervention in next section.

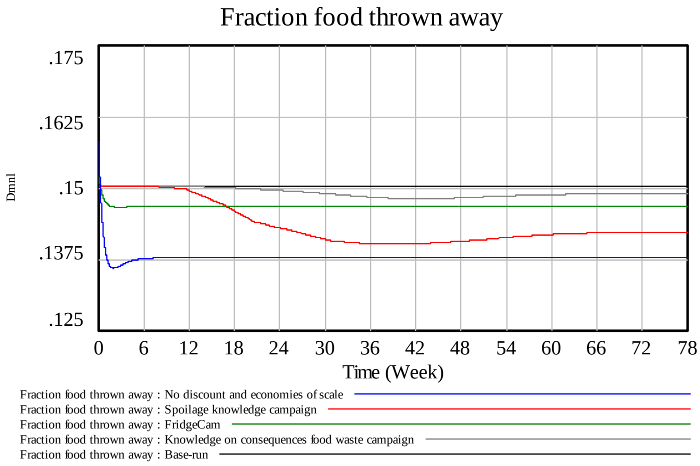


Figure 57: overview results simulations interventions on Fraction food thrown away

6.5 Combining the interventions

This section presents and discusses the effects of combined simulations of multiple interventions identified in previous section by means of the System Dynamics model. As stated in previous sub-section, it is assumed that some interventions enlarge each other's effect on the waste of food. This effect is illustrated in this section. Section 6.4.1 elaborates on the simulation results of the first intervention strategy where the 'Knowledge on consequences food waste campaign' is combined with the 'No discount and economies of scale intervention'. Section 6.4.2 elaborates on the simulation results of the second intervention strategy where the 'Knowledge on consequences food waste campaign' is combined with the 'Spoilage knowledge campaign'. The results of the interventions strategies are compared in section 6.4.3. A more detailed overview on the results of the combined simulations is given in **appendix I.** The result of this section is an overview of the combined effects of the interventions on the waste of food on the level of a household of which the most effective combination is considered under changing circumstances to test its robustness in next section.

6.5.1 Intervention strategy 1: No discount and economies of scale & Knowledge on consequences food waste

This sub-section presents and discusses the results of simulating the first intervention strategy. The combined effect of the interventions on the food waste system is illustrated in figure 58**.** A more detailed overview of the results of the combined simulation is given in **appendix I**. The result of this combined simulation is compared with the results of the second intervention strategy in sub-section 6.5.3.

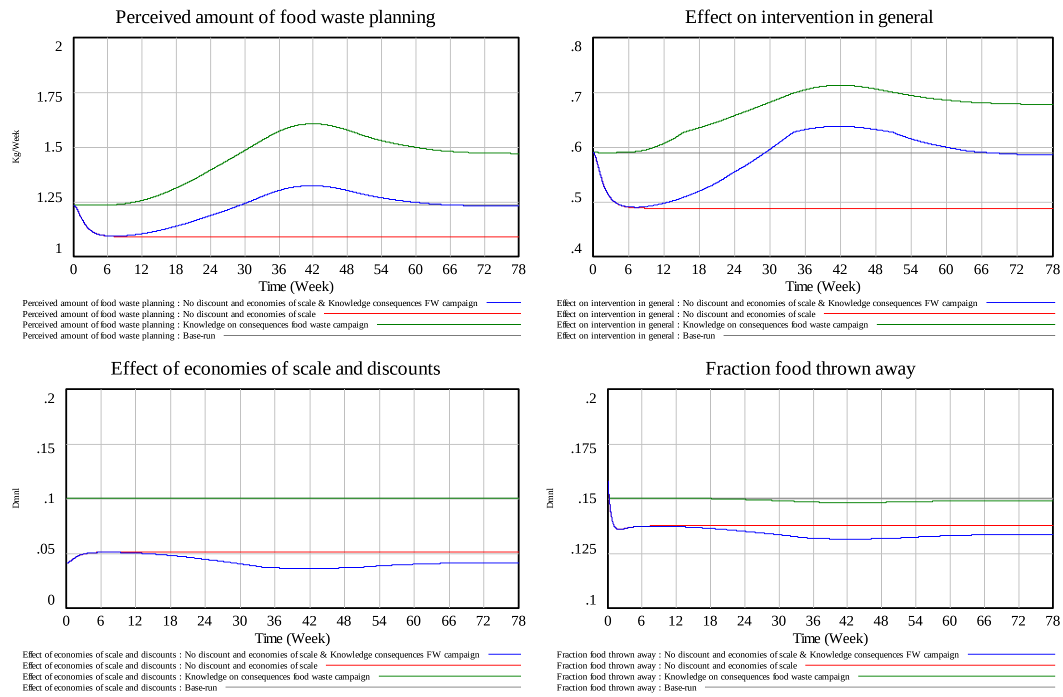


Figure 58: effect of the intervention the first intervention strategy

An enlarging effect can be identified based on the results presented in figure 58. Simulating the interventions combined results in a bigger decrease of the *Fraction food thrown away* than simulating these interventions individually.

As illustrated, an enlarging effect is identified regarding the *Perceived amount of food waste planning*. Combining the interventions results in an increase of the *Effect on intervention in general,* which increases the effectivity of the interventions applied. This increase results in a decrease of the *Effect of economies of scale and discounts*, which again resulted in a lower *Amount of bought food* via the *Degree of overbuying*, finally resulting in a lower *Amount of stored food*. Based upon the results, a decrease around the 1.6% of the *Fraction food thrown away* is identified at the end of simulating the 'No discount and economies of scale intervention' and the Knowledge on consequences food waste combined.

6.5.2 Intervention strategy 2: Spoilage knowledge campaign & Knowledge on consequences food waste

This sub-section presents and discusses the results of simulating the second intervention strategy. The result on the *Fraction food thrown away* is given in figure 59. A more detailed overview of the results of the simulation of the intervention strategy is given in **appendix I**. The result of the simulation of this intervention strategy is compared with the results of the other intervention strategy in next sub-section.

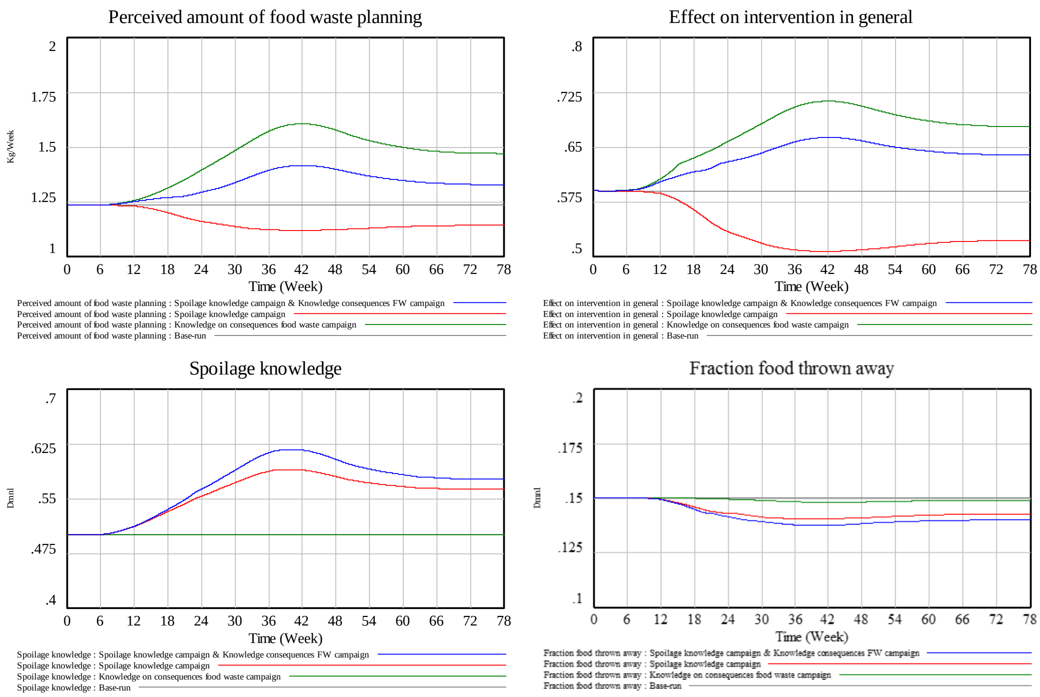


Figure 59: effect of the intervention the second intervention strategy

An enlarging effect is identified based on the results presented in figure 59**.** Simulating the interventions combined results in a bigger decrease of the *Fraction food thrown away* than simulating these interventions individually.

As illustrated, an enlarging effect is identified regarding the *Perceived amount of food waste planning*. Combining the interventions results in an increase of the *Effect on intervention in general,* which increases the effectivity of the interventions applied*.* This increase results in an increase of the *Spoilage knowledge*. This shift results in an increase of the average time it takes before food is discarded during the storing phase. Finally this shift results in a lower *Total stored food discarded*. Based upon the results, a decrease around the 1% of the *Fraction food thrown away* is identified at the end of simulating the 'Spoilage knowledge campaign' and the Knowledge on consequences food waste combined.

6.5.3 Comparing the intervention strategies

The results of the effects of the intervention strategies are compared in this section. The effects of the intervention strategies on *Fraction food thrown away* are illustrated in table 13 and figure 60. Based upon the results, insights are derived in this sub-section.

For both simulated intervention strategies, an enlarging effect resulted. The resulting enlarged effect had a bigger effect while applying the first intervention strategy. This can be explained by the causal relation defined in section 6.3.1, which states that the effect of an intervention is dependent on its individual effect combined with fraction the *Effect of an intervention on general*, which is dependent on the *Perceived amount of food waste planning.* The bigger the individual effect of an intervention, the bigger the enlarging effect is while combing it with the 'Knowledge on consequences food waste campaign'.

As illustrated in table 14, the combined effect of the intervention strategies is greater than the individual parts accumulated. Combining the No discounts and economies of scale with the Knowledge on consequences food waste resulted in the biggest decrease; according to the results of the simulation, a combined reduction of 19.4% of the avoidable food waste can be realised. This result indicates that combing interventions may result in effective approaches for reducing the waste of food on the level of a household.

Table 14: overview results individual and combined potential effect of the interventions on the Fraction of food thrown away

Intervention (t= week 78)	Fraction food thrown away total *(%)*	Fraction food thrown away avoidable (%)	Relative improvement of an avoidable (%)
None	+/- 15.0%	+/- 8.25%	n.a
Knowledge consequences FW campaign	+/- 14.9%	+/- 8.15%	+/- 1.2%
Spoilage knowledge campaign	+/- 14.2%	+/- 7.45%	+/- 9.7%
Intervention strategy 2	+/- 14,0%	+/- 7.25%	+/- 12.1%
No discounts and economies of scale	+/- 13.8%	+/- 7.05%	+/- 15.8%
Intervention strategy 1	+/- 13.4%	+/- 6.65%	+/- 19.4%

However, based upon the results of the simulation it can also be concluded that combining interventions may have an decreasing effect. As stated, applying an intervention decreases the food wasted within a household, which also results in a decrease of *Perceived amount of food waste planning* via the *Total food waste.* A decrease of this amount affects the *Effect of an intervention on general.* This implies that combining two interventions that only focus on reducing the waste of food decrease each other's effect. Combining multiple interventions on reducing the waste of food may thus have a counterproductive effect. This counterproductive aspect is considered in more detail in section 7.2.3.

Based upon the enlarging and decreasing effect that interventions may have on each other that is illustrated in this section, two important aspects are identified that should be considered while designing intervention strategies. While applying multiple interventions, the focus needs to be on two aspects within a households. First, the 'knowhow' within a household should be considered. Households should know how to reduce the waste of food. In the System Dynamics model, the 'knowhow' is increased by applying the 'FridgeCam', the 'Spoilage knowledge campaign', and the No discounts and economies of scale intervention. Secondly, the 'willingness' within a household should be considered. People should have a positive attitude towards reducing the waste of food. In the System Dynamics model, the 'willingness' within a household is increased by applying the Knowledge on consequences food waste intervention. Focusing on the 'knowhow' and on the 'willingness' results in more effective intervention strategies regarding the reduction of the waste of food.

The first interventions strategy where the 'Knowledge on consequences food waste campaign' combined with the 'No discount and economies of scale intervention' is considered further in next section. As aforementioned and illustrated in figure 60, this intervention strategy has the most promising decreasing effect on the *Fraction food thrown away.* Therefore, this strategy is considered while changing important uncertain parameters in section 6.5 to test its robustness.

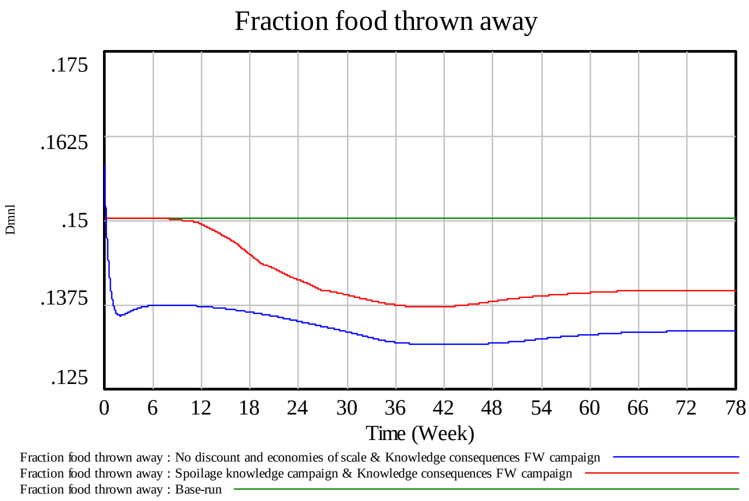


Figure 60: overview results simulations interventions on Fraction food thrown away

6.6 Robustness of the second intervention strategy

This section tests the robustness of the first intervention strategy where the Knowledge on consequences food waste intervention is combined with the 'No discount and economies of scale intervention'. During the data gathering in chapter 4, multiple uncertain parameters are identified. These parameters are varied univariate and multivariate in **appendix J**. The result of this section is an overview of the robustness of the intervention strategy on the effects on the *Fraction food thrown away.*

The effect of changing the *Degree of over planning*, the *Use by date*, the *Provision factor* and the *Effect on household* are presented in figure 61. Based on the result of the robustness tests, it is concluded that the behaviour regarding the intervention strategy on the *Fraction food thrown away* is the same under changing the important uncertain parameters combined. However, the actual size of the effect on the *Fraction of food waste* may vary. This implies that the results of the individual and combined simulations should be considered carefully. The actual effects of these interventions are uncertain. However, the potential effects can be used as rough indications of the possible potential effects of the interventions. They may give an idea of the possible effects of such an intervention on the waste of food.

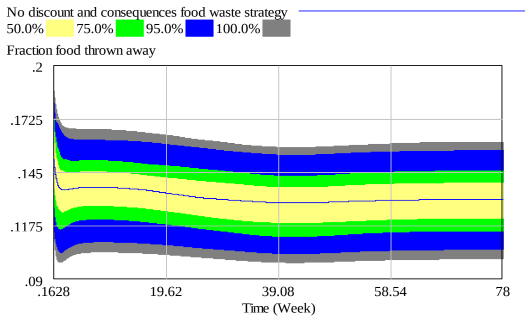


Figure 61: multivariate robustness analysis of the intervention strategy

6.7 Conclusions of this chapter

This chapter presents the results of the simulation of the interventions that are defined in chapter 3 by means of the resulted improved model defined in chapter 5. In this chapter, these interventions are simulated individually. Based upon the effects of the reduction of the food wasted, the two most effective interventions are further considered and transformed into intervention strategies. An intervention strategy where the Spoilage campaign is combined with the 'Knowledge on consequences food waste campaign' and an intervention strategy where the 'No discount and economies of scale intervention' is combined with the 'Knowledge on consequences food waste campaign' and an intervention strategy. These intervention strategies are simulated combined and based upon these simulations, it is concluded that the intervention strategy in which the 'No discount and economies of scale intervention' is combined with the 'Knowledge on consequences food waste campaign' decreased the waste of food on the level the most. To test the robustness of this effect, the intervention strategy is simulated while changing the uncertain parameters that are identified in chapter during the uncertainty analysis in section 5.3.4 simulates strategies.

Based upon the results of the individual simulation, it is concluded that the waste of food on the level of a household is fragmented, the waste of food is caused in multiple phases. Interventions do not have a big individual effect on the total food waste. Reducing the waste of food effectively demands multiple interventions affecting multiple phases within the system, often from multiple perspectives from different actors.

As argued in section 2.5 and incorporated into the System Dynamics model in section 6.3.1 an enlarging effect can be reached by combining interventions with the 'Knowledge on consequences food waste campaign' seemed to enlarge the effects of the other interventions, which is illustrated by the simulations. Increasing the *Knowledge on consequences of food waste* increases the *Moral attitude* and thereby the *Perceived amount of food waste*. Increasing the *Perceived amount of food waste* results in a more effective intervention. This incorporated mechanism is used to illustrate the assumptions that households should know how to reduce the waste of food (i) and that the household are willing to reduce the waste of food (ii). A counterproductive effect is also identified; combining other interventions than the 'Knowledge on consequences food waste campaign' resulted in a lower accumulated effect than summing the effects individually together. This lower resulting effect can be explained by the feedback loops present within the simulation model. One intervention reduces the amounts of food wasted within a household, thereby the *Perceived amount of food waste* decreases, resulting in less effective interventions due to the mechanism described in section 6.3.1. Testing the intervention strategy 'No discount and economies of scale intervention' is combined with the 'Knowledge on consequences food waste campaign' by changing important uncertain parameters did not affect its behaviour. Only the effect on the waste of food varied. Based upon the simulations, it can be concluded that the intervention is robust, but that the actual size of the effect on the waste of food generated by the household is uncertain.

The results of this chapter are the simulated effects of the interventions identified in chapter 3 by means of the improved System Dynamics model from chapter 5. These results of this chapter are considered in a broader perspective in next chapter.

7 Reviewing the results

This chapter relates the insights and results derived from the previous chapter to reality. This chapter reviews the results from a broader perspective to provide insights towards the Task Force. The simulated results of previous chapter are considered in section 7.1. Based upon the results, advice is given to the Task Force are described in section 7.2. Section 7.3 covers the possible uses of the resulted improved System Dynamics model. The insights derived in this chapter are summarised in the conclusion of this chapter, given in section 7.4.

7.1 Putting things into perspective

This section elaborates on the simulated results of the individual and combined effects of the interventions elaborated on in previous chapter. The results of the simulations are rough indications of potential effects of the intervention on the waste of food. To provide a better estimate of the potential effects of reducing the waste of food on the level of a household, the potential effects are combined with food waste data that is generated within the Netherlands. Potential reductions of the waste of food within the Netherlands are elaborated on in section 7.1.1. Besides, the total waste of food within the Netherlands is discussed in the Netherlands in sub-section 7.1.2. The results of this section is an indication of potential effects the interventions on the waste of food generated by households within the Netherlands and an estimate of the potential share of this waste regarding the total waste of food within the Netherlands.

7.1.1 The waste of food generated by households within the Netherlands

This sub-section elaborates on the potential effect on the waste of food within the Netherlands. Potential effects are based upon the results of the simulations performed in previous chapter. The results are used to indicate the possible effects of the interventions on the waste of food generated by households within the Netherlands. As, mentioned during the output validation, on average a person generates 62,5 kilogram food waste within the Netherlands in 2016. Based upon last years, on average 45% of the waste of food on the level of a household was unavoidable, resulting in 55% of the waste of food that was avoidable (van Doornen, 2017). An overview of the potential effects of the interventions and interventions strategies on the total waste of food within the Netherlands are given in table 15. These estimates are based upon a population of 17 million in 2016.

According to the data provided by CREM (2017); over the year 2016 an average total food wasted generated by households was around the 1060 million kilogrammes within the Netherlands. Roughly 478 million kilogram of this waste was assumed to be unavoidable and roughly 584 million kilogram was assumed to be avoidable. Based upon the estimations, it can be concluded that in 2016 the Dutch households wasted around 584 million kilogram food, which was avoidable.

Table 15: overview indication potential effect interventions of food waste within the Netherlands

Intervention	Unavoidable waste (million kilogrammes)	Avoidable waste (million kilogrammes)	Reduced waste (million kilogrammes)
No intervention	478	584	n.a
Knowledge on cosequences food waste campaign	478	577	7
Spoilage knowledge campaign	478	528	57
Intervention strategy 2	478	514	71
No discounts and economies of scale	478	492	92
Intervention strategy 2	478	471	113

As mentioned in previous chapter, the potential effects of the interventions are uncertain. Even though, the effects may provide rough indications of possibilities regarding the reduction of the food wasted by applying interventions. According to the simulations, a maximal reduction around the 113 million kilogrammes can be realised by applying the first intervention strategy where the 'No discount and economies of scale intervention' are combined. The resulting potential effects are based upon rough estimates and uncertain but they give insight in the possible size of these potential effects of the interventions.

7.1.2 The waste of food within the Netherlands regarding the whole supply chain

This sub-section compares the amount of food waste generated by households with the total waste of food over the whole Food Supply chain within the Netherlands. As mentioned in the introduction, households are the major contributors to the waste of food within developed regions. Within the Netherlands, it is estimated that in 2015 a total amount of food is wasted between 105 and 152 kilogrammes per person (Soethoudt et al., 2015). The actual food waste is uncertain, but it is certain that it is between the lower and upper layer. The unavoidable waste of food is not included in this estimation. Considering the avoidable waste of food only, it can be concluded that the Dutch households are accountable for 22% to 31% of all food wasted within the Netherlands. The waste of drinks are not included in this study, which could potentially increase the percentage. Van Doornen (2017) included the waste of drinks and estimated that 41 kilogram avoidable food per person is wasted including the waste of drinks, resulting in a share between 27% and 39%. Based upon average estimated share around the 30%, it can be argued that reducing the waste of food within households is likely to have a considerable effect on reducing the waste of food within the food supply chain as a whole.

7.2 Advice for the Task Force based upon the insights derived in this study

This section provides advice to the Task Force based on the results of the simulations performed in previous chapter. As mentioned in the introduction, a Task Force is launched on the 26th of January in 2017 during the National Food Summit in the Netherlands. This collaboration of Wageningen University & Research, Alliantie Verduurzaming Voedsel, and the Ministry of Economic Affairs is discussed in more detail in section 7.2.1. The simulated results of previous chapter are transformed into advice for the Task Force is in section 7.2.2. The result of this section is an advice for the Task Force, based on the insights derived from the simulation of the interventions performed in previous section.

7.2.1 Task Force Circular Economy in Food

This sub-section describes the Task Force. A Task Force was created to bundle all the interventions regarding the reduction of food supply chain as a whole, and therefore the Task Force is assumed to also focus on reducing the waste of food on the level of a household (WUR, 2017). As mentioned in section 7.1.1, around the 30% of the food wasted overall within the Netherlands is caused by households. Within this Task Force, participants that are relevant over the whole food supply chain are present. Promising higher-levelled facilitating parties are added regarding the food supply chain like financial parties, ICT parties, Transport parties, Packaging parties, and the government. However, it is not clear which parties will focus on the waste of food on the level of a household and what their actions are or what goals they do want to reach. The Task Force functions as a think-thank encouraging its participants to innovate towards a circular economy.

From a multi-actor perspective, the Task Force is promising. The System Dynamics model can be used to illustrate that to effectively reduce the food waste, involvement of multiple stakeholders is needed. The Task Force may improve the collaboration regarding the waste of food on the level of a household and the resulting System Dynamics model may contribute to the collaboration, which is elaborated on in section 7.3.2.

7.2.2 Recommendations for the Dutch government and the Task Force

This sub-section provides advice for the Task Force based on the insights derived during this study. The advice is focussed on how to combine multiple interventions according to the results of the simulations. The result of this sub-section is an overview of what kinds of interventions can be combined and what kind of interventions should not be combined and their potential effects according to the results of the simulations.

As stated in chapter 3 and elaborated in section 6.3.1 it is assumed in this study that the potential effect on the food waste system of an intervention is dependent on the on the perceived amount of food waste within a household. As illustrated in section 6.5, combining interventions that focus on the 'knowhow' and the 'willingness' within a household results in an enlarging effect regarding reducing the waste of food. In the System Dynamics model created in this study, the *Moral attitude* is improved by increasing the *Knowledge on consequences food waste* within a household. Increasing the *Moral attitude* within a household results in a higher 'willingness' within a household. As mentioned before, this mechanism is a simplification of reality. However, the idea that households should have to be encouraged to decrease their food waste is interesting to consider. The 'willingness' within a household is likely to be dependent on more factors than only the *Knowledge consequences food waste.* Households should know how to reduce the waste of food, but perhaps more importantly, they need to be willing. Considering combination where these two aspects are considered may have an enlarging effect; the combined results of these interventions may be bigger than the individual effects accumulated. This synergy, this creation of a whole that is greater than the simple sum of its parts is illustrated in in section 6.5. This enlarging effect is illustrated in the left part of figure 62. The left graph illustrates that if the individual effect of the 'No discounts and economies of scale intervention' and the individual effect of the 'Knowledge on consequences food waste campaign' are accumulated, they are smaller than simulating the interventions combined. Combining the interventions results in an enlarging effect on the *Fraction food thrown away*.

During the combined simulation in section 6.5 it is illustrated that combining an intervention with the 'Knowledge on consequences food campaign' waste resulted in a greater whole than the sum of its parts. Another aspects that arose during the combined simulations are that it is assumed that combining two interventions that do not affect the *Moral attitude* did reduce each other's effect. This decrease can be explained by the fact that lowering the waste of food generated by a household decreases the *Perceived amount of food waste planning* and thereby the effect of the other intervention and vice versa. This enlarging and decreasing effect are illustrated in the right part of figure 62. The right graph illustrates that if the individual effect of the 'No discounts and economies of scale intervention' and the individual effect of the 'Spoilage knowledge campaign' are accumulated individually, they are bigger than stimulating the interventions combined.

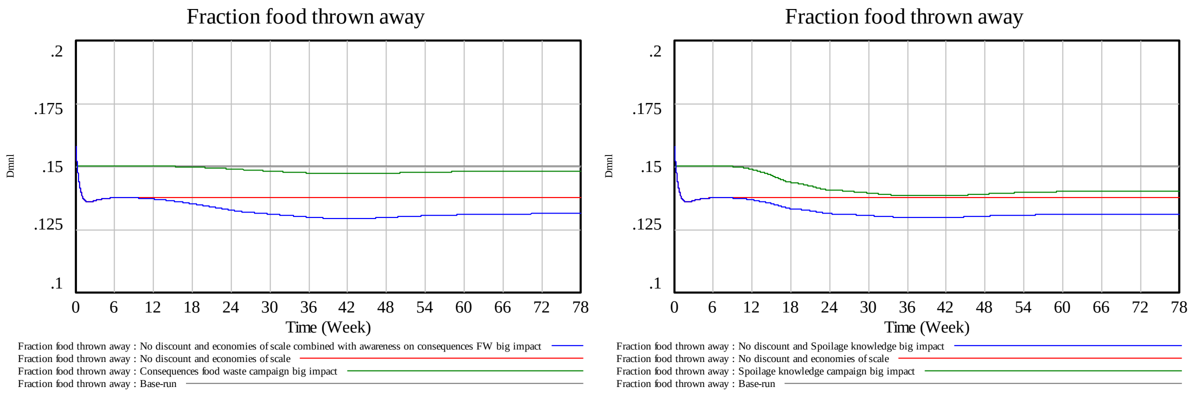


Figure 62: an enlarging effect (left) and a decreasing effect (right) of combining interventions

A third option is to focus only on the 'willingness' within a household. If multiple interventions focus on the *Knowledge on consequences food waste* results in a small simulated effect on the *Fraction food thrown away*. In this study, it is assumed that the planning behaviour and the preparing behaviour are affected by affecting the 'willingness' within a household but the effects on the waste of food are relatively small, 'knowhow' is needed to effectively reduce the waste food according to the results of the simulations.

Even though the simulations are based on simplifications of reality, the mechanisms are interesting to consider. It may be possible that interventions decrease or increase each other's effects. These aspects are interesting to consider while designing new intervention strategies on reducing the waste on the level of a household by the Task Force.

7.3 Usability of the System Dynamics model

This section elaborates on the possibilities regarding the usage the model introduced in this study for the Task Force. The resulting System Dynamics model can be used for multiple purposes. The possible purposes are considered in sub-section 7.3.1. Based upon these possible purposes, possibilities regarding the usage of these models are discussed in sub-section 7.3.2. The result of this section is an overview of the possible purposes of the model.

7.3.1 Policy analysis model classification

This sub-section defines the possible policy goals of a simulation model. To determine the possible goals of the resulting model the adopted framework by Yucel & van Daalen (2009) given in figure 63 is used. This framework is an adaption of Mayer et al. (2004). The possible goals are described in this sub-section. Note that a model may not fit one purpose. Some models do share the characteristics of multiple models. Besides, the purposes of these models may share common aspects but a clear distinction is applicable. Possible models are reviewed regarding Task Force in next sub-section. Based upon the adapted framework, the following policy related models are identified (Yucel & van Daalen, 2009):

- *Analytical models*: the objective of these models is to research and analysis. The models are constructed based on scientific and empirical facts. The models functions as tools to gain insights about the system that is of interest. The main concern is representing the "real system".

- *Advisory models*: the objective of these models is to design and recommend. These models are oriented towards studying an action and its impact within a certain system boundary rather than understanding the system or an observed phenomenon. These actions might involve policies to be used.

- *Strategic models*: the objective of these models is to design advice strategically. This type of models focuses on other actors and their reactions to certain actions taken. These models represent all the actors that are involved in the problem context and all the possible actions.

- *Mediation models*: the objective of these models is to mediate. A certain policy may involve multiple parties that have different views on an issue. Solving the problem may require the parties to understand each other's perspectives. In such a case, a model can be used as a tool for communication. The ultimate goal is much more pragmatic. These models can serve mental model alignment, creating agreement about a policy or design, generating commitment about a decision, or clarification of the problem (Andersen et al. 1997).

- *Participatory models:* the objective of these models is to democratize. Such a model is oriented towards including the involvement from different stakeholders that are of interest. The involvement of the stakeholders is used for input to the policy analysis process from different stakeholders.

- *Discussion models*: the objective of these models is to clarify values and arguments. These models are used to facilitate elicitation of norms and values of the stakeholders involved. These models are often conceptual models or mind maps.

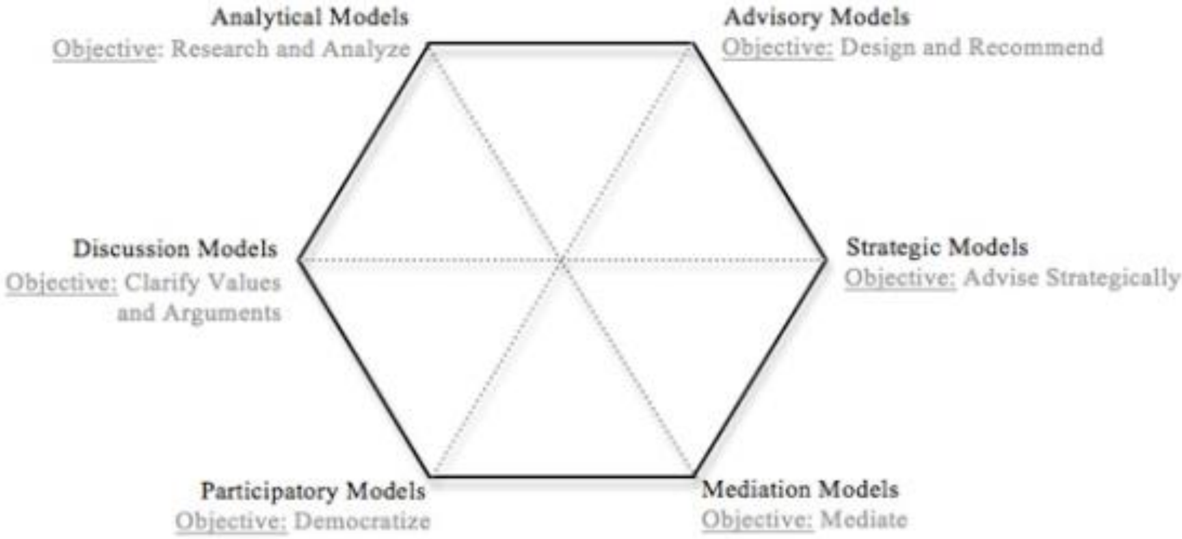


Figure 63: overview of the types of models for supporting policy-making (Yucel & van Daalen, 2009)

7.3.2 Review the policy analysis models for the Task Force

This sub-section reviews the policy related models described in previous sub-section and discusses potential of using these policy related models regarding the Task Force. In this sub-section, two possible types of models are concerned; a possible Advisory models and Mediation models. These types of models are discussed regarding their potential added value regarding the Task Force.

- *Advisory models*: one of the major goals of the Task Force is to identify measures on how to cope with the waste of food on the level of a household. The Task Force could adapt the resulting System Dynamics model to increase the insights regarding the potential effects of interventions and intervention strategies. The quality of the data regarding the parameters and relations present with in the model and the actual effects of the intervention needs to be improved before actual insights can be derived. Also, other simulation methods can be used or combined resulting in more accurate estimations.

  Assume that there is a simulation model that is able to simulate the waste of food and is able to simulate the potential effects of interventions more accurate. This model can be used by the Taskforce to improve the decision making regarding the usage of interventions that can be combined to design effective intervention strategies. However, not every party may be willing to cooperate.

- *Mediation models*: there are different stakeholders that are present within the Task Force that need to cooperate to decrease the food wasted, over the whole food chain but also on the level of a household. Not all stakeholders may have a positive attitude towards the reduction of the food waste on the level of a household. It may be possible that reducing the waste of food on the level of a household is not of interest. A supermarket for example may increase its turnover if more food is wasted by households. Solving the problem may require the parties to understand each other's perspectives. The resulting System Dynamics model can be adjusted to function as a communication tool between the parties. The System Dynamics model may also visualise the potential impact of such a stakeholder that is not interested.

  Before the model is able to function as a *Mediation model*, adaptions of the current System Dynamics model are needed. The model should make clear what the effects are from certain stakeholders, visualising the actual effect of these stakeholders may enable them to cooperate. The model should also make clear that cooperation is needed to effectively reduce the waste of food. This can be done within the consumer stage but also within the whole food supply chain, which puts the actions of stakeholders in perspective.

7.4 Conclusions

The results from previous chapter are considered in this chapter. The results are reviewed from a broader perspective. As mentioned in previous chapters, there are uncertainties regarding the value of the parameters and relations within the System Dynamics model and the potential effects of the interventions. Therefore, precise predictions on the effect of interventions are not possible. However, the results provide a rough indication of the possible effect. Besides, the insights regarding the behaviour of the system may interesting and important to consider.

Recently, a Task Force is created that focuses on the decrease of the waste of food within the Netherlands over the whole Food Supply Chain. This Taskforce focuses thus also on the waste of food on the level of a household. Within this Task Force, important stakeholders are included that are needed for reducing the waste of food within households.

The following insights are derived based upon reviewing the results of the simulation from a broader perspective. Within the Netherlands, the households are a major contributor to the waste of food. Regarding the total food waste over the whole food supply chain, households are estimated to be accountable for 30% of all the food wasted within the Netherlands. Within the Netherlands, affecting the waste of food generated by households could decrease the avoidable food waste by millions of kilogrammes. Therefore, the advice is that the Task Force should consider interventions that focus on reducing the waste of food wihtin households.

The following insight is derived based on the results of the simulation: households should 'knowhow' to reduce the waste of food, but perhaps more importantly, they need to be 'willing'. Considering intervention strategies where these two aspects are considered may have an enlarging effect. The combined results of these interventions may be bigger than the individual effects accumulated during the simulations. A synergy results. Another aspects that arose during the combined simulations is that combining two interventions that do not affect the 'willingness' within a household but only affect the 'knowhow' within a household did reduce each other's effect. Combining multiple interventions that focus on the 'willingness' within a household resulted not in an relatively small effect. Focusing on the 'knowhow' is needed for effective interventions strategies. Combining multiple interventions should focus on both aspects to realise a synergy and to be successful. Based upon the results of the combined simulations, the advice for the Task Force is to consider the 'willingness' within a household. Focusing interventions effectively may have an enlarging effect and is interesting to further consider.

The possible purposes of the model for the Task Force are reviewed in this chapter. Based upon it is concluded that there are two important type of models that can result: an *Advisory models* and *Mediation model.* Before the resulting System Dynamics model can function as one of these models adaptions are needed.

8 Conclusions

This chapter answers the research questions defined in chapter 1. The conclusions regarding these research questions are given in section 8.1. Following this, a discussion is presented in section 8.2 in which the contribution to science is argued, a reflection on the process is elaborated on, and the limitations of the research methods are discussed. Recommendations for further research are given in the last section of this chapter, in section 7.3

8.1 Addressing the research questions

This section first answers the main research questions. Following this, an overview of the conclusions per research question is elaborated on. This study addressed the following main research question:

"What are the possible effects of interventions on the food waste related behaviour on the level of a household?"

The simulated effects of the interventions are uncertain and cannot be taken for granted. However, they provide a rough indication on the potential effect of these interventions. Based upon the results of the simulation, it is assumed that households are responsible for 22% to 31% of the total food wasted within the Netherlands. Therefore, affecting the food waste generated by households is considerable. The process in which food is wasted is fragmented. To effectively reduce the waste of food within households, multiple interventions should focus on different phases within this process. But, two aspects are important to consider when interventions are combined. An intervention strategy should focus on the 'knowhow' and on the 'willingness' within a household. Focusing on both aspects results in a synergy. The combined effect of the intervention strategy is bigger than the individual effects accumulated.

8.1.1 Part i: conceptualisation

"What are the main mechanisms resulting in the food waste behaviour on the level of a household?"

Based upon the analysis of the qualitative model, the following behaviour regarding the food waste within a household can be identified: households tend to plan to buy more food than actually needed. While making a planning, a household partly considers the food and leftovers that are stored. Households tend to buy even more food than they initially planned to do. The bought food is stored, however, more food will be stored than needed for the preparation. This will result in food that is stored for longer periods. Storing food for longer periods may result in food waste due to the moulding process. Besides, food may be discarded because it has reached the use by or best before date. Furthermore, households tend to make more food than actually needed. The actual food that is consumed differs from the food that is prepared. This is caused by the preferences and hectic lifestyles that are present within households and because more food is prepared than actually needed. This difference between the food prepared and consumed results in edible food leftover, of which a part is thrown away directly after a meal and ends up as food waste. The resulting edible food leftover is stored, after which it is partly eaten and partly thrown away, ending up as wasted food due to the moulding process of the leftovers.

Based upon the qualitative model, multiple feedback mechanisms are identified. A difference is made between feedback mechanisms regarding the storage of food and leftovers and feedback mechanisms regarding the waste of food. The stored food and leftovers are partly considered while a household plans the food that needs to be bought. Households with a high moral attitude regarding the waste of food are more willing to change their planning and preparing behaviour. This behavioural change results in less planned and prepared food. All the feedback mechanisms are assumed to be negative. The combined effect of these mechanisms is assumed to have a balancing effect on the food waste system; an equilibrium of the generated waste of food is approached.

This study tried to capture all the relevant factors that are needed to represent the waste of food generated on the level of a household. However, multiple definitions of food waste are used in the scientific field of food waste on the level of a household. The use of multiple definitions results in different ways of measuring and presenting food waste, which troubles the creation of the causal relation diagram. Assumptions and simplifications are inevitable, which results in a high aggregation level of the causal relation diagram. This implies that simulating interventions based upon this causal relation diagrams generates general effects of the interventions on the food waste on the level of a household.

"How can the generation of food on the level of a household be influenced from a multi-actor perspective?"

The following interventions are identified:

- *FridgeCam*; this technical intervention is from an company perspective. It increases the degree that a household can check their inventory while making a planning. Besides, this intervention affects the usage of a shopping list. Applying this intervention enables a household to estimate the food needed better while determining the amount of food planned.
- *No discount and economies of scale*; this is technical intervention from a supermarkets perspective. If supermarkets remove their products with an economic of scale discount and not offer other type of discounts decreases the extra unnecessary food bought by a household.
- *Spoilage knowledge campaign*; this is a social intervention from a governmental perspective. Increasing the knowledge regarding the spoilage within a household encourages people to trust their own instincts. Thereby food may be stored and used within a longer time frames, which makes it more likely that the stored food will not be thrown away.
- *Awareness consequences food waste campaign*; this is a social intervention from a governmental perspective. Increasing the knowledge regarding the consequences of wasting food is assumed to results in an behavioural change regarding the planning and preparing behaviour within a household. Less food is planned to be bought and less food is prepared, both resulting in less food thrown away.

Applying an intervention within a households results in a temporary feedback loop. An intervention affects the waste of food within a household, which results in a lower effect of the intervention itself. The temporary feedback loop has a negative nature, resulting in more balancing loops present within the causal relation diagram identified in research question.

Quantitative research relating the effect of interventions is limited. As a result only qualitative relations can be defined. Combined with the high levelled aggregation level of the causal relation diagram; the System Dynamics simulation method is noted as a suitable method for simulating the potential effects of the interventions.

8.1.2 Part ii; specification & Interpretation

"What are the effects of interventions on the waste food within households?"

The System Dynamics model is used to simulate the effects that are identified during the second research question. Based upon the results of the individual simulation, it is concluded that the waste of food on the level of a household is fragmented, the waste of food is caused in multiple phases. Interventions do not have a big individual effect on the avoidable food waste. Reducing the waste of food effectively demands multiple interventions affecting multiple phases within the food waste system on the level of a household, often from multiple actors perspectives. An enlarging effect is identified during the combined model simulation. Based upon this effect, it is concluded that households should know how to reduce the waste of food (i) and household should be willing to reduce the waste of food (ii). Combining interventions that effect both aspects; the 'knowhow' and 'willingness' enlarged each other effect on reducing the waste of food. The intervention strategy ''No discount and economies of scale intervention'' combined with the 'Knowledge on consequences food waste campaign' is tested on its robustness by changing important uncertain parameters. This did not affect its behaviour. Only the effect on the reduction of the waste of food varied. Based upon the robustness analysis, it can be concluded that the behaviour of the intervention is robust, but that the actual size of the effect on the waste of food generated by the household is uncertain. The actual effects given by the simulation cannot therefore be taken for granted and should be considered carefully.

8.1.3 Part iii: integration

The following insights are derived based upon reviewing the results of the simulation from a broader perspective. Within the Netherlands, the households are a major contributor to the waste of food. Regarding the total food waste over the whole food supply chain, households are estimated to be accountable for 30% of all the food wasted within the Netherlands. Within the Netherlands, affecting the waste of food generated by households could decrease the avoidable food waste by millions of kilogrammes. Therefore, the advice is that the Task Force should consider interventions that focus on reducing the waste of food wihtin households.

As mentioned before, focussing on the 'willingness' and on the 'knowhow' within a household resulted in a synergy. However, combining interventions that did not include both aspects resulted in counterproductive effects. Combining multiple interventions that focused on the 'willingness' only within a household resulted in an relatively small effect on reducing the waste of food. Based upon relatively small impact, it can be concluded that for effectively reducing the waste of food, the 'knowhow' should be considered. Combining interventions that both focus on the 'knowhow' resulted in a lower accumulated effect than accumulating the effects individually together. A decreasing effect resulted. Based upon the decreasing effect, it can be concluded that for effectively reducing the waste of food, the 'knowhow' should be considered. Based upon the possible effects of combining interventions, it is concluded that the Task Force should consider the 'willingness' and the 'knowhow' within a household.

8.2 Discussion

This section reflects on this study. The contribution to science is this study is discussed in sub-section 8.2.1. The limitations of this study are considered in sub-section 8.2.2. Partly based upon the limitations elaborated on in this section, topics for further research are given in next section.

8.2.1 Contribution to science

The contribution of this study is discussed in this sub-section. Besides filling the knowledge gaps defined in the introduction by providing an overview of the factors and the causal relations between those factors that explain the generation of food waste behaviour on the level of a household (i), an overview of interventions that can affect this food waste behaviour (ii), and potential effects of these interventions on the waste of this food by means of a simulation System Dynamics model (iii). Interesting insights are derived based upon the results of these simulations. The contribution to science is twofold; this study aimed to incorporate causality while investigating food waste and this study introduced a simulation study regarding the waste of food on the level of a household.

Causality perspective: this study incorporated causality regarding the investigating the waste of food on the level of a household. Causal relation diagrams are identified, resulting in a simplified overview of related factors that are needed to generate the food waste behaviour on the level of a household. Little is known on the mechanisms underlying the waste of food and this study aimed at approaching understanding these mechanisms by incorporating causality while analysing the system. Even though the empirical research towards the exact causal mechanisms is lacking, this study is able to identify the relations needed for generating the desired behaviour by means of educated guesses, resulting in interesting underlying causal mechanisms. Based upon these mechanisms interesting insights are derived.

Simulation perspective: approaching the causality within enabled the use of a simulation method to present the food waste system on the level of a household. This study aimed to simulate the effects of interventions on waste of food. This study illustrated the potential of using simulation models regarding this field of science. Using a simulation approach to simulate the food waste behaviour and the potential effects of interventions on this behaviour results to interesting insights.

8.2.2 Limitations of this study

The limitations of this study are considered in this sub-section. These limitations are discussed per chapter. The resulting limitations are partly considered during next section, during the topics for further research.

The conceptualisation of the food waste system was limited by the available data regarding the factors that are responsible for the generation of food waste within a household. Regarding the literature available on these factors wide variety of definitions of food waste on the level of a household is used, which result in a wide variety of measuring methods of food waste. An ambiguous domain of food waste makes comparing food waste studies hard to do (Koivupuro et al., 2012; Parfitt et al., 2010; Silvennoinen et al., 2014). Also, the scope of this study has implications; this study focusses on the last stage of the Food Supply Chain, important relations or effects may be left out. Due to a lack of factors and data, no distinction between households and types of food are made, resulting in a high aggregation level. Such a high aggregation level results in results that are uncertain and not applicable for specific households and types of food. The result of these limitations is that the conceptualisation of the food waste system resulted in a causal relation diagram with multiple uncertain factors with a high aggregation level.

During the intervention analysis, the changeable parameters and relevant actors are combined to determine possibilities regarding the interventions. This overview of possibilities is limited due to the limited number of actors and changeable parameters defined in previous chapter. Increasing both would increase the quality of the overview. The available scientific data also limited the review of possible interventions. Most interventions are suggestions and data regarding the effect of these interventions are lacking. The result of these limitations is that promising interventions may not be considered.

During the data gathering and model building a lack of data resulted. Regarding the fact that causality is almost not considered in the field of food waste on the level of a household, assumptions regarding the parameter values and relation between the variables within the System Dynamics model had to be made; the precise way in which the variables within the system do influence each other causally is often uncertain. Empirical research is lacking (Roodhuyzen et al, 2017). These assumptions resulted in uncertain values and relations, and thereby in an uncertain System Dynamics model.

A variety of static and dynamic tests are performed. But not all were possible due to the uncertain nature of the System Dynamics model. These model are hard to validate and comparing the model with actual data was hard due to the use of multiple definitions used in the scientific field of food waste. Besides, the uncertainties surrounding the results of the System Dynamics model also influenced comparing the results with real world data.

Limitations during the model use are the credibility of the results of the simulations. The results of the model use cannot be taken for granted. The effects of the interventions are assumed due to a lack of data. As mentioned before, the System Dynamics has also a high aggregation level resulting in hard to interpret effects of the simulations. There are too much uncertainty regarding the results of the model and therefore the results of the simulation should be taken carefully into account. No actual impacts of the effect regarding the simulated interventions can be derived. However, the behaviour of the system is interesting to consider. The underlying mechanisms are meaningful and insights can be derived. The enlarging and decreasing effect of interventions are insightful.

8.3 Recommendation for further research

This section elaborates on the recommendation for further research. A multitude of new research possibilities arose from this research and the most important topics are discussed in this section.

- This study illustrated the possible effects of combining interventions on reducing the waste of food within a household. However, the underlying mechanism are partly dependent on assumptions and further research could investigate the underlying assumptions and to quantify its effect. The underlying mechanisms could be tested, to what degree do households change their planning and preparing behaviour, knowing that they waste food and what is the effect of the moral attitude within a household.
- As mentioned in previous sub-section, data regarding the interventions on reducing the waste of food within a household is lacking. Many more interventions are possible and the actual effects of these interventions are not recorded or documented. An interesting topic would be the research to actual effects of interventions and investigating more interventions from more actors.
- Interesting mechanisms are identified by designing a causal relation diagram on the level of a household regarding the waste of food. As mentioned in previous section, a limitation of this study is the scope considered during this study. During this study only the households within the consumer stage are considered of the Food Supply Chain. Investigating the causality within other stages may also result in interesting insights. More so, investigating the causal relations over the whole Food Supply Chain, that may not be known beforehand. Resulting in unexpected effects that are important to consider.
- In this study a System Dynamics approach is used. Dependant on the available data in the future regarding the waste of food on the level of a household, other modelling techniques are applicable like Agent-Based Simulation. Combinations of multiple simulation techniques are also interesting to consider since within the food waste system on the level of a household since it is better to represent the reality of the food waste system.

References

Abdulla, M., Martin, R. C., Gooch, M., & Jovel, E. (2013). The importance of quantifying food waste in Canada. *Journal of Agriculture, Food Systems, and Community Development*, *3*(2), 137–151.

Abeliotis, K., Lasaridi, K., & Chroni, C. (2014). Attitudes and behaviour of Greek households regarding food waste prevention. *Waste Management & Research*, *32*(3), 237–240. http://doi.org/10.1177/0734242X14521681

Andersen, D. F., Richardson, G. P., & Vennix, J. a M. (1997). Group Model Building : Adding More Science to the Craft. *System Dynamics Review*, *13*(2), 187–201. http://doi.org/10.1002/(SICI)1099-1727(199722)13:2<187::AID-SDR124>3.0.CO;2-O

Aschemann-Witzel, J., de Hooge, I., Amani, P., Bech-Larsen, T., & Oostindjer, M. (2015). Consumer-Related Food Waste: Causes and Potential for Action. *Sustainability*, *7*(6), 6457–6477. http://doi.org/10.3390/su7066457

Barr, S. (2007). Factors Influencing Environmental Attitudes and Behaviors. *Environment and Behavior*, *39*(4), 435–473.

Beretta, C., Stoessel, F., Baier, U., & Hellweg, S. (2013). Quantifying food losses and the potential for reduction in Switzerland. *Waste Management*, *33*(3), 764–773. http://doi.org/10.1016/j.wasman.2012.11.007

Blichfeldt, B. S., Mikkelsen, M., & Gram, M. (2015). When it Stops Being Food. *Food, Culture & Society*, *18*(1), 89–105. http://doi.org/10.2752/175174415X14101814953963

Bonabeau, E. (2002). Agent-based modeling: methods and techniques for simulating human systems. *Proceedings of the National Academy of Sciences*, *99*(suppl. 3), 7280–7287. http://doi.org/10.1073/pnas.082080899

Borshchev, A., & Filippov, A. (2004). From System Dynamics to Agent Based Modeling: *In Proceedings of the 22nd International Conference of the System Dynamics Society*, *22*.

Brown, T., Hipps, N. A., Easteal, S., Parry, A., & Evans, J. A. (2013). Reducing domestic food waste by lowering home refrigerator temperatures. *International Journal of Refrigeration*, *40*, 246–253. http://doi.org/10.1016/j.ijrefrig.2013.11.021

Bucci, M., Calefato, C., Colombetti, S., Milani, M., & Montanari, R. (2010). Fridge Fridge on the Wall: What Can I Cook for Us All?: An HMI Study for an Intelligent Fridge. *Proceedings of the International Conference on Advanced Visual Interfaces*, 415. http://doi.org/10.1145/1842993.1843093

Buzby, J. C., & Hyman, J. (2012). Total and per capita value of food loss in the United States. *Food Policy*, *37*(5), 561–570. http://doi.org/10.1016/j.foodpol.2013.04.003

Canali, M., Amani, P., Aramyan, L., Gheoldus, M., Moates, G., Östergren, K., … Vittuari, M. (2016). Food Waste Drivers in Europe, from Identification to Possible Interventions. *Sustainability*, *9*(1), 37. http://doi.org/10.3390/su9010037

Cappellini, B., & Parsons, E. (2012). Practising Thrift At Dinnertime: Mealtime Leftovers, Sacrifice And Family Membership. *Sociological Review*, *60*(2), 121–134. http://doi.org/10.1111/1467-954X.12041

Cox, J., Giorgi, S., Sharp, V., Strange, K., Wilson, D. C., & Blakey, N. (2010). Household waste prevention – a review of evidence. *Waste Management & Research*, *28*(3), 271–273. http://doi.org/10.1177/0734242X10361506

Delley, M., & Brunner, T. A. (2017). Foodwaste within Swiss households: A segmentation of the population and suggestions for preventive measures. *Resources, Conservation and Recycling*, *122*(December 2012), 172–184. http://doi.org/10.1016/j.resconrec.2017.02.008

Delley, M., & Brunner, T. A. (2017). Foodwaste within Swiss households: A segmentation of the population and suggestions for preventive measures. *Resources, Conservation and Recycling*, *122*(December 2012), 172–184. http://doi.org/10.1016/j.resconrec.2017.02.008

Evans, D. (2012). Beyond the Throwaway Society: Ordinary Domestic Practice and a Sociological Approach to Household Food Waste. *Sociology*, *46*(1), 41–56. http://doi.org/10.1177/0038038511416150

Evans, D. (2011). Blaming the consumer – once again : the social and material contexts of everyday food waste practices in some English households. *Critical Public Health*, *21*(4), 429–440. http://doi.org/10.1080/09581596.2011.608797

Farr-Wharton, G., Foth, M., & Choi, J. H. J. (2014). Identifying factors that promote consumer behaviours causing expired domestic food waste. *Journal of Consumer Behaviour*, *13*, 393–402. http://doi.org/10.1002/cb

Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., … Zaks, D. P. M. (2011). Solutions for a cultivated planet. *Nature*, *478 (7369)*, 337–342. http://doi.org/10.1038/nature10452

Fonseca, J. R. S. (2014). A Latent Class Model to discover Household Food Waste Patterns in Lisbon City in Support of Food Security, Public Health and Environmental Protection. *International Journal on Food System Dynamics*, *4*(3), 184–197.

Forrester, J. W. (1992). Policies, decisions and information sources for modeling. *European Journal of Operational Research*, *59*(1), 42–63. http://doi.org/10.1016/0377-2217(92)90006-U

Ganglbauer, E. (2013). Towards food waste interventions: an exploratory approach. *ACM Conference on Pervasive and Ubiquitous Computing*, 337–342. http://doi.org/10.1145/2494091.2501086

Ganglbauer, E., Fitzpatrick, G., & Comber, R. (2013). Negotiating food waste: Using a practice lens to inform design. *ACM Transactions on Computer-Human Interaction (TOCHI)*, *20*(2), 1–25. http://doi.org/10.1145/2463579.2463582

Garrone, P., Melacini, M., & Perego, A. (2014). Opening the black box of food waste reduction. *Food Policy*, *46*, 129–139. http://doi.org/10.1016/j.foodpol.2014.03.014

Gille, Z. (2012). From Risk To Waste: Global Food Waste Regimes. *Sociological Review*, *60*(S2), 27–46. http://doi.org/10.1111/1467-954X.12036

Gjerris, M., & Gaiani, S. (2013). Household food waste in Nordic countries : Estimations and ethical implications. *Etikk I Praksis. Nordic Journal of Applied Ethics*, *7*(1), 6–23. http://doi.org/10.5324/eip.v7i1.1786

Göbel, C., Langen, N., Blumenthal, A., Teitscheid, P., & Ritter, G. (2015). Cutting food waste through cooperation along the food supply chain. *Sustainability (Switzerland)*, *7*(2), 1429–1445. http://doi.org/10.3390/su7021429

Graham-Rowe, E., Jessop, D. C., & Sparks, P. (2014). Identifying motivations and barriers to minimising household food waste. *Resources, Conservation and Recycling*, *84*, 15–23. http://doi.org/10.1016/j.resconrec.2013.12.005

Graham-Rowe, E., Jessop, D. C., & Sparks, P. (2015). Predicting household food waste reduction using an extended theory of planned behaviour. *Resources, Conservation and Recycling*, *101*, 194–202. http://doi.org/10.1016/j.resconrec.2015.05.020

Griffin, M., Sobal, J., & Lyson, T. A. (2009). An analysis of a community food waste stream United States Department of Agriculture. *Agriculture and Human Values*, *26*, 67–81. http://doi.org/10.1007/s10460-008-9178-1

Halloran, A., Clement, J., Kornum, N., Bucatariu, C., & Magid, J. (2014). Addressing food waste reduction in Denmark. *Food Policy*, *49*, 294–301. http://doi.org/10.1016/j.foodpol.2014.09.005

Hebrok, M., & Boks, C. (2017). Household food waste: Drivers and potential intervention points for design – An extensive review. *Journal of Cleaner Production*, *151*, 380–392. http://doi.org/10.1016/j.jclepro.2017.03.069

Jagau, H. L., Vyrastekova, J., Luis, H., & Jana, J. (2017). British Food Journal For Authors Behavioral approach to food waste: an experiment. *British Food Journal*, *119*(4). http://doi.org/10.1108/BFJ-05-2016-0213

Jörissen, J., Priefer, C., & Bräutigam, K. R. (2015). Food waste generation at household level: Results of a survey among employees of two European research centers in Italy and Germany. *Sustainability (Switzerland)*, *7*(3), 2695–2715. http://doi.org/10.3390/su7032695

Koivupuro, H., Hartikainen, H., Silvennoinen, K., Katajajuuri, J., Heikintalo, N., Reinikainen, A., & Jalkanen, L. (2012). Influence of socio-demographical , behavioural and attitudinal factors on the amount of avoidable food. *International Journal of Consumer Studies*, *36*(2), 183–191. http://doi.org/10.1111/j.1470-6431.2011.01080.x

Kummu, M., de Moel, H., Porkka, M., Siebert, S., Varis, O., & Ward, P. J. (2012). Lost food, wasted resources: Global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. *Science of the Total Environment*, *438*, 477–489. http://doi.org/10.1016/j.scitotenv.2012.08.092

Lipinski, B., Hanson, C., Lomax, J., Kitinoja, J., Waite, R., Searchinger, T. (2013). Reducing Food Loss and Waste (Working Paper), 1–40.

Mayer, I., Van Daalen, E., & Bots, P. (2004). *Perspectives on Policy Analysis: A Framework for Understanding and Design*. *International Journal of Technology Policy and Management* (Vol. 4). http://doi.org/10.1504/IJTPM.2004.004819

Meer huishoudens langdurig onder lage-inkomensgrens in 2015. (2017, 2, 8). Retrieved from: https://www.cbs.nl/nl-nl/nieuws/2017/06/meer-huishoudens-langdurig-onder-lage-inkomensgrens-in-2015

Muir, J. F., Pretty, J., Robinson, S., Thomas, S. M., & Toulmin, C. (2010). Food security: the challenge of feeding 9 billion people. *Science*, *327*(5967), 812–818.

Parfitt, J., Barthel, M., & Macnaughton, S. (2010). Food waste within food supply chains: quantification and potential for change to 2050. *Philosophical Transactions of the Royal Society of London*, *365*((1554)), 3065–3081. http://doi.org/10.1098/rstb.2010.0126

Parizeau, K., Massow, M. Von, & Martin, R. (2015). Household-level dynamics of food waste production and related beliefs , attitudes , and behaviours in Guelph , Ontario. *Waste Management*, *35*, 207–217. http://doi.org/10.1016/j.wasman.2014.09.019

Principato, L., Secondi, L., Alberto, C., Secondi, L., & Pratesi, C. A. (2015). Reducing food waste : an investigation on the behaviour of Italian youths. *British Food Journal*, *117*(2), 731–748. http://doi.org/10.1108/BFJ-10-2013-0314

Quested, T. E., Marsh, E., Stunell, D., & Parry, A. D. (2013). Spaghetti soup : The complex world of food waste behaviours. *Resources, Conservation & Recycling*, *79*, 43–51. http://doi.org/10.1016/j.resconrec.2013.04.011

Quested, T. E., Parry, A. D., Easteal, S., & Swannell, R. (2011). Food and drink waste from households in the UK. *Nutrition Bulletin*, *36*(4), 460–467. http://doi.org/10.1111/j.1467-3010.2011.01924.x

Reisinger, H., van Acoleyen, M., O'Connor, C., Hestin, M., Laureysens, I., Morton, G., Dolley, P., Nelen, D., and Vanderreydt, I. (2011). (2011). *Evolution of (bio-) waste generation/prevention and (bio-) waste prevention indicators*.

Roodhuyzen, D. M. A., Luning, P. A., Fogliano, V., & Steenbekkers, L. P. A. (2017). Putting together the puzzle of consumer food waste: Towards an integral perspective. *Trends in Food Science & Technology.*

Rutten, M. M. (2013). What economic theory tells us about the impacts of reducing food losses and/or waste: implications for research, policy and practice. *Agriculture & Food Security*, *2*(1), 13. http://doi.org/10.1186/2048-7010-2-13

Schader, C., Schmidt, U., & Brei, J. (2013). *Food Wastage Footprint: Full-cost accounting*.

Schneider, F. (2008). Wasting food – An insenstent behaviour. *Proc. Waste: The Social Context*, *8*, 1–10.

Schriber, T. J., Brunner, D. T., & Smith, J. S. (2012). How discrete-event simulation software works and why it matters. In *Proceedings of the 2012 Winter Simulation Conference* (p. 3). http://doi.org/10.1109/WSC.2012.6465271

Secondi, L., Principato, L., & Laureti, T. (2015). Household food waste behaviour in EU-27 countries: A multilevel analysis. *Food Policy*, *56*, 25–40. http://doi.org/10.1016/j.foodpol.2015.07.007

Sharp, V., & Wilson, D. C. (2010). Delivery and impact of household waste prevention intervention campaigns (at the local level). *Waste Management & Research*, *28*(3), 256–268. http://doi.org/10.1177/0734242X10361507

Sharp, V., & Wilson, D. C. (2010). Methods to monitor and evaluate household waste prevention. *Waste Management & Research*, *28*(3), 269–280. http://doi.org/10.1177/0734242X10361508

Silvenius, F., Grönman, K., Katajajuuri, J. M., Soukka, R., Koivupuro, H. K., & Virtanen, Y. (2014). The role of household food waste in comparing environmental impacts of packaging alternatives. *Packaging and Technology and Science*, *27*(4), 277–292. http://doi.org/10.1002/pts

Silvennoinen, K., Katajajuuri, J., & Hartikainen, H. (2014). Food waste volume and composition in Finnish households. *British Food Journal*, *116*(6), 1058–1068. http://doi.org/10.1108/BFJ-12-2012-0311

Soethoudt, H., Vollebreft, M., & Van der Burgh, M. (2012). *Monitor Voedselverspilling*.

Stancu, V., Haugaard, P., & Lähteenmäki, L. (2016). Determinants of consumer food waste behaviour: Two routes to food waste. *Appetite*, *96*, 7–17. http://doi.org/10.1016/j.appet.2015.08.025

Stefan, V., Herpen, E. Van, Alina, A., & Lähteenmäki, L. (2013). Avoiding food waste by Romanian consumers : The importance of planning and shopping routines. *Food Quality and Preference*, *28*(1), 375–381. http://doi.org/10.1016/j.foodqual.2012.11.001

Sterman, J. D. (2001). *Business dynamics: systems thinking and modeling for a complex world*. McGraw-Hill Higher Education.

Thyberg, K. L., & Tonjes, D. J. (2016). Drivers of food waste and their implications for sustainable policy development. *Resources, Conservation and Recycling*, *106*, 110–123. http://doi.org/10.1016/j.resconrec.2015.11.016

van Doornen, C. (2017). *Oplegnotitie Voedselverspilling bij huishoudens in Nederland in 2016*.

Verghese, K., Lewis, H., Lockrey, S., & Williams, H. (2015). Packaging's Role in Minimizing Food Loss and Waste Across the Supply Chain. *Packaging and Technology and Science*, *28*, 603–620. http://doi.org/10.1002/pts

Visschers, V. H. M., Wickli, N., & Siegrist, M. (2016). Sorting out food waste behaviour : A survey on the motivators and barriers of self-reported amounts of food waste in households. *Journal of Environmental Psychology*, *45*, 66–78. http://doi.org/10.1016/j.jenvp.2015.11.007

Vittuari, M., Politano, A., Gaiani, S., Canali, M., Azzurro, P., Elander, M., … Easteal, S. (2015). *Review of EU legislation and policies with implications on food waste* (FInal Repo). Retrieved from http://www.eu-fusions.org/index.php/download?download=161:review-of-eu-legislation-and-policies-with-implications-on-food-waste.

Whitehair, K. J., Shanklin, C. W., & Brannon, L. A. (2013). Written Messages Improve Edible Food Waste Behaviors in a University Dining Facility. *Journal of the Academy of Nutrition and Dietetics*, *113*(1), 63–69. http://doi.org/10.1016/j.jand.2012.09.015

Williams, H., Wikström, F., Otterbring, T., Löfgren, M., & Gustafsson, A. (2012). Reasons for household food waste with special attention to packaging. *Journal of Cleaner Production*, *24*, 141–148. http://doi.org/10.1016/j.jclepro.2011.11.044

WRAP. (2013). *Household Food and Drink Waste in the United Kingdom 2012*.

WUR. (2017). Dutch Taskforce connects initiatives against food waste. Retrieved from http://www.wur.nl/en/newsarticle/Dutch-Taskforce-connects-initiatives-against-food-waste.htm

Yamaguchi, K. (2017). *Principle of Accounting System Dynamics - Modeling Corporate Financial Statements*.

Young, W., Russell, S. V., Robinson, C. A., & Barkemeyer, R. (2016). Can social media be a tool for reducing consumers' food waste? A behaviour change experiment by a UK retailer. *Resources, Conservation and Recycling*, *117*, 9. http://doi.org/10.1016/j.resconrec.2016.10.016

Yücel, G., & van Daalen, E. (2009). An Objective-Based Perspective on Assessment of Model-Supported Policy Processes. *Journal of Artificial Societies and Social Simulation*, *12*(4), 3.

Appendix A: System Analysis

This appendix elaborates on the qualitative analysis according to chapter 2. Per phase, the factors identified by Roodhuyzen et al. (2017) needed to generate the phase specific behaviour are transformed into measurable variables and extra variables that are needed are added, finally resulting in multiple causal relation diagrams. Per phase, a causal relation diagram is created phase. The resulting causal sub-diagrams are summarized and combined into one causal relation diagram that represent the food waste system on the level of a household in chapter 2.

Planning

In this sub-section is structured as follows: first the factors identified by the systematic literature review by Roodhuyzen et al. (2017) will be given. The factors that are considered during this study are elaborated on in the first part. Secondly, the factors are discussed that are not considered. In the last part of this section, based upon the previous identified factors, combined with the main process variables, extra variables needed, and the food waste variables causal relation diagrams are identified.

Factors identified by Roodhuyzen et al. (2017)

All the factors that are connected to planning phase within the process of food waste will be taken into account in this section. Important is the connection to the amount of food that is being planned by a household. The "Planned amount of food needed for a household will be the central factor in this section. Factors that are considered in this study:

- **Planning routines** (routines regarding planning of shopping and meals) were significantly negatively correlated with food waste. Planning routines can be divided up into three practices: inventory checking, planning meals in advance, and using a shopping list. This factor has been studied by Stefan et al. (2013).

  This factor has been derived by Gjerris & Gaiani (2013) who argues that with poor planning overall, which estimates to be responsible for the increase of wasted food. This factor has also been derived by Principato et al. (2015), and Williams et al. (2012).
- **Using a shopping list** was negatively correlated with the amount of food that is being wasted. It has been assumed that better planning would lead to a better approximation of the amount of food needed and thereby on the reduction of food that will be thrown away (Jörissen et al., 2015). This can be explained by the fact that people who use a shopping list will not buy unnecessary things that they already have or do not need at all. That using a shopping list decreases the amount of wasted food has also been studied by Ganglbauer et al. (2013), Quested et al. (2013), and Fonseca (2014).

  Graham-Rowe et al. (2014) also derived the factor not using a shopping list as responsible factor for a poor planning (failing to compile or comply with a shopping list). This factor has also been derived by Parfitt et al. (2010), and Principato et al. (2015).
- **Inventory checking**. Checking levels of food in cupboards and fridge prior to shopping is suggested to be behaviour that contributes to food waste reduction. There is a negative causal relation with food waste. The accuracy of the amount of food that needs to be bought increases while taking into account what is already available in house. This factor has been studied by Quested et al. (2013), Ganglbauer et al. (2013), and Farr-Wharton et al. (2014).

  This factor has also been derived by Parfitt et al. (2010), Principato et al. (2015), and Graham-Rowe et al. (2014). Inventory checking fails when no check stocks in cupboards, fridges and freezers prior to shopping takes place.
- **Over planning.** The social relations (family context) in which food practices are located may lead to food waste (e.g. when food providers balance out concerns about the family eating 'properly' with concerns about the family eating at home or at all, more food is provisioned than consumed in reality). This factor has been studied by Evans (2012).

The following factors are not considered during this study:

- **Dietary transition.** Purchasing food with the intention to eat healthily, and subsequently failing to do so is correlated with the amount of wasted food. This factor has been studied by Evans (2012). Respondents with a person on a special diet in their household were more likely to see food waste reduction as a very convenient household strategy was studied by Parizeau et al. (2015). This factor has also been studied by Evans. (2011). Dietary transition has also been derived by Parfitt et al. (2010), Abdulla et al. (2013), Buzby & Hyman (2012), and Parizeau et al. (2015). No distinction has been made between different types of food that have been wasted due to the aggregation level of the qualitative model, therefore it has no use to take this variable into account.
- **Planning meals in advance** is estimated to reduce the amount of wasted food (Quested et al., 2013). It has been assumed that planning your meals in advance would increase the accuracy for estimated food needed for a household. This factor has been studied by Quested et al. (2013). This factor has also been derived factors by Graham-Rowe et al. (2014), Jörissen et al. (2015), and Parfitt et al. (2010). This factors is not considered because it shares a lot of characteristics with the factors over planning. Planning meals in advance results in a lower degree of over planning, however, more factors might be responsible that are left out.

Designing a causal relation diagram
The following variables are identified:

Main process variables and variables from other phases.

- **Amount of planned food**. This is the variable that is central within the planning phase. It is the amount of food needed minus the *Amount of stored food* and the *Amount of leftovers stored*. This variable can be measured by the amount of kilograms food planned per week per household (*Kg/week/household*).

- **Amount of bought food**. This is the variable that is central within the purchasing phase. The *Amount of planned food* will be used as input for the *Amount of bought food*. The higher the *Amount of planned food*, the higher the *Amount of bought food*, which results in a positive causal relation. This variable can be measured by the amount of kilograms food bought per week per household (*Kg/week/household*).

- **Amount of stored food.** This is the variable that is a central variable in the storing phase. This variable is needed in order to estimate the amount of food available within a household. The more food is stored the higher the *Amount of stored food*, therefore a positive causal relation is present. This variable can be measured by the amount of kilograms food stored per week per household (*Kg/week/household*).

- **Amount of leftovers stored.** This is the variable that is a central variable in the leftover phase. This variable is needed in order to estimate the amount of food available within a household. The more leftovers are stored, the higher the amount of stored food, therefore a positive causal relation is present. This variable can be measured by the amount of kilograms food stored per week per household (*Kg/week/household*).

Variables based upon factors identified by Roodhuyzen et al. (2017)

- **Degree of inventory checking**. The factor *Inventory checking* can be transformed into the variable Degree of inventory checking. More inventory checking will lead to a higher *Perceived amount of inventory*. Therefore it has a positive causal relation. This variable can be measured in a low amount of checking and a high amount of checking, represented by a fraction between the 0 and 1. A degree of inventory checking of 80% can be translated as follow:

- **Degree of over planning.** This variable will be used for representing the factor *Degree of over planning*. It is connected to the *Amount of planned food*. More purposely over planning will lead to a higher *Amount of planned food*, resulting in a positive causal relation. The amount of purposely over planning can be expressed as an fraction between 0 and 1, where 10% means that instead of 100 kg food is being bought that week, 110kg food will be bought that week by the household.

- **Degree of using shopping list.** The factor using a shopping list can be transformed into this variable. Using more shopping lists will increase the accuracy of the planned food regarding the *Amount of food needed for a household* and thereby decrease the *Amount of planned food*, which results in a negative causal relation between the Usage of shopping list and the *Amount of planned food*. The *Degree of using shopping list* can be expressed as an fraction between 0 and 1.

Extra variables needed in order to generate the planning behaviour:

- **Perceived amount of inventory.** This variable is needed to connect the variables *Amount of stored food*, *Amount of leftovers stored*, and the *Degree of inventory checking*. There is a negative causal relation between this variable and the *Amount of planned food*; if there is more food available within a household, the *Amount of planned food* will decrease. This variable can be measured by the amount of kilograms food stored per week per household (*Kg/week/household*).

- **Average amount of food needed for a household.** The amount of food can will deducted within the consumption phase of the process. This variable is needed as input for the *Amount of planned food*, which can be represented by a positive causal relation. A higher *Average amount of food needed for a household* results in a higher *Amount of planned food*. This variable can be measured by the amount of kilograms food consumed per week per household (*Kg/week/household*).

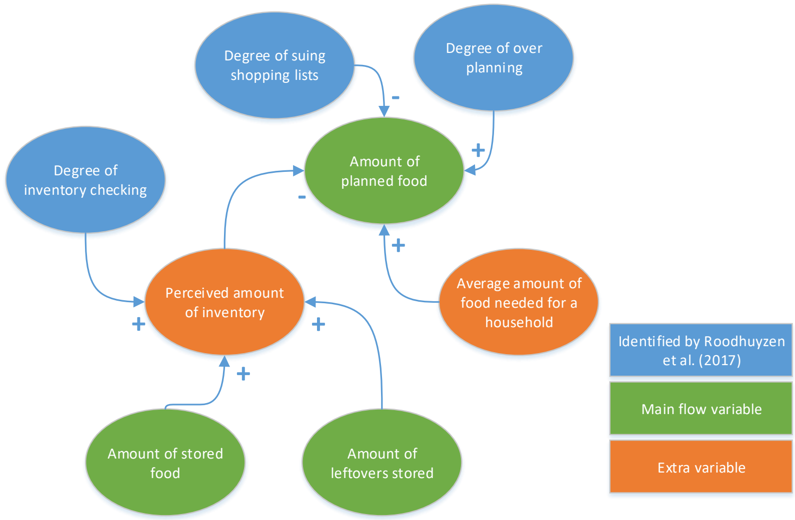


Figure 64: causal loop diagram for the planning phase

Purchasing

In this sub-section is structured as follows: first the factors identified by the systematic literature review by Roodhuyzen et al. (2017) will be given. The factors that are considered during this study are elaborated on in the first part. Secondly, the factors are discussed that are not considered. In the last part of this section, based upon the previous identified factors, combined with the main process variables, extra variables needed, and the food waste variables causal relation diagrams are identified.

Factors identified by Roodhuyzen et al. (2017)
All the factors that are connected to purchasing phase within the process of food waste will be taken into account in this section. Important is the connection to the amount of food that is being planned and stored by a household. The "*Amount of bought food*" for a household will be the central factor in this section. Factors that are considered in this study:

- **Frequency of shopping**. It is estimated to be correlated with the amount of food wasted. Planning to purchase food at relatively fixed intervals, buying roughly the same things each time) which are easily thrown out of balance by the rather more fluid nature of the ways in which lives are lived, studied by Evans (2011) and Evans (2012). Buying large quantities for the whole week results in suboptimal matching with daily needs and a higher likelihood of spoilage of particularly perishable products. Moreover, buying large quantities can be linked to the wish to minimise inconveniences and to avoid untimely trips to the shops, which can result in stocking up more food than needed was also studied by Jörissen et al. (2015) and Williams et al. (2012).
- **Price awareness.** A higher level of household price awareness (measured in terms of caring about the ratio price/kg and usage of discount coupons) was associated with less food waste. This factor has been studied by Williams et al. (2012). It has been studied that households that did not often purchase food offers and discounted food products were associated with significantly more food waste. This would indicate that people who tend to buy cheaper foods also value food more and waste less of it (Koivupuro et al., 2012). (Jörissen et al., 2015) also studied that buying discounted products associated with slightly less food waste in this and also other studies. This is explained by the fact that people tending to buy discounted products have a higher regard for food because they cannot afford to waste money. Parizeau et al. (2015) have also studied this factor.

  Parizeau et al. (2015) adds the following to this derived factor: households concerned with finding low food prices produced less avoidable waste. Higher household price awareness was associated with lower food waste has been derived by Silvennoinen (2014) and Jörissen et al. (2015).
- **Packaging of the products.** It is estimated to be connected to the economics of scale; household that believed that buying too large packages was a reason for wasting food sometimes or most of the time were associated with significantly higher levels of food waste. Most of the times, the needed package was not available, ending up in buying a too big package or that to big packages were cheaper per Kg. This has been studied by Koivupuro et al. (2012) and this studied factors has also been backed up by Ganglbauer et al. (2013), Jörissen et al. (2015), Evans (2011), and Evans. (2012).

  Other authors who also derived this factor are Koivupuro et al. (2012), Gjerris & Gaiani (2013), Jörissen et al. (2015), Halloran et al. (2014), Silvenius et al. (2012), and Williams et al. (2012).
- **Overbuying**. Routines of household food provisioning and the contingencies of everyday life; routinely purchase more food than will be eaten will result in too much food that not will be eaten and thus food waste. This factor has been studied by Evans (2012). Ganglbauer et al. (2013); Buying more than intended or really needed, as a consequence of Economy of scale", i.e. big quantities being less expensive compared to small ones, leading to buying too much and subsequently throwing it away. This is backed up by a study from Parizeau et al. (2009).

  This factor has also been derived by Graham-Rowe, et al. (2014), Beretta et al. (2013), Williams et al. (2012), Parizeau et al. (2015), and Verghese et al. (2015**)**

The following factors are not considered during this study:

- **Shopping routines.** Routines regarding overbuying were significantly positively correlated with food waste. The results suggest that household food waste is mostly an outcome of consumers' food provisioning routines (planning and shopping routines) rather than of conscious intentions not to waste food this factor has been studied by Stefan et al. (2013). This is a too high levelled factor and considered during the aforementioned factors that are considered.
- **Quality of purchased groceries**. One of the most mentioned drivers for food waste due to the faster moulding process, a factor that has been studied by Jörissen et al. (2015). Since no distinction has been made yet between different types of food that have been wasted, it has no use to take this variable into account. Also, in the Netherlands a high quality level is assumed.
- **Price of food.** Respondents that thought food is very cheap were found to waste more food than average. This factor has been studied by Silvennoinen (2014). This factor has also been derived by Rutten et al. (2013). This factor is studied by Göbel et al. (2015), which adds the following: a high concentration of discount stores and strong price competition leading to price dumping and low food prices, explaining why people in industrialized countries can afford to waste food. (Quested et al., 2013) argues that cheaper food is correlated with a higher food waste. Lowered food prices coupled with an apparent abundant availability of food have encouraged negligence towards food and an increase in wasteful behaviour (Stefan et al., 2013). The price of food is a too high levelled factor and not considered due to the generic nature of the food considered in this model. Food that is expensive for some is considered during the price-awareness variable.
- **Impulsive buying:** The presentation of goods in shops stimulates consumers to buy beyond necessary demand, and different products to those they actually need, resulting in disposal of unconsumed foods. Derived by Göbel et al. (2015), Gille (2013), Graham-Rowe, et al. (2014), Jörissen et al. (2015), Parfitt et al. (2010), and Prinicpato et al, (2015). This factors is partly considered during the aforementioned factors Packaging of the products and overbuying
- **A lack of coordination**. A lack of coordination between household members that are both involved in shopping and the planning within a household, might result in double bought products, which will be in the end resulting in too much stock, which cannot be eaten in time, what again will be thrown away according and result in wasted food. This factor has been studied by Ganglbauer et al. (2013). In this study the lack of coordination is presented in the planning phase by the factors degree of using a shopping list, degree of overbuying and in the purchasing phase by the factor frequency of shopping. Therefore, this variable is not considered.
- **Packaging of material** After emptying a package of Soygurt drink (soy-based yoghurt-like product), more of the product was left in the package with LPB packaging (liquid packaging board) compared to polypropylene packaging (plastic beaker), a factor that has been studied by (Silvenius et al., 2012). This factor does fall outside of the scope of this study and is therefore not considered.

Designing a causal relation diagram
The following variables are identified:

Main process variables and variables from other phases.

- **Amount of planned food**. This is the variable that is central within the planning phase. The *Amount of planned food* will be an input for the *Amount of bought food*. More planned amount of food will result in more food bought. Therefore a causal relation is applicable between the variables. This variable can be measured by the amount of kilograms food planned per week per household (*Kg/week/household*).

- ***Amount of bought food***. This is the variable that is central within the purchasing phase. The *Amount of bought food* will be used as input for the *Amount of stored food*. The higher the *Amount of bought food*, the higher the *Amount of stored food*, which results in a positive causal relation. This variable can be measured by the amount of kilograms food bought per week per household (*Kg/week/household*).

- **Amount of stored food.** This is the variable that is a central variable in the storing phase. This variable is needed in order to estimate the amount of food available within a household. The more food is stored the higher the *Amount of stored food*, therefore a positive causal relation is present. This variable can be measured by the amount of kilograms food stored per week per household (*Kg/week/household*).

Variables based upon factors identified by Roodhuyzen et al. (2017)

- **Degree of appropriate amount of food.** The factor *Packaging of the products* can be divided up into mainly two different variables; the *Degree of appropriate amount of food* and the *Effect of economies of scale and discounts.* More available different weights of food while doing groceries will result in less food that will be overbought, resulting in a lower *Degree of overbuying*. Therefore, a negative causal relation does exists. This variable can be measured in a low amount of checking and a high amount of checking, represented by a value between the 0 and 1.

- **Degree of overbuying.** The factor *Overbuying* can be transformed is the variable *Degree of overbuying.* This variable is directly related with the *Amount of bought food*. If the *Degree of overbuying* increases, than more food is being bought than planned, increasing the *Amount of bough food*. Therefore a positive causal relation does exist. This variable represented by a fraction between the 0 and 1, which represents the percentage of overbuying.

- **Frequency of shopping.** This variable covers the same named factor *Frequency of shopping.* This variable is connected to the *Amount of bought food*. The higher the frequency, the lower the *Amount of bought food*, therefore a negative causal relation does exists. This variable can be represented by a value between the 1 and 7, where 1 represents one time a week to the groceries and 7 every day.

- **Price-awareness.** This variable covers the same named factor *Price awareness.* This variable is connected to the *Amount of bought food*. The higher the price awareness, the less food is being bought (representing a more accurate representation of the amount of food needed). Therefore a negative causal relation does exists. This variable can be represented with a fraction between 0 and 1, where 0 is a low price awareness and 1 is a high awareness.

- **Effect of economies of scale and discounts**. The factor *Packaging of the products* can be divided up into mainly two different variables; the *Degree of appropriate amount of food* and the *Effect of economies of scale and discounts*. When the price per kg increases while the amount of food increases, increases the *Degree of overbuying*, therefore a positive causal relation does exist. This variable can be represented by fraction, which illustrates the amount of food that will be bought more. A fraction of 0.1 means that households tend to buy 10% more than needed due to the price KG/ratio.

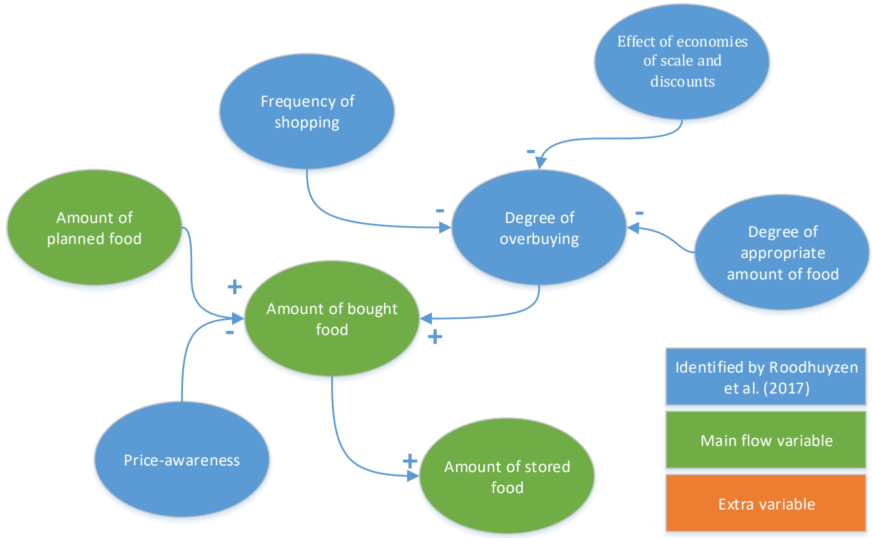


Figure 65; causal loop diagram for the purchasing phase

Storing

In this sub-section is structured as follows: first the factors identified by the systematic literature review by Roodhuyzen et al. (2017) will be given. The factors that are considered during this study are elaborated on in the first part. Secondly, the factors are discussed that are not considered. In the last part of this section, based upon the previous identified factors, combined with the main process variables, extra variables needed, and the food waste variables causal relation diagrams are identified.

Factors identified by Roodhuyzen et al. (2017)
All the factors that are connected to storing phase within the process of food waste will be taken into account in this section. Important is the connection to the amount of food that is being planned by a household. The "*Amount of stored food*" for a household will be the central factor in this section. Factors that are considered in this study:

- **Spoiled food.** The materiality of food implying decay over time, has been one of the most commonly reported type of waste. This factor has been studied by Ganglbauer et al. (2013) Evans (2012) Parizeau et al. (2015), Silvennoinen (2014), Williams et al. (2012), and Jörissen et al. (2015).
  This factor has also been derived by Buzby & Hyman (2012), Gille (2013), Jörissen et al. (2015), Koivupuro et al. (2012), Parfitt et al. (2010), and Williams et al. (2012).
- **Reached the best before date or best-by date.** Strict, unquestioning adherence to the recommendations of best-before dates ('objectification of edibility') seemed to increased household food waste, while using one's senses to judge edibility ('internalization of edibility') seemed to reduce it. Commonly reported type of waste included food that had reached its best before date has been studied by Blichfeldt et al. (2015), Parizeau et al. (2015) and Silvennoinen (2014).
  Throwing away food that has passed its sell-by date derived by Graham-Rowe et al. (2014), Koivupuro et al. (2012), Parfitt et al. (2010), Principato et al. (2015), and Silvenius et al. (2012).
- **Storing time**: Stored for too long: Food decreased in quality, went mouldy or ran past consumption date derived by Beretta et al. (2013), Brown et al. (2013), and Garonne et al. (2014).
- **Spoilage knowledge.** Self-assessment of competencies and skills to judge edibility determines whether people will rely on their senses or use best-before dates to judge. Being thus able to determine food that is still being edible, resulting in less discarded, and thereby wasted food. This factor has been studied by Blichfeldt et al. (2015).

People also tend to throw food away when it looked bad has been derived by Jörissen et al. (2015), Koivupuro et al. (2012), and Williams et al. (2012).

- **Storing knowledge.** Not considering food that is well-suited to the freezer as 'proper' food, thereby discouraging the use of the freezer as a way to preserve food for longer periods of time (Evans, 2011). Food management knowledge and skills (e.g. food storage knowledge) facilitated waste minimisation studied by Graham-Rowe, et al. (2014). Current household food item location knowledge, referring to whether a consumer knows where to locate a desired food item within the household (major factor) studied by Farr-Wharton et al. (2014).

  This factor has also been derived by Jörissen et al. (2015), Parfitt et al. (2010), and Williams et al. (2012).
- **Storing conditions.** Storing food under sub-optimal conditions, which leads to losses in quality via for example spoilage and drying is a factor derived by Koivupuro et al. (2012). Wrong storage conditions like wrong temperature of the fridge and other storing devices has also been derived by Brown et al. (2013), Buzby & Hyman, (2012), Gjerris & Gaiani (2013), and Griffin et al. (2009), Parfitt et al. (2010), and Principato et al. (2015).
- **Consumers' confusion over food labelling**. This factor is considered to be an important factor correlated to unnecessary food wastage due to misunderstanding of the use by and best before date is derived by (Abeliotis et al., 2014). Food knowledge Those who more frequently read nutrition labels on the food they purchased produced less organic waste, this factor has been studied by (Parizeau et al., 2015).

  This is also derived by (Buzby & Hyman, 2012); consumer confusion over ''use-by'' and ''best before'' dates so that food is discarded in packaging. Also derived by (Gjerris & Gaiani, 2013; Koivupuro et al., 2012; Parfitt et al., 2010; Principato et al., 2015; Verghese et al., 2015).

The following factors are not considered during this study:

- **Rate of other garbage**. Households that avoided throwing away food based on the length of time it had been in the fridge produced lower rates of garbage and organic waste. This factor has been studied by Parizeau et al. (2015). This factor falls outside the scope of this study. As mentioned in chapter 2, the focus is in food waste only.
- **Difficult to empty.** 'Difficult to empty', 'too large packages' and (passed) 'best before date' were packaging-related reasons for food waste reported by the respondents. Together, these packaging-related reasons were found to be responsible for 20-25% of the food waste, a factor studied by (Williams et al., 2012). This factor has not be taken into account. The packaging of products have been taken into account during the buying phase, in the storing phase, it falls outside the scope.
- **High sensitivity to food hygiene.** Additional suggested factors driving household waste (between brackets: stage in the household food 'journey'). High sensitivity to food hygiene has been derived by Parfitt et al. (2010) and Principato et al. (2015). This factors will not be taken into account due to the fact that it can be represented by strictly following the best before and used by variables.

Designing a causal relation diagram
The following variables are identified:

Main process variables and variables from other phases:

- **Amount of bought food**. This is the variable that is central within the purchasing phase. This variable will be the input for the *Amount of stored food*. More food bought will result in an increase of the *Amount of stored food*. This variable can be measured by the amount of kilograms food planned per week per household (*Kg/week/household*).

- **Amount of stored food**. This is the variable that is central within the storing phase. In this causal relation diagram, no relation has been made from the *Amount of stored food* and the Amount of prepared food. If more food is stored, it will not lead to more prepared food. This variable can be measured by the amount of kilograms food bought per week per household (*Kg/week/household*).
- **Amount of prepared food.** This is the variable that is a central variable in the preparing phase. The amount of prepared food has a negative causal relation regarding the *Amount of stored food*. If more food is being prepared, more stored food is needed, which results in a lower *Amount of stored food*. This variable can be measured by the amount of kilograms food stored per week per household (*Kg/week/household*).

Variables based upon factors identified by Roodhuyzen et al. (2017):

- **Storing conditions.** The same named factor *Storing conditions* has been transformed into this variable. Better storing conditions will lead to an increase of the *Affected best before date* and the *Affected use by date*. Therefore positive causal relations does. This variable can be expressed a fraction of storing conditions, where 0 is no conditions at all and 1 is perfect *Storing conditions*.

- **Best before date.** The factor *Reached the best before date or best-by date* has been divided up into two variables; *Use by date*, and *Best before date*. This variable has a causal relation towards the *Amount of edible food discarded* via the *Affected best before date*. Longer best by dates results in less thrown away amount of edible food. A negative causal relation does exists. This variable can be expressed by the average number of days the food is still under the best by date.

- **Use by date.** The factor *Reached the best before date or best-by date* has been divided up into two variables; *Use by date*, and *Best before date*. This variable has a causal relation towards the *Amount of inedible prepared food discarded* away via the *Affected use by date*. Longer *Best before dates* results in less thrown away amount of edible food. A negative causal relation does exists. This variable can be expressed by the average number of days the food is still under the best before date.

- **Spoilage knowledge.** The factor *Spoilage knowledge* and *Consumers' confusion over food labelling* will be transformed into the variable *Spoilage knowledge*. More *Spoilage knowledge* has a causal relation with the *Affected best before date* and the *Affected use by date***.** In both cases, more spoilage knowledge will increase the best-by and best before date. Two positive causal relations do exists. This variable can be expressed by the average *Spoilage knowledge* present within a household, represented with a fraction between the 0 and 1, where no spoilage knowledge at all is 0 and 1 is perfect spoilage knowledge.

Extra variables needed in order to generate the planning behaviour:

- **Affected used by date**: the affected used by date is needed to incorporate the effect of the *Storing conditions* and the *Spoilage knowledge*. Increasing both variables does have a positive effect on the *Affected used by date*, therefore two positive causal relations are present. Important to consider is that *the Use by date* is about the safety of food and therefore the effect of the *Storing conditions* and the *Spoilage knowledge* is assumed to be limited. This variable is represented by an amount of days.

- **Affected best before date:** the affected best before date is needed to incorporate the effect of the *Storing conditions* and the *Spoilage knowledge*. Increasing both variables does have a positive effect on the *Affected best before date*, therefore two positive causal relations are present. The *Best before date* is about the quality of the food, and therefore the effect of the *Spoilage knowledge* and *Storing conditions* is assumed to be bigger in regards to the *Use by date*. This variable is represented by an amount of days.

Food waste variables

- ***Amount of inedible prepared food discarded***: this food waste variable represents the waste resulting from surpassing the *Use by date.* In this study it is assumed that the food thrown away as a result of surpassing the *Use by date*, the food actually became unsafe and therefore inedible. Throwing food away results in a decrease of the *Amount of stored food*. This variable can be measured by the amount of kilograms food stored per week per household (*Kg/week/household*).

- **Amount of edible food discarded**: this food waste variable represents the waste resulting from surpassing the *Best before date*. In this study it is assumed that most of the food that is being discarded based upon the *Best before date* is actually still eatable. Throwing food away results in a decrease of the *Amount of stored food*. This variable can be measured by the amount of kilograms food stored per week per household (*Kg/week/household*).

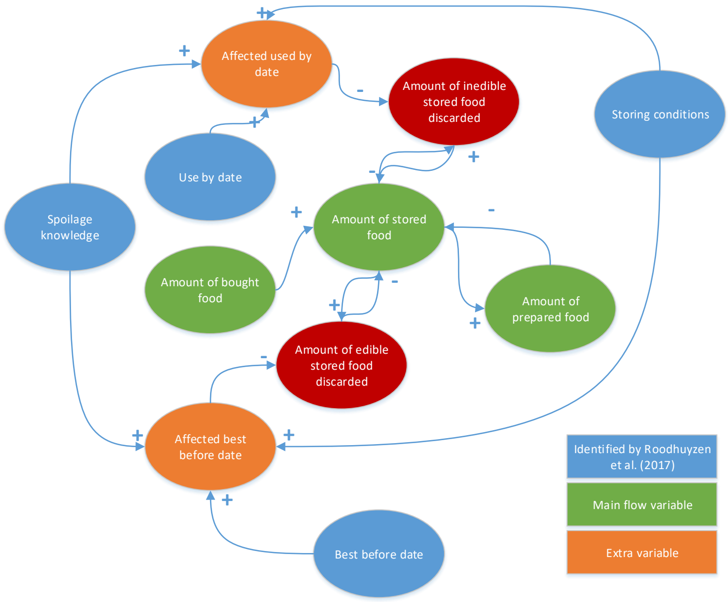


Figure 66: causal loop diagram for the storing phase

Preparing

In this sub-section is structured as follows: first the factors identified by the systematic literature review by Roodhuyzen et al. (2017) will be given. The factors that are considered during this study are elaborated on in the first part. Secondly, the factors are discussed that are not considered. In the last part of this section, based upon the previous identified factors, combined with the main process variables, extra variables needed, and the food waste variables causal relation diagrams are identified.

Factors identified by Roodhuyzen et al. (2017)

All the factors that are connected to preparing phase within the process of food waste will be taken into account in this section. Important is the connection to the amount of food that is being consumed by a household. The "*Amount of stored food*" for a household will be the central factor in this section. The following factors are considered:

- **Cooking skills.** Wastage of edible parts of food because of inappropriate methods of preparation (e.g. bread crust, potato skin, offal). This factor has been studied by Parizeau et al. (2015).

This factor has been derived by Beretta et al. (2013), Parfitt et al. (2010), and Jörissen et al. (2015).

- **Cooking & serving too much**. Due to a lack of experience was one of the most mentioned drivers for food waste studied by Jörissen et al. (2015). Preparing too much food was the reason for around 25% of the food waste. studied by Williams et al. (2012). Other authors that studied this factor are Silvennoinen (2014).

  This factor has also been derived by Koivupuro et al. (2012), Parfitt et al. (2010). Jörissen et al. (2015), Graham-Rowe, et al. (2014), Williams et al. (2012), Beretta et al. (2013), Principato et al. (2015), and Gille, (2013).
- **Amount of edible food leftover:** this is the amount of food leftover after dinner within a household. It is the difference between the amounts of food prepared and consumed. This a factors studied by Williams et al. (2012), Jörissen et al. (2015), and Silvennoinen. (2014).

  This factor is also derived by multiple authors (Koivupuro et al., 2012; Parfitt et al., 2010; Jörissen et al., 2015; Graham-Rowe, et al., 2014; Williams et al., 2012; Beretta et al., 2013; Principato et al., 2015; (Parfitt et al., 2010; (Gille, 2013).

The following factors are not considered during this study:

- **Anxieties surrounding food safety and storage**. Concerns regarding food safety tend to 'win out' over anxieties about wasting food studied by Evans (2011). Anxiety about eating 'old' food derived by Gille (2013). This factor has not be taken into account due to the fact that this factor is already taken into account by the *Best before date* or *Use by date* in the storing phase.
- **Package was is too difficult to empty** derived by Silvenius et al. (2012). This factor has not be taken into account since the packaging of the products have not been taken into account during the storing and preparing phase and therefore fall outside the scope during the qualitative analysis.
- **Removal of edible portions of food such as skins during preparation**. This is done in order to obtain desired sensory or nutritional quantities, a factor studied by Parizeau et al. (2015) and derived by Griffin et al. (2009). This factor has been taken into account since this waste of food is not per se avoidable. This should be considered during the definition making. While the focus is on the avoidable part of the waste of food.

Designing a causal relation diagram

The following variables are identified:

Main process variables and variables from other phases.

- **Amount of stored food**. This is the variable that is central within the storing phase. This variable will have no effect on the amount of prepared food. It is assumed that if more food is available within a household, it does not increase the amount of food that is being prepared. Therefore there is no causal relation between the *Amount of stored food* towards the Amount of prepared food. This variable can be measured by the amount of kilograms food planned per week per household (*Kg/week/household*).

- **Amount of prepared food**. This is the variable that is central within the preparing phase. The *Amount of prepared food* is needed in order to estimate the food that is being left over, which is the difference between the *Amount of prepared food* and consumed. Based upon, it can be concluded that there is a positive causal relation between the *Amount of prepared food* and the Amount of edible food leftover. This variable can be measured by the amount of kilograms food bought per week per household (*Kg/week/household*).

- **Amount of consumed food.** This is the variable that is a central variable in the consuming phase. The *Amount of consumed food* has a negative causal relation regarding the amount of edible food leftover. If more food is being consumed, less edible food will result. This variable can be measured by the amount of kilograms food stored per week per household (*Kg/week/household*).

Variables based upon factors identified by Roodhuyzen et al. (2017)

- **Cooking skills.** The factor *Cooking skills* is transformed into this variable. This variable has an effect on the *Amount of inedible prepared food discarded*. A higher *Cooking skills* results in a lower *Amount of inedible prepared food discarded*, therefore a negative causal relation can be deducted. This variable can be expressed a fraction, where 0 is no skill at all where a person transforms all the prepared into inedible food and 1 as perfect cooking skill where no food is being discarded as result of this skill.

- **Provision factor.** The factor *Cooking & serving too much* has been transformed into this variable. The *Provision factor* has a positive causal relation with the *Amount of prepared food*. If a households serves too much food, that could be represented with a higher *Provision factor*. A higher *Provision factor* results thus in a higher Amount of food that is being prepared, which can be illustrated with a positive causal relation. This variable can be expressed a fraction, where 0 is no extra food made and 1 twice as much as actually needed.

- **Amount of edible food left over**. This variable is needed in order to estimate the amount of food that is left over consumption of the prepared food. The *Amount of edible food left over* can be calculated by subtracting the consumed food of the prepared food. The resulting amount of food is the *Amount of edible food left over*. The *Amount of edible food left over* will be used as input during the consumption phase. This variable can be measured by the amount of kilograms food stored per week per household (*Kg/week/household*).

Extra variables needed in order to generate the planning behaviour:

- **Average amount of food needed for a household.** The amount of food will be deducted within the consumption phase of the process. This variable is needed as input for the *Amount of prepared food*, which can be represented by a positive causal relation. A higher *Average amount of food needed for a household* results in a higher *Amount of planned food* and *Amount of prepared food*. This variable can be measured by the amount of kilograms food consumed per week per household (*Kg/week/household*).

Food waste variables

- **Amount of inedible prepared food discarded**: represents the waste of food that results of cooking. Burning food may result inedible and unsafe food, which not will be eaten within a household. This amount should be considered while determining the *Amount of edible food leftover*. This variable can be measured by the amount of kilograms food consumed per week per household (*Kg/week/household*).

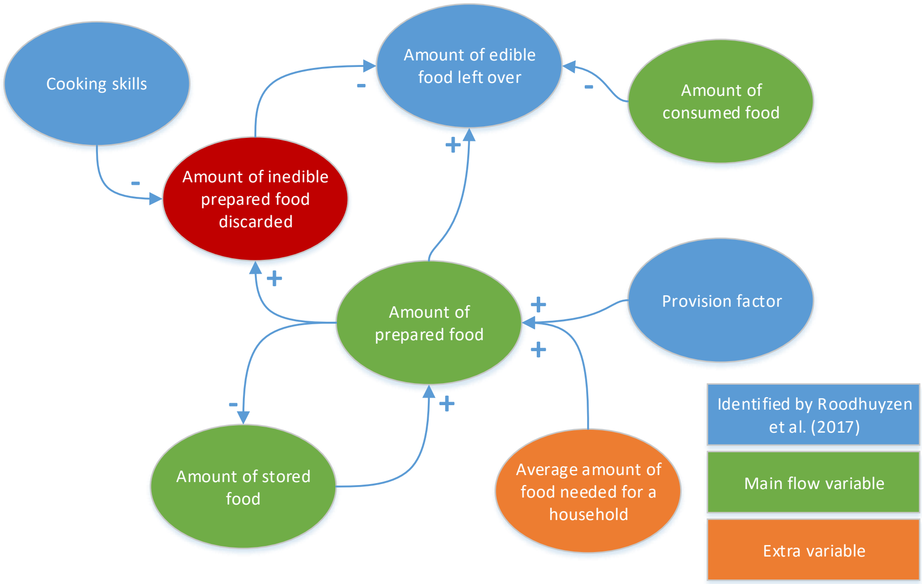


Figure 67: causal loop diagram for the preparing phase

Consuming

In this sub-section is structured as follows: first the factors identified by the systematic literature review by Roodhuyzen et al. (2017) will be given. The factors that are considered during this study are elaborated on in the first part. Secondly, the factors are discussed that are not considered. In the last part of this section, based upon the previous identified factors, combined with the main process variables, extra variables needed, and the food waste variables causal relation diagrams are identified.

Factors identified by Roodhuyzen et al. (2017)

All the factors that are connected to consuming phase within the process of food waste will be taken into account in this section. Important is the connection to the amount of food that is being prepared and the leftovers that are being stored by a household. The "*Amount of consumed food*" by a household will be the central factor in this section. The following factors are considered in this study:

- **Personal preferences;** Being unsatisfied with the taste or freshness of food, or not wanting to eat the same food many times studied by Koivupuro et al. (2012). Commonly reported type of waste included additional (less) reported types were food that households tried and did not like studied by (Parizeau et al., 2015). This factor has also been studied by Cappellini & Parsons (2012) and Evans (2012).
  Taste preferences: Wastage of edible parts of food because the person does not like its taste or smell derived by Beretta et al. (2013) and Jörissen et al. (2015).
- **Unpredictability of daily life**: Buying more than intended or really needed, as a consequence of unpredictability of daily life or of food habits (e.g. unpredictability of presence at home due to spontaneous and busy lifestyles, or household members with unpredictable eating habits and the sudden presence of guest) has been studied by Ganglbauer et al. (2013), Evans (2011), Evans (2012), Farr-Wharton et al. (2014), and Cappellini & Parsons (2012).
  Contemporary hectic lifestyles has also been derived by Gjerris & Gaiani (2013), Parizeau et al. (2015), and Williams et al. (2012). Parizeau et al derived that households that tend to have erratic lifestyles still tend to buy enough food for households with a predictable life.
- **Amount of edible food leftover:** this is the amount of food leftover after dinner within a household. It is the difference between the amounts of food prepared and consumed. This a factors studied by Williams et al. (2012), Jörissen et al. (2015), and Silvennoinen. (2014).

This factor is also derived by multiple authors (Koivupuro et al., 2012; Parfitt et al., 2010; Jörissen et al., 2015; Graham-Rowe, et al., 2014; Williams et al., 2012; Beretta et al., 2013; Principato et al., 2015; (Parfitt et al., 2010; (Gille, 2013).

The following factors are not considered during this study:

- **Psychological tastes, attitudes, and preferences leading to plate waste/scrapings, e.g. human aversion, or refusal to eat a food for religious reasons** (Buzby & Hyman, 2012). Human eversions have been taken into account within the Personal preferences factor. The refusal to eat food because of religious reasons has not been taken into account in this study.

Designing a causal relation diagram
The following variables are identified:

Main process variables and variables from other phases.

- **Amount of prepared food** . This is the variable that is central within the preparing phase. The *Amount of prepared food* is needed in order to estimate the food that is being left over, which is the difference between the *Amount of prepared food* and consumed. Based upon, it can be concluded that there is a positive causal relation between the *Amount of prepared food* and the *Amount of edible food leftover*. This variable can be measured by the amount of kilograms food bought per week per household (*Kg/week/household*).

- **Amount of consumed food.** This is the variable that is a central variable in the consuming phase. The *Amount of consumed food* has a negative causal relation regarding the *Amount of edible food leftover*. If more food is being consumed, less edible food will result. This variable can be measured by the amount of kilograms food stored per week per household (*Kg/week/household*).

- **Amount of leftovers stored.** This is the variable that is central in the leftover phase**.** The *Amount of leftover stored* is only affected by the *Amount of edible food leftover*. This variable can be measured by the amount of kilograms food stored per week per household (*Kg/week/household*).

Variables based upon factors identified by Roodhuyzen et al. (2017)

- **Preference within a household.** The factor *Personal preferences* can be transformed into the same named variable. Regarding the *Amount of consumed food*, a negative causal relation can be deducted. If there are more preferences within a household, less food will be consumed. This variable can be expressed a fraction, where 0 is no preference at all and 1 as a maximum diverse preferences within household.

- **Unpredictability of a household.** The factor *Unpredictability of daily life* can be transformed into the variable *Unpredictability of a household*. Regarding the *Amount of consumed food*, a positive causal relation can be deducted. If there a higher Unpredictability within a household, less food will be consumed. This variable can be expressed a fraction, where 0 is no Unpredictability at all and 1 as a maximum Unpredictability within a household.

- **Amount of edible food leftover**. This variable is needed in order to estimate the amount of food that is left over consumption of the prepared food. The *Amount of edible food leftover* can be calculated by subtracting the consumed food of the prepared food. The resulting amount of food is the *Amount of edible food leftover*. This amount will be used as input during the following phase, the consumption phase. This variable can be measured by the amount of kilograms food stored per week per household (*Kg/week/household*).

Extra variables needed in order to generate the planning behaviour:

- **Average amount of food needed for a household.** The amount of food will be deducted within the consumption phase of the process. This variable is needed as input for the *Amount of prepared food*, that has been described in previous section. However this variable also affects the *Amount of consumed food* which can be represented by a positive causal relation. A higher amount of actual food needed for a household results in a higher *Amount of consumed food*. This variable can be measured by the amount of kilograms food consumed per week per household (*Kg/week/household*).

Food waste variables

- **Amount of leftovers discarded directly**: A part of the food that is being leftover will be stored and further considered during the re-using leftover phase. However, a part will be thrown away directly during the consuming phase. The more food will be leftover, the more food may be thrown away. This variable can be measured by the amount of kilograms food stored per week per household (*Kg/week/household*).

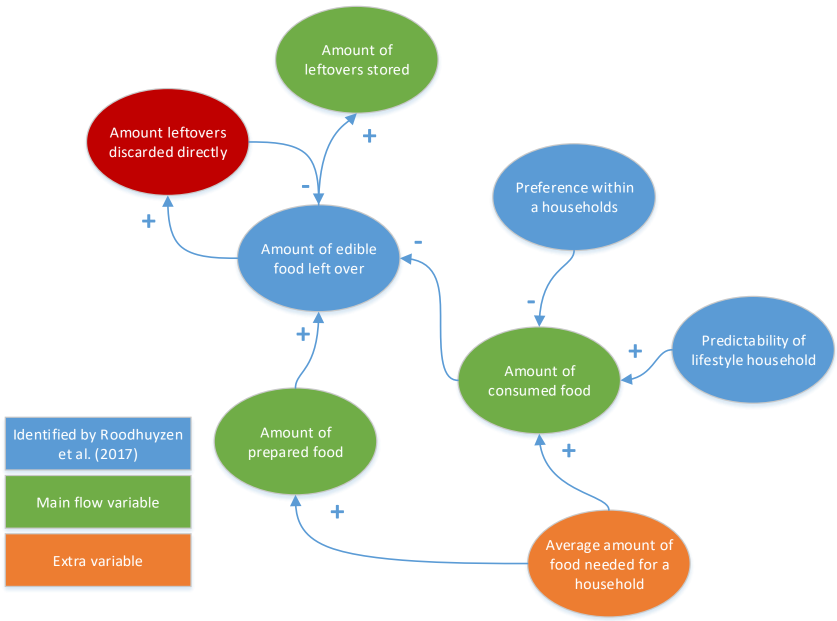


Figure 68: causal loop diagram for the consuming phase

Re-using leftovers

In this sub-section is structured as follows: first the factors identified by the systematic literature review by Roodhuyzen et al. (2017) will be given. The factors that are considered during this study are elaborated on in the first part. Secondly, the factors are discussed that are not considered. In the last part of this section, based upon the previous identified factors, combined with the main process variables, extra variables needed, and the food waste variables causal relation diagrams are identified.

Factors identified by Roodhuyzen et al. (2017)

All the factors that are connected to leftover phase within the process of food waste will be taken into account in this section. Important is the connection to the amount of food that is being prepared and the leftovers that are being stored by a household. The "Amount of leftovers consumed" and "The *Amount of leftovers stored*" by a household will be the central factors in this section. The following factors are considered in this study:

- **Desire to consume leftovers.** Households with no desire to consume leftover food: referring to having lost desire to consume leftovers before they expire has been studied by Farr-Wharton et al. (2014). Socio-temporal context of food practices and food waste. Dislike of eating the same thing again in the time frame before it expires, resulting in disposal of leftovers has been studied by Evans (2012).

  Food that is left on the plate and food that was out of date were the most reported reasons for the waste of food, followed by an undesirable appearance multiple types of spoilage derived by Parizeau et al. (2015) and Verghese et al. (2015). Not eating the food that needs to be eaten first has been derived by (Jörissen et al., 2015).
- **Amount of edible food leftover:** this is the amount of food leftover after dinner within a household. It is the difference between the amounts of food prepared and consumed. This a factors studied by Williams et al. (2012), Jörissen et al. (2015), and Silvennoinen. (2014).

  This factor is also derived by multiple authors (Koivupuro et al., 2012; Parfitt et al., 2010; Jörissen et al., 2015; Graham-Rowe, et al., 2014; Williams et al., 2012; Beretta et al., 2013; Principato et al., 2015; (Parfitt et al., 2010; (Gille, 2013).
- **Leftover knowledge:** This is the type of knowledge related to the material elements of the foodstuffs and the likely contexts of their reuse. Forward thinking about the likely contexts of reuse of leftovers is a factor studied by (Cappellini & Parsons, 2012).

The following factors are not considered during this study:

- **Feeding of leftovers to pets**. Rather feeding the pets than using them for human consumption is a factor that has been derived by Griffin et al. (2009). "Consumers who stated to discard meal leftovers differed from those who say they do not in the following aspects: Discard leftovers of meals and give to those in need and to their animals is a factor that has been studied by Fonseca (2014). The definition given in chapter 2 of food waste focusses on the consumption of humans and not animal and therefore this factor is not considered.
- **Meat eaters.** Consumers who stated to discard meal leftovers differed from those who say they do not in the following aspects: Frequently eat meat (versus rarely eating meat is a factor that has been studied by (Fonseca, 2014). Since no difference has been made between different types of food, no distinction will be made during the leftover phase.
- **Buy fresh foods pre-packaged**. "Consumers who stated to discard meal leftovers differed from those who say they do not in the following aspects: Usually buy fresh foods pre-packaged (versus rarely buying fresh foods pre-packaged) is a studied by Fonseca. (2014). Since no difference has been made between different types of food and the freshness of food, no distinction will be made during the leftover phase.
- **Frequency of shopping.** Consumers who stated to discard meal leftovers differed from those who say they do not in the following aspects: They rarely shop (versus frequently shopping and being the main shopper) is a factor studied by Fonseca (2014). Frequency of shopping has been taken into account during the purchasing phase and is not connected to the leftover phase.
- **Buy promotions regularly.** Consumers who stated to discard meal leftovers differed from those who say they do not in the following aspects; like product promotions and regularly make impulse purchases (versus not liking product promotions and reading product labels) is a factor that has been studied by (Fonseca, 2014). This factor has already been taken into account during the purchasing phase, impulsive buying has not been taken into account, and promotions have been correlated with price-awareness.

Designing a causal relation diagram
The following variables are identified:

Main process variables and variables from other phases.

- **Amount of consumed food** . This is the variable that is central within the consuming phase. The *Amount of consumed food* is needed in order to estimate the food that is being left over, which is the difference between the *Amount of prepared food* and consumed. Based upon, it can be concluded that there is a negative causal relation between the *Amount of consumed food* and the *Amount of edible food leftover*. This variable can be measured by the amount of kilograms food bought per week per household (*Kg/week/household*).

- **Amount of leftovers consumed.** This is the variable that is one of the two central variables regarding the leftover phase. The *Amount of leftovers consumed* has a positive causal relation towards the *Amount of consumed food*. If a household eats more leftovers, more food overall will be consumed. The *Amount of leftovers consumed* has a negative relation with the *Amount of leftovers stored*. If more leftovers are being eaten, the amount stored leftovers will decrease. This variable can be measured by the amount of kilograms food stored per week per household (*Kg/week/household*).

- **Amount of leftovers stored.** This is the variable that is one of the two central variables regarding the leftover phase. The *Amount of leftovers stored* has a positive causal relation with the Amount of leftovers discarded directly. If more leftovers are being stored, the more will be thrown away. This variable can be measured by the amount of kilograms food stored per week per household (*Kg/week/household*).

Variables based upon factors identified by Roodhuyzen et al. (2017)

- **Desire to consume leftovers.** The factor *Desire to consume leftovers* can be transformed into the same named variable. There is a positive causal relation between the Desire to consume leftovers and the *Amount of leftovers consumed*. If the desire is higher, the more leftovers will be consumed. This variable can be expressed by a fraction of the leftovers eaten ranging from 0, which represents nothing, to 1 representing eating all possible leftovers.

- **Amount of edible food leftover**. This variable is needed in order to estimate the amount of food that is left over consumption of the prepared food. The *Amount of edible food leftover* can be calculated by subtracting the consumed food of the prepared food. The resulting amount of food is the *Amount of edible food leftover*. This amount will be used as input during the following phase, the consumption phase. This variable can be measured by the amount of kilograms food stored per week per household (*Kg/week/household*).

- **Leftover knowledge**. Households should know how to re-use leftovers. This is represented by this variable. Having more knowledge may increase the amount of leftovers that are consumed within a household. This variable is represented by a level of knowledge, that is a fraction ranging from 0 (no knowledge at all) to a value of 1 (full knowledge).

Extra variables needed in order to generate the planning behaviour:

- **Moulding time leftovers.** This variable is based upon the *Best before date* and the *Use by date* in the storing phase, however, the storing time for leftovers will be lower than the storing time for the stored food. There is a positive causal relation with the storing time and the *Amount of leftovers discarded*. The longer the storing time of the leftovers, the more leftovers will need to be discarded due to spoilage. This variable can be measured by the number of days that the leftovers have been stored.

Food waste variables

- **Amount of leftovers discarded**. Storing leftovers to long results in inedibility. The leftovers will become moulded. This discarded amount of food will be taken from the storage, decreasing the *Amount of leftovers stored.* This variable can be measured by the amount of kilograms food stored per week per household (*Kg/week/household*).

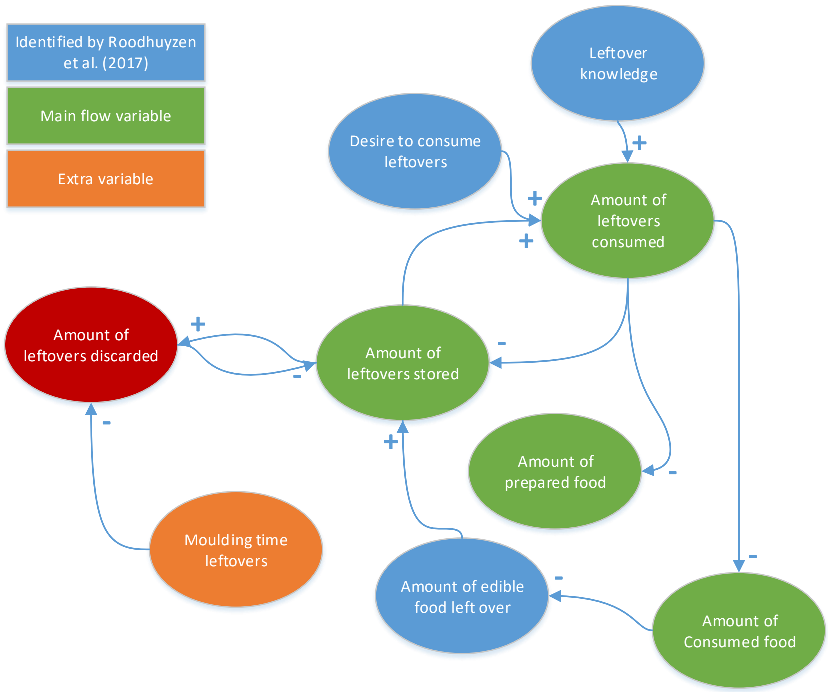


Figure 69: causal loop diagram for the leftover phase

Overall overview of the food waste system

The causal relation diagram identified in previous section should be connected and transformed into one causal loop diagram, which represents the system of food waste within a household. In order to provide a more complete overview, multiple general variables based upon factors identified by Roodhuyzen et al. (2017) and a desk research will be added to this overview. Based upon the causal loop diagram with the included general variables, an aggregated overview will be identified in next section.

factors identified by Roodhuyzen et al. (2017)

All the factors that are connected to leftover phase within the process of food waste will be taken into account in this section. The previous identified sub-diagrams are connected in chapter 2. General variables are identified in this section.

- **Awareness on negative consequences of wasting food**. Educated households on this topic try, taste and smell the food to a greater degree, are more willing to eat such food, and/or perform better planning has been studied by Williams et al. (2012). Principato et al. (2015) derived that a greater awareness and concern about food waste increases the likelihood to plan purchases, and thereby the reduction of food that is being wasted. It has been assumed that people who tend to be more aware on the negative consequences do have better planning routines overall. This is due to the fact that people who do care, tend to do everything about it in order to reduce food waste. People with good knowledge of the negative problems linked to food waste are more likely to avoid wasting food. This factor is derived by Principato et al. (2015), Gjerris & Gaiani (2013). - Knowledge about food waste, its causes and related problems: People with good knowledge of the negative problems linked to food waste are more likely to avoid wasting food.

- **Degree of concern food waste**. Lack of priority: Giving low priority to minimising household food waste, studied by Graham-Rowe et al. (2014). Lack of concern was significantly negatively correlated to the intention not to waste food, studied by Stefan et al. (2013). Exemption from responsibility: Perceiving that the responsibility for food waste lies with the food industry and supermarkets, rather than the consumer, studied by (Graham-Rowe, et al., 2014). People with a high environmental and civic consciousness waste less food. Derived (Principato et al., 2015). Waste awareness about waste and its impacts was connected to lower rates of waste production, derived by (Parizeau et al., 2015).
- **Household size.** Households with one person wasted most food per capita, and wasted significantly more per capita than households with two or more members. The total amount of waste increases while the amount of members within a household increases. This factor has been studied Jörissen et al. (2015), Koivupuro et al. (2012), Quested et al. (2013), Parizeau et al. (2015), Williams et al. (2012), and Fonseca (2014).

  Single households create the most food waste when compared to households with several occupants derived by Halloran et al. (2014). Smaller households waste more food per capita than larger households, single-person householders tend to throw away more per capita, households with children tend to waste more than households without children. This factor has been derived by Parfitt et al. (2010). The larger the household, the less waste was produced per capita. Single households produced most food waste has also been derived by (Silvennoinen, 2014).
- **Moral attitude.** Agreeing with the statement "I think it is important that I do not waste food" was positively correlated to reporting to have recently tried to reduce the amount of food wasted" Studied by Studied by (Parizeau et al., 2015). (Principato et al., 2015): The moral aspect of attitudes seems relevant for food waste as well, as most consumers feel bothered or guilty when engaging in wasteful behaviour. This factor has been studied by Stefan et al. (2013). Studied by Stefan et al. (2013). The same factor has been studied by Principato et al. (2015. It has been studied by (Blichfeldt et al., 2015). Seeing wasting food as 'wrong' and having the desire to do the 'right' thing was a motivation to minimise waste studied by (Graham-Rowe, et al., 2014). Studied by (Parizeau et al., 2015). Derived by (Parizeau et al., 2015). Studied by Stefan et al. (2013). Doing the 'right' thing: Seeing wasting food as 'wrong' and having the desire to do the 'right' thing was a motivation to minimise waste. Studied by (Graham-Rowe, et al., 2014)

The following factors are not considered during this study:

- **Preference of children.** Overall, households with children produced more food waste. However, these same households produced less total waste per capita. This suggests that the rate of waste production was lower for children than for adults in these households. This factor has been studied by Parizeau et al. (2015), Williams et al. (2012), and Jörissen et al. (2015).This factor has also been derived by Parfitt et al. (2010). This factor is already considered during the preference within a household and unpredictability of household variables within the qualitative model.
- **Perceived behavioural control** relates to the degree to which consumers think reducing food waste is under their control. This factor has been studied by Stefan et al. (2013) and studied by Koivupuro et al. (2012). This factor is not considered since it partly is captured within the *Moral attitude*.
- **Home economic skills.** Poor home economics skills are assumed to result in more food waste. Going from planning to purchasing to re-using leftovers into new meals results in a decrease of food waste. This factor has been derived by Parfitt et al. (2010)**.** This factor has already been covered in multiple phases. The planning aspects have been covered in

the planning phase, and the leftovers in the leftover phase therefore this factor is not considered.

- **Gender.** No consensus has been reached in the scientific literature regarding the waste of food within a household. For instance it has been studied that a male is responsible for more food waste by Fonseca (2014). Opposite results are studied by Koivupuro et al. (2012) and derived by Silvennoinen (2014). Principato et al. (2015) concluded in their study that gender and being worried about the cost of wasted food were not significantly related. Contradicting outcomes of studies makes it hard to take the gender into account and therefore it will not be taken into account.
- **Age.** Younger people are more profiled as food wasters versus older people has been studied by (Fonseca, 2014), Stefan et al. (2013), Quested et al. (2013). The fact that older people do waste less food is also derived by (Gjerris & Gaiani, 2013; Parfitt et al., 2010; Principato et al., 2015). The difference between the age and the waste of food is not considerable and there is also not a consensus; while young people tend to waste more food, old people also have the habit to do so. Therefore is this factor not considered during this study.
- **Income of a household**. Household income was not found to be correlated with food waste, studied by Williams et al. (2012). Household income is positively related to the generation of food waste has been studied by Stefan et al. (2013) and Principato et al. (2015). This factor has also been derived by multiple authors (Abdulla et al., 2013; Parfitt et al., 2010; Silvennoinen, 2014; Principato et al., 2015; Gjerris & Gaiani, 2013). The income of a household has already been taken into account during the purchasing phase: price awareness. Besides, there is no consensus in the current scientific literature on the importance of income regarding the waste of food.
- **Exemption from responsibility.** Perceiving that the responsibility for food waste lies with the food industry and supermarkets, rather than the by themselves is a factor studied by (Graham-Rowe, et al., 2014). This factor is considered during the Moral attitude within a household.

designing a causal relation diagram
The following variables are identified:

Variables based upon factors identified by Roodhuyzen et al. (2017)

- **Knowledge on consequences food waste**. Knowing what food waste is and what the consequences are environmentally and for other people all over the world. Knowledge on consequences food waste is represented by a fraction. A fraction of 0 results in no knowledge at all and a fraction of 1 is full knowledge regarding the waste of food.

- **Moral attitude:** The feelings of guilt when discarding food. The feeling of ethical wrongdoing. The Moral attitude is expressed by a fraction between 0 and 0. An attitude of 0 means total lack of concern regarding the waste of food. An attitude of 1 means fully feeling guilty when wasting food. This variable influences Perceived amount of food waste within a household.

- **Household size.** This variable is considered since it determines the amount of food that is planned, bought stored and prepared, consumed, and re-used. This variable influences the *Average amount of food needed for a household*. This variable is expressed by the number of members that are present within a household.

Extra variables needed in order to generate the planning behaviour:

- **Perceived food waste.** The *Perceived amount of food waste* is a variable that represent the amount of waste from the households perspective. Based upon the *Perceived amount of food waste,* households may adapt their planning and preparing behaviour. This amount is expressed by kilogram per week per household.

- **Average Kg/person.** The *Average Kg/person* is needed to estimate the *Amount of food needed for a household* combined with the *Household size*. It is the expressed in the amount of kilograms a person consumes on average per week.

Food waste variables

- **Total food waste**. This is the amount of food wasted within a household in total. It is the accumulation of all. This variable can be expressed by kilograms per week per household.

Appendix B: Data-gathering & Model building

In this appendix, a more detailed result data-gathering and model building is given. This appendix is structured as follows: per phase, the System Dynamics sub-models are given and available data is discussed. The most important insights regarding the uncertain parameters and relations present within these System Dynamics models are concluded and elaborated on in chapter 4.

Planning

The data that is needed in order to generate the planning behaviour will be taken into account in this sub-section. As mentioned before, the behaviour of interest is that people tend to plan to buy more food than actually needed. This implies that within the model the *Adjusted amount of planned food* should be greater than the *Average amount of food needed for a household*. The qualitative model for the planning phase can be transformed into a Vensim sub-model, which can be found in **figure 70**. In this section, extra variables are needed that are not explicitly mentioned in qualitative model, chapter 2. These are the *Adjusted amount of planned food*, *the Effect of using a shopping list, Fraction of inventory remembered by household, Fraction of inventory taken into account,* and *Amount of planned food with over planning*. The variables derived from the qualitative analysis in section 2.3.1 are depicted in blue and the extra variables are depicted in green. Variables from another phase do not have a colour.

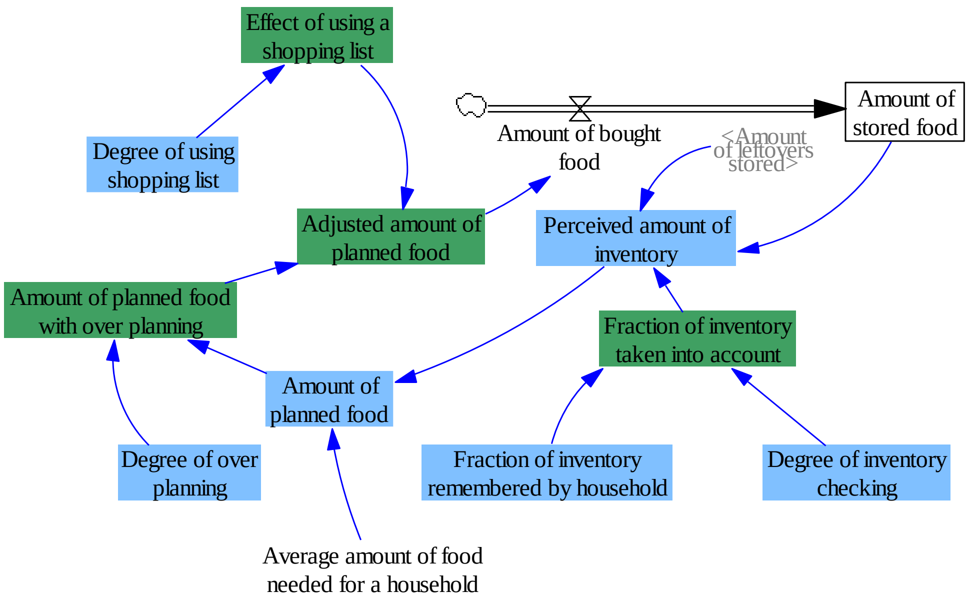


Figure 70; planning phase sub-model

The relation between the *Amount of bought food* and the *Amount of stored food* will be taken into account during the storing phase. The relation between the *Amount of planned food* and the *Amount of bought food* will be taken into account during the next phase, the purchasing phase. The parameter values of the *Amount of bought food* will also be taken into account during the purchasing phase, the *Amount of stored food* will be taken into account during the storing phase, the *Amount of leftovers stored* will be taken into account during the re-using leftover phase. The *Average amount of food needed for a household* will be considered in the last phase, the general phase. **Based upon figure 70**, the following relations and parameters can be identified for which data is needed in order to generate the desired behaviour:

Parameter values within the planning phase

Based upon the sub-model identified by **figure 70,** the following parameters can be identified:

- **Degree of inventory checking**: households tend to buy more food than needed due to not checking the available amounts of food within the household. No scientific data is available on this topic, therefore a estimation is inevitable. Regarding the average Dutch household, it could be assumed that products that are being used a lot will also be checked more. It is assumed that on average household checks the *Amount of stored food* and the *Amount of leftovers stored* 50% of the time before going to the supermarket.

- $Degree\ of\ inventory\ checking = 0.5$
  - Dimension: dimensionless

- **Degree of over planning:** people tend to plan to buy more than actually needed resulting in a higher *Amount of planned food* than the *Average amount of food needed for a household*. There is no information available in the scientific literature on the exact amount of food people tend to plan to buy more, therefore is estimation used. In order to represent the wishes to have more food than needed a percentage of 10% is being used. This value of this parameter represents the fraction planned more than actually needed. For Dutch households it is assumed to be 10%
  - $Degree\ of\ over\ planning = 0.10$
    - Dimension: dimensionless

- **Degree of using shopping lists:** In Karlsruhe as well as in Ispra, 70% of the households surveyed use a shopping list. When using a shopping list, the amount of food thrown away per capita is lower by about 20% in Karlsruhe and 25% (Jörissen et al., 2015), in Ispra. On average, it is assumed that households use a shopping list 70% of the time based upon the study of Jörissen et al. (2015)**.**
  - $Degree\ of\ using\ shopping\ lists\ =\ 0.7$
    - Dimension: dimensionless

- **Fraction of inventory remembered by household:** when people do go to do groceries, it might be possible that people remember what they do have in their inventory, even when they do not make a shopping list. Therefore this variable is needed. It is assumed that a household is able to remember around 80% of the inventory.
  - *Fraction of inventory remembered by household = 0.8*
    - Dimension: dimensionless

Relations within the planning phase
Based upon the sub-model identified by **figure 70**, the following relations can be identified:

- **Adjusted amount of planned food** is influenced by the variables *Amount of planned food with over planning* and the *Effect of using a shopping list*. Using a shopping list will increase the approximation of the *Amount of planned food*; using a shopping list more is correlated with more food waste (Jörissen et al., 2015). Therefore it is assumed that using a shopping list will reduce the *Amount of planned food*. This is represented by multiplying the *Effect of using a shopping list* with the *Amount of planned food*. This will result in the following mathematical relation:
  - $Adjusted\ amount\ of\ planned\ food = (Amount\ of\ planned\ food\ with\ over\ planning * Effect\ of\ using\ a\ shopping\ list) + Amount\ of\ planned\ food\ with\ over\ planning$
    - Dimension: Kg/Week

- **Effect of a shopping list** is influenced by the variable *Degree of using shopping lists*. Using a shopping list more often has been presented by a relation between the usage of a shopping list and the effect of this usage on the *Amount of planned food*. It is assumed that never using a shopping list will increase the *Amount of bought food* with 10% and using a shopping list always will result no extra food bought. The relation is assumed shaped according to **figure 71**. The x-axis represent the *Degree of using shopping lists* and the y-axis represents the effect of the usage of these shopping lists.
  - $Effect\ of\ using\ a\ shopping\ list\ =$
    - Dimension: dimensionless

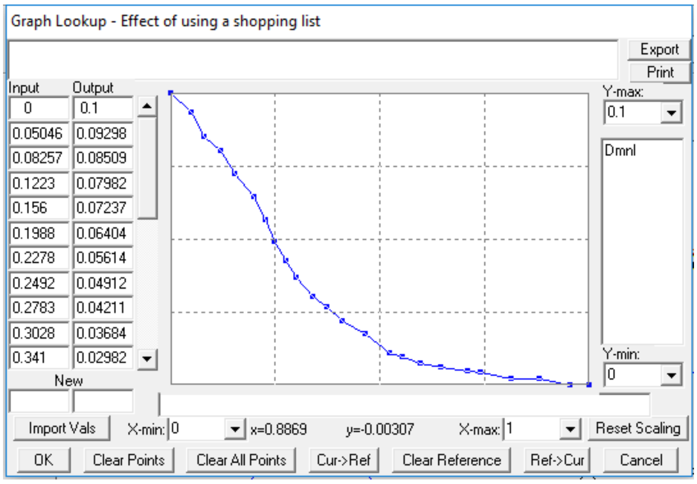


Figure 71: Graph Lookup Effect of using a shopping list

- **Amount of planned food with over planning** is influenced by the variables *Amount of planned food* and the *Degree of over planning*. This amount can be calculated by multiplying these variables by one another combined with the original *Amount of planned food*. This will result in the following mathematical relation:
    - $Amount\ of\ planned\ food\ with\ over\ planning\ =\ Amount\ of\ planned\ food\ +\ (Degree\ of\ over\ planning\ *\ Amount\ of\ planned\ food)$
        - Dimension: Kg/Week

- **Amount of planned food** is influenced by the variables *Average amount of food needed for a household* and the *Perceived amount of stored food*. The actual needed food is the *Average amount of food needed for a household* minus the *Perceived amount of inventory*. To consider the fact that having a lot food stored, which is more than the needed, an IFTHENELSE function is needed. This function ensures that the planning will not go negative, which is not possible in reality. This will result in the following mathematical relation:
    - $Amount\ of\ planned\ food = IF\ THEN\ ELSE(\ Perceived\ amount\ of\ inventory >= Average\ amount\ of\ food\ needed\ for\ a\ household,\ 0.1, (Average\ amount\ of\ food\ needed\ for\ a\ household - Perceived\ amount\ of\ inventory))$
        - Dimension: Kg/Week

- **Perceived amount of inventory** is influenced by the variables *Amount of stored food, Amount of leftovers stored*, and *Fraction inventory* taken into account. The *Fraction inventory taken into account* can be multiplied with the *Amount of stored food* and the *Amount of leftovers stored*. This will result in the following mathematical relation:
    - $Perceived\ amount\ of\ inventory\ =\ (Fraction\ of\ inventory\ taken\ into\ account)\ *\ (Amount\ of\ stored\ food\ +\ Amount\ of\ leftovers\ stored)$
        - Dimension: Kg/Week

- **Fraction of inventory taken into account** is influenced by the variables *Fraction of inventory remembered by household* and the *Degree of inventory checking*. It will result in a fraction of the inventory that will be taken into account between 0 and 1. In order to not check more than 100% of the inventory, the *Degree of inventory checking* should cover the part that is not remembered by the household. This will result in the following mathematical relation:
    - $Fraction\ of\ inventory\ taken\ into\ account = Fraction\ of\ inventory\ remembered\ by\ household\ +\ ((1 - Fraction\ of\ inventory\ remembered\ by\ household) * Degree\ of\ inventory\ checking$
        - Dimension: dimensionless

Purchasing

The data that is needed in order to generate the buying behaviour will be taken into account in this sub-section. The behaviour of interest is that people tend to buy even more food than actually planned, which was already more than actually needed, ending up with too much food available for consumption. The qualitative model for the purchasing phase can be transformed into a Vensim sub-model, which can be found in **figure 72**. In this section, an extra variable is needed that is not explicitly mentioned in qualitative model, in chapter 2. This is the *Effect of the frequency of shopping*. The variables derived from the qualitative analysis in section 2.3.2 are depicted in blue and the extra variables are depicted in green. Variables from another phase do not have a colour.

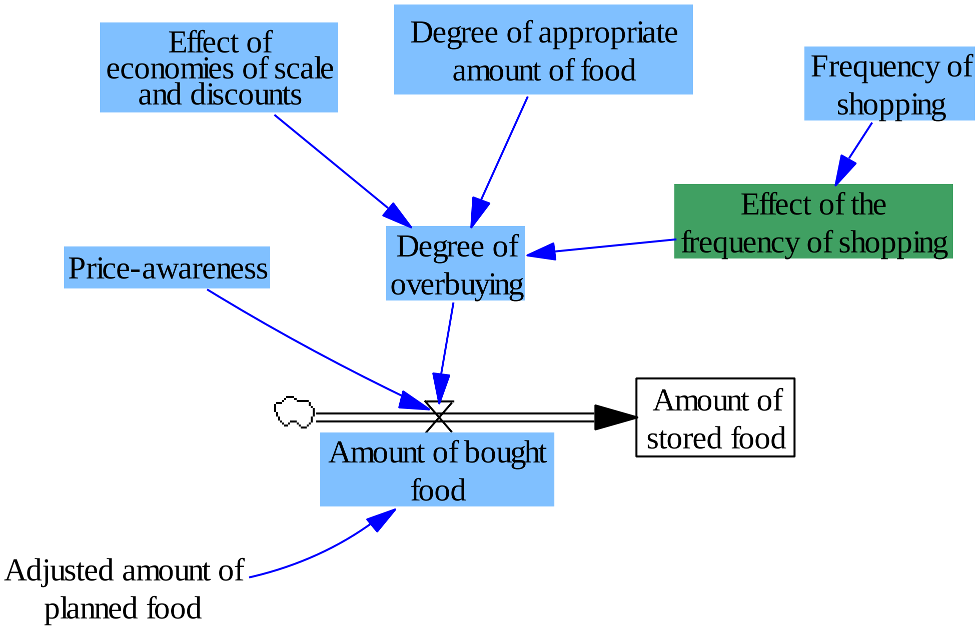


Figure 72: purchasing phase sub-model

The data for the relation between the *Amount of bought food* and *the Amount of stored food* will be discussed in next phase, during the storing phase. The value of the variable *Amount of planned food* has been discussed during the planning phase and will not be covered in this sub-section. Based upon **figure 72**, the following relations and parameters can be identified for which data is needed in order to generate the desired behaviour:

Parameter values within the purchasing phase

Based upon the sub-model identified by figure XX, the following parameters can be identified:

- **Price-awareness**; a value should be used in order to represent the price-awareness of a household. Households with a higher amount *Price-awareness* do not buy unneeded amounts of food. It is assumed that only 5% of the people within the Netherlands do tend to not buy more than actually planned since they cannot afford it. The Netherlands is an industrialised country; it can be assumed that almost every household has enough income to not worry about buying more food than actually needed. Therefore it is assumed that 95% of the food will be bought, resulting in a value of 0.95.
    - $Price - awareness \ = \ 0.95$
        - Dimension: dimensionless

- **Effect of economies of scale and discounts**; it might that bigger amounts of food are cheaper due to the economies of scale. Quantity discounts might resulting in too much unneeded food, which not will be eaten in the end and end up as food waste. A part of these discount packages have been taken into account under the Price-awareness variable, but there are also people who intend to buy and waste also more (Jörissen et al. 2015). It is assumed that given a standard Dutch household, people do tend to buy 10% more on average than needed, since no data is available on this topic.

- o $Effect\ of\ economies\ of\ scale\ and\ discounts = 0.10$

- **Degree of appropriate amount of food**; if a certain amount is not available; it might be possible that people do buy more food than needed. It has been assumed that people tend to buy too much food rather than not enough, resulting in food that not will be prepared or eaten in the end. It has been argued that this is mainly the case for households with one person (Evans, 2011; Koivupuro et al., 2012; Ganglbauer et al., 2013; Jörissen et al., 2015). In the Netherlands, around 38% of the households is single membered. Assume that 1/3rd of the time these households have to buy more food than needed, which is 50% more than needed each time. This can be represented by a fraction of food that has been bought too much, which can be calculated by 0.38*0.33*05.
  - o $Degree\ of\ appropriate\ amount\ of\ food = 0.0627$
    - ▪ Dimension: dimensionless

- **Frequency of shopping**; shopping more is assumed to lead to less wasted food. In this study it is assumed that people tend to shop 3 times a week. Based upon an online survey provided by the ING. Based upon 64.000 households, it has been stated that the average Dutch household shops 3 times a week as average in order to buy the food needed. This value will also be used for this parameter.
  - o $An\ amount\ of\ 3\ trips\ per\ week$
    - ▪ Dimension: dimensionless

Relations within the purchasing phase
Based upon the sub-model identified by figure XX, the following relations can be identified:

- **The Amount of bought food** is influenced by the variables *Amount of planned food*, *Price-awareness*, and *Degree of overbuying*. The *Degree of overbuying* will be calculated compensated by the fraction of the *Price-awareness*. These values will be multiplied by each other. This will result in the following mathematical relation:
  - o $Amount\ of\ bought\ food = (Adjusted\ amount\ of\ planned\ food * Degree\ of\ overbuying * "Price - awareness") + Adjusted\ amount\ of\ planned\ food$
    - ▪ Dimension: Kg/Week

- **The Degree of overbuying** is influenced by the variables *Price/Kg ratio, Degree of appropriate amount of food*, and the *Effect of the frequency of shopping*. All the variables will lead to a higher percentage of overbuying and can be cumulated. This will result in the following mathematical relation:
  - o $The\ Degree\ of\ overbuying = ((Effect\ of\ economies\ of\ scale\ and\ discounts + Degree\ of\ appropriate\ amount\ of\ food) * (Effect\ of\ the\ frequency\ of\ shopping)) + (Effect\ of\ economies\ of\ scale\ and\ discounts + Degree\ of\ appropriate\ amount\ of\ food)$
    - ▪ Dimension: dimensionless

- **Effect of the frequency of shopping** is a product of the frequency of shopping. Jörissen et al. (2015) state that the difference between households that go every second day, twice a week, and every week isn't that big; around the 130, 140, and 150 gram food waste per person. Households in Germany have thus shown a little decrease regarding the waste of food, while increasing the number of trips; Williams et al. (2012) state also that more Swedish households do increase the Amount of food waste when decreasing the number of trips, with an average food waste of 2kg (purchase seldom) and 1,25kg (purchase often). Taking into account that going more often to the supermarket will lead to a lower amount of food waste, it is assumed that doing more groceries will result in lower amount of bought food. Based upon the available the data the relative *Amount of bought food* will increase by the behaviour given in **figure 73**. The x-axis represent the *Frequency of shopping* and the y-axis represents the effect of these frequencies on the *Degree of overbuying.*

- $Effect\ of\ the\ frequency\ of\ shopping\ =$
  - Dimension: dimensionless

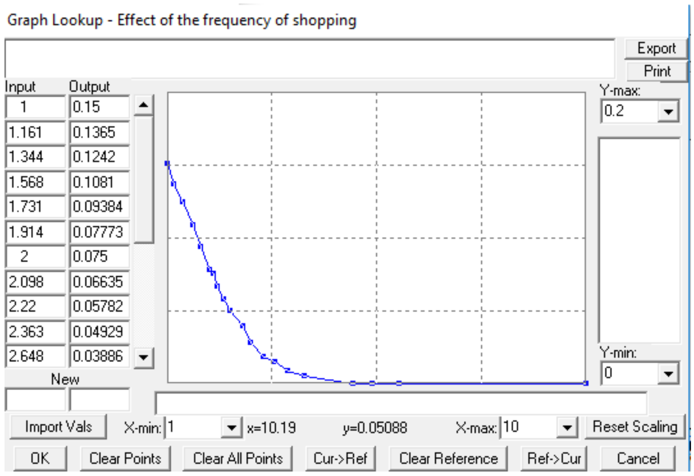


Figure 73: Graph Lookup Effect of frequency of shopping

Storing

The data that is needed in order to generate the storing behaviour will be taken into account in this sub-section. The behaviour of interest is that people need to store the food that has been bought, which will result in two types of food waste due to the fact that people tend to plan to buy more food than needed, and even buy more food than planned ending up with even more food than actually needed. The qualitative model for the storing phase can be transformed into a Vensim sub-model, which can be found in **figure 74**. In this section, extra variables are needed that are not explicitly mentioned in qualitative model, chapter 2. These are: *Effect of storing conditions, Effect spoilage knowledge, Fraction storing effect on used by date, Spoilage knowledge*, and the *Effect on the used by date*. The variables derived from the qualitative analysis in section 2.3.3 are depicted in blue and the extra variables are depicted in green. Variables from another phase do not have a colour.

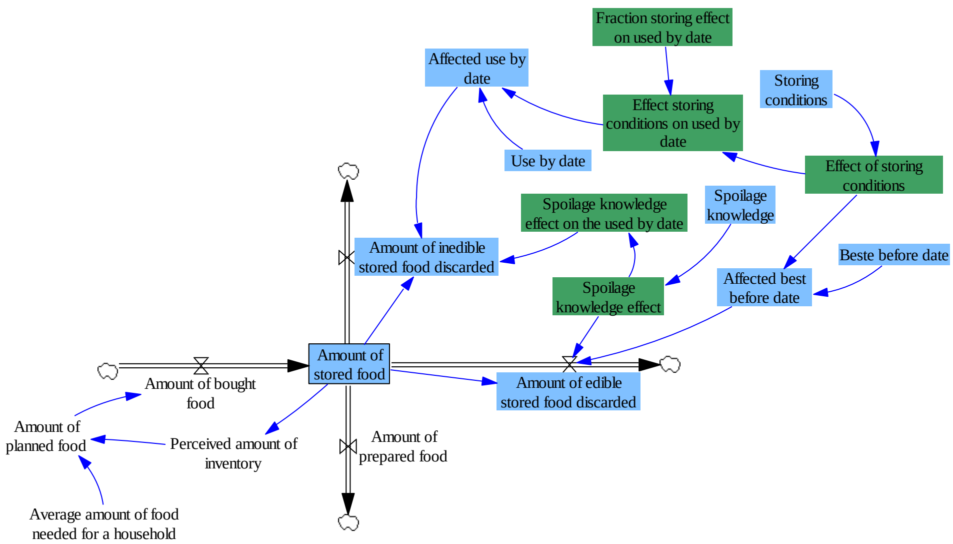


Figure 74; storing phase sub-model

The data for the relation between the Amount of bought planned and the Amount of bought food has been discussed in previous phase, the purchasing phase. The relation between the stored amount of food & the perceived amount of inventory and the relation between the perceived amount of inventory & the *Amount of planned food* have already been discussed during the planning phase. The relation between the Amount of stored food and the *Amount of prepared food* will be discussed in next section, the preparing phase. Based upon **figure 74**, the following relations and parameters can be identified for which data is needed in order to generate the desired behaviour.

Parameter values within the storing phase
Based upon the sub-model identified by figure 74, the following parameters can be identified:

- **Storing conditions**; these conditions represent the quality in which food can be stored. In the current literature, no average level of *Storing conditions* can be found. In the Netherlands, it can be assumed that people are well educated on how to store their food and almost every household does have the right measures to store food; a freezer and a fridge. Therefore a value of 0.7 has been chosen.
  - $Storing\ conditions = 0.7$
    - Dimension: dimensionless

- **Spoilage knowledge**: knowing the difference between what is actually spoiled and what is still edible, even when it has surpassed the best-by date or the used-by date is not known well enough within the Netherlands. It has been estimated that only 50% of the households do actually know how to cope with these aspects. It might be possible that households tend to throw food away when it has surpassed the best-before date while it still is edible. Therefore a value of 0.5 will be used throughout this study.
  - $Spoilage\ knowledge\ =\ 0.5$
    - Dimension: dimensionless

- **Use by date:** important is that the use by date should be lower than best before date. Since there are many different types of products, and they are taken together in this study as an average. Therefore a specific estimation is hard to make. Therefore a rough estimation has been used, which is 1/3rd of the best before date. In this study it has been assumed that the *Use by date* is 1 week. It will take 1 week on average before the *Use by date* has been reached and the food needs to be thrown away.
  - $Use\ by\ date =\ 1$
    - Dimension: Weeks

- **Best before date:** the best before should be higher than the used by date. Since there are many types products possible and due to the fact that an average will be taken into account during this study, a specific estimation is hard to make. As mentioned at the *Use by date,* the *Best before date* will be 3 times as much. Therefore a rough estimation has been used of 3 weeks . Food might still be eatable when it has surpassed the *Best before date.*
  - $Best\ before\ date\ =\ 3$
    - Dimension: Weeks

- **Fraction storing effect on used by date:** this variable is needed in order to represent a different effect on the different kinds of dates. Where *Storing conditions* do have a bigger impact on the *Best before date*, a smaller impact should be expected on the *Used by date*. As mentioned in section 2.3.3, the *Best before date* is about quality and the U*sed by date* is about safety. Therefore, the *Used by date* cannot be stretched too much. It is assumed that having storing conditions will have 1/10th of the effect on a used by date regarding the *Best before date*.
  - $Fraction\ storing\ effect\ on\ used\ by\ date\ \ =\ 0.1$
    - Dimension: dimensionless

Relations within the storing phase
Based upon the sub-model identified by figure 74, the following relations can be identified:

- **Amount of stored food** is influenced by the *variables Amount of bought food, Amount of inedible stored food discarded, Amount of edible stored food discarded*, and *Amount of prepared food*. Due to the fact that this variable has been modelled as a stock, the value of this variable can be calculated by adding the *Amount of bought food* and extracting the *Amount of inedible stored food discarded*, *Amount of edible stored food discarded*, and *Amount of prepared food*. This will result in the following mathematical relation:
    - $Amount\ of\ stored\ food\ =$ $Amount\ of\ bought\ food - (Amount\ of\ inedible\ stored\ food\ discarded\ +$ $Amount\ of\ edible\ stored\ food\ discarded\ +\ Amount\ of\ prepared\ food)$
        - Initial value: in this section a value of 2.5 will be used. However, in order to estimate the correct value, a test will be performed in section 5.3.5 and based upon results of this test, a value will be chosen.
            - $Initial\ value\ =\ 2.5$
                - Dimension: Kg/Week

- **Amount of inedible stored food discarded** is influenced by the variables *Amount of stored food, Affected use by date*, and the *Spoilage knowledge effect on the used by date. The Amount of stored food /Affected use by date* will be multiplied with the *Spoilage knowledge effect on the used by date*. Where the knowledge effect is bigger, less food will be thrown away on the short term, represented by the used by date, resulting in less food waste. This will result in the following mathematical relation:
    - $Amount\ of\ inedible\ stored\ food\ discarded\ =\ ((Amount\ of\ stored\ food\ /$ $(Perceived\ used\ by\ date)\ *\ (Spoilage\ knowledge\ effect\ on\ the\ use\ by\ date))$
        - Dimension: Kg/Week

- **Amount of edible stored food discarded** is influenced by the variables *Amount of stored food, Perceived best before by date,* and the *Spoilage knowledge*. The *Amount of stored food* divided by the *Affected use by date* will be multiplied with *Spoilage knowledge effect*. Where the effect is bigger, more food will be thrown away on the longer term represented by the *Best before date*, resulting in less food waste. This will result in the following mathematical relation
    - $Amount\ of\ edible\ stored\ food\ discarded\ =\ (Amount\ of\ stored\ food/$ $Perceived\ best\ before\ date)\ *\ Spoilage\ knowledge\ effect$
        - Dimension: Kg/Week

- **Spoilage knowledge effect on the used by date** is dependent on the variable Spoilage knowledge effect. Having a higher Spoilage knowledge will result in a shift from being dependent on the *Best before date* rather than on the *Use by date*. This will represent a shift in the average time before food will be thrown away. Increasing the *Spoilage knowledge* will thus increase the average time it takes before food will be discarded. In order to be less dependent on the *Used by date*, the spoilage knowledge effect should be compensated. This will result in the following mathematical relation:
    - $Spoilage\ knowledge\ effect\ on\ the\ used\ by\ date\ =\ 1 -\ Spoilage\ knowledge\ effect$
        - Dimension: dimensionless

- **Spoilage knowledge effect** is a influenced by the variable *Spoilage knowledge*. Having more spoilage knowledge will result in a higher *Effect of spoilage knowledge*. As stated, *Spoilage knowledge* can differ from nothing with the input value (0%) and to full knowledge with the input value 1 (100%). The behaviour regarding the effect is assumed to be s-shaped, as can be seen in **figure 75**. The x-axis represents the *Spoilage knowledge* and the y-axis represent the effect on the *Amount of edible stored food discarded.*
    - $Effect\ of\ spoilage\ knowledge\ =$
        - Dimension: dimensionless

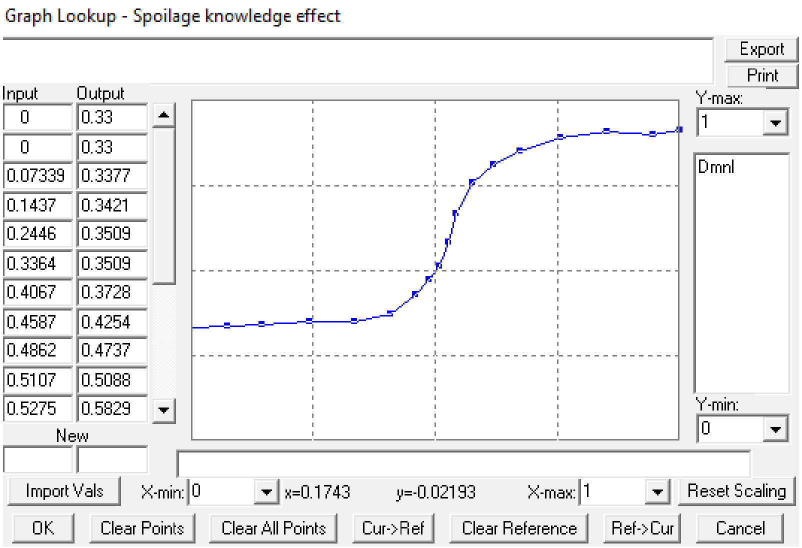


Figure 75; Graph Lookup Spoilage knowledge effect

- **Effect storing conditions on used by date** is influenced by the variables *Effect of storing conditions* and *Fraction storing effect on used by date*. This variable is needed in order to represent the lowered effect on the used by regarding the best before date. Because the effect is 1/10th of the original effect, it can be calculated by multiplying the influencing variables. This will result in the following mathematical relation:
  - $Effect\ storing\ conditions\ on\ used\ by\ date\ = Effect\ of\ storing\ conditions\ *\ Fraction\ storing\ effect\ on\ used\ by\ date$
    - Dimension: dimensionless

- **Affected best before date** is influenced by the variable is a product of Effect storing conditions and Best before date. The Affected best before date is the Best before date, which is almost influenced by Effect of storing conditions. 100% of the effect will be taken into account. This will result in the following mathematical relation:
  - $Perceived\ best\ before\ date\ = (Best\ before\ date\ *\ Effect\ of\ storing\ conditions) + Best\ before\ date$
    - Dimension: Weeks

- **Affected used by date** is influenced by the variable is a product of Effect storing conditions on used by date and Used by date. The Affected use by date is the Used by date, which is almost not influenced by Effect of storing conditions. Only 10% of the effect will be taken into account. This will result in the following mathematical relation:
  - $Affected\ use\ by\ date\ = Use\ by\ date\ + (Use\ by\ date\ *\ Effect\ storing\ conditions\ on\ used\ by\ date)$
    - Dimension: Weeks

- **Effect of storing conditions** is a product of the Storing conditions. Having no storing conditions will have a negative effect, resulting in an output of 10%, which has the value of -0.1. Having perfect storing conditions will lead to a positive effect, which is 10%, accompanied with a value of 0.1. Between these values, a s-shaped has been estimated, which can be found **in figure 76.**
  - $Effect\ of\ storing\ conditions\ =$
    - Dimension: dimensionless

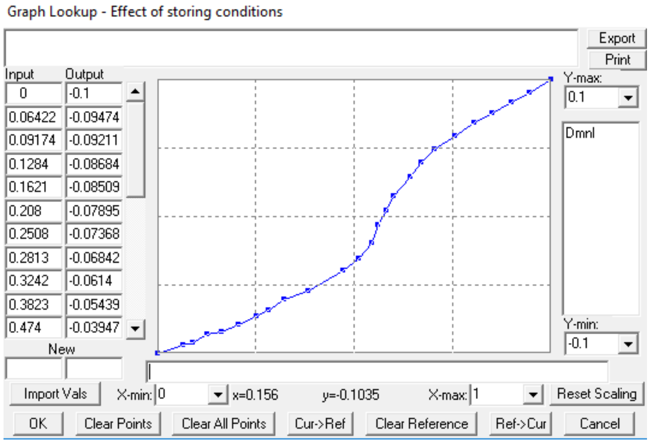


Figure 76; Graph Lookup Effect of storing conditions

Preparing

The data that is needed in order to generate the preparing of food behaviour will be taken into account in this sub-section. The behaviour of interest is that people need to prepare the food that has been stored, which will result in one food waste variable. The qualitative model for the preparing phase can be transformed into a Vensim sub-model, which can be found in **figure 77**. In this section, extra variables are needed that are not explicitly mentioned in qualitative model, chapter 2. These are *Fraction stored food of the total amount of food needed for a household, Effect of stored food*, and *Total amount of edible food leftover*. The variables derived from the qualitative analysis in section 2.3.4 are depicted in blue and the extra variables are depicted in green. Variables from another phase do not have a colour.

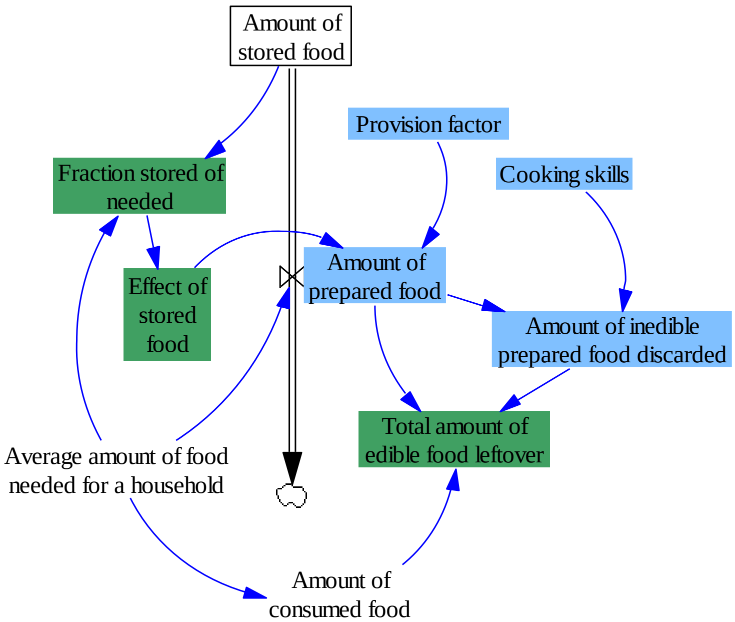


Figure 77: preparing phase sub-model

The value of the Amount of stored food has been discussed in previous phase, the storing phase. The *Average amount of food needed for a household* and the *Average Kg/person* will be considered in the last phase, during the general phase. The value of the *Amount of consumed food* will be taken into account during next phase, the consuming phase. Based upon **figure 77**, the following relations and parameters can be identified for which data is needed in order to generate the desired behaviour:

Parameter values within the preparing phase

Based upon the sub-model identified by **figure 77**, the following parameters can be identified:

- **Provision factor;** this factor represents the amount of food households ought to make more than actually needed by a household for consumption. Households do prefer to make too much food in order to make sure that everyone eats enough. No data is available regarding this topic. Given that households tend to prepare more food than needed, but not too much it is assumed that the average household will use an additional percentage of 5% above the *Average amount of food needed for a household* .
  - $Provision\ factor = 0.05$
    - Dimension: dimensionless

- **Cooking skills;** it is important to consider that food should not be edible in order to be ruined. No scientific literature on the *Cooking skills* of the average household within the Netherlands is available, therefore it is assumed that on average, a household ruins food $1/40^{th}$ of the time (including breakfast, lunch, and dinner). In order to represent this value a cooking skill of 97.5% will be used, which represents the fraction of the times that the cooking does succeed.
  - $Cooking\ skills\ =\ 0.975$
    - Dimension: dimensionless

Relations within the preparing phase

Based upon the sub-model identified by **figure 77**, the following relations can be identified:

- **Amount of prepared food** is influenced by the variables *Average amount of food needed for a household, Provision factor*, and the *Effect of the storage*. Regarding the *Effect of the storage*, the amount resulting from the multiplication of *Provision factor* and the *Average amount of food needed for a household* will be multiplied by this factor. This will result in the following mathematical relation:
  - $Amount\ of\ prepared\ food\ =\ IF\ THEN\ ELSE\ (Amount\ of\ stored\ food\ >= 0, (Average\ amount\ of\ food\ needed\ for\ a\ household\ - Amount\ of\ leftovers\ consumed)\ + ((Average\ amount\ of\ food\ needed\ for\ a\ household - Amount\ of\ leftovers\ consumed)\ *\ (Provision\ factor\ +\ Effect\ of\ stored\ food)), 0)$
    - As mentioned during the structure assessment in section 5.2.3**,** an if then else function is needed in order to model the decision of the household that they cannot prepare more food than is available in the storage. If not enough food is available within a household, than the household will prepare what is available and nothing more, resulting in a non-negative storage.
      - Dimension: dimensionless

- **Amount of inedible prepared food discarded** is influenced by the variables *Amount of prepared food* and *Cooking skills*: The *Amount of prepared food* will be used as input for the *Amount inedible food prepared*. A fraction of the *Amount of prepared food* will be ruined based upon the *Cooking skills* of the household, which will be can be calculated by multiplying these variables. This will result in the following mathematical relation:
  - $Amount\ of\ inedible\ prepared\ food\ discarded = (Cooking\ skills\ * Amount\ of\ prepared\ food)$
    - Dimension: Kg/Week

- **Total amount of edible food leftover** is a product of the following variables: *Amount of consumed food, Amount of inedible prepared food discarded,* and *Amount of prepared food. The Amount of edible food leftover* is the difference between the *Amount prepared food* and the *Amount of consumed food* minus the *Amount of inedible prepared food discarded*. This will result in the following mathematical relation:

- $Total\ amount\ of\ edible\ food\ leftover = Amount\ of\ consumed\ food - (Amount\ of\ prepared\ food - Amount\ of\ inedible\ prepared\ food\ discarded)$
    - Dimension: Kg/week

- **Effect of stored food** is influenced by the variable *Fraction stored food needed.* This fraction represents the fraction of the total amount of food needed for a household that is present within the storage. In order to estimate the effect of the storage on the *Amount of prepared food*, a look-up function will be used. Having a full storage, having more than a full meal for all members within a household for a week will result in an additional 5% of prepared food. Having no food at all stored will result in no increase. The effect between these points can be illustrated by **figure 78**. The x-axis represent the fraction of meals present within the storage and the y-axis is the Effect of stored food ranging from 0 to 0.05.
  - $Effect\ of\ stored\ food =$
    - Dimension: dimensionless

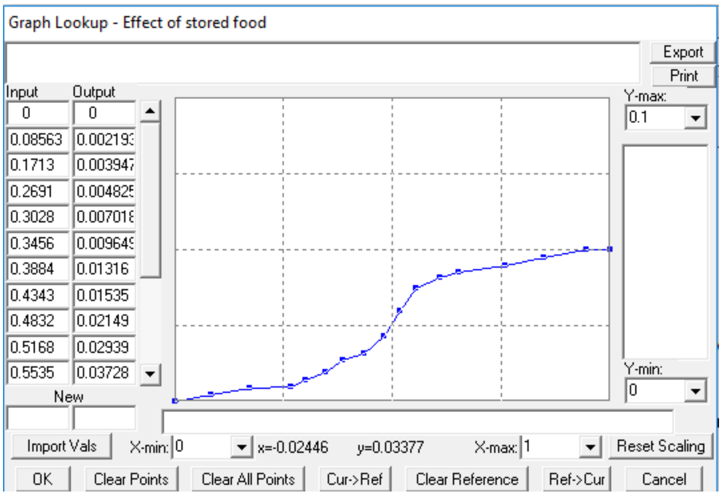


Figure 78; Graph Lookup Effect of stored food

- **Fraction stored food of the total amount of food needed for a household** is influenced by the variables *Amount of stored food* and the *Average amount of food needed for a household*. This fraction represents the amount of meals that are present within a household. The *Amount of stored food* will be divided by the Average food needed for a household in order to calculate the fraction. This will result in the following mathematical relation:
  - $Fraction\ stored\ food\ of\ the\ total\ amount\ of\ food\ needed\ for\ a\ household = Amount\ of\ stored\ food / Average\ amount\ of\ food\ needed\ for\ a\ household$
    - Dimension: dimensionless

Consuming

The data that is needed in order to generate the consuming behaviour will be taken into account in this sub-section. The behaviour of interest is that households need to consume the food that has been prepared, which will result into one food waste variable. The qualitative model for the consuming phase can be transformed into a Vensim sub-model, which can be found in **figure 24.** In this section a difference has been made between the Total amount of edible food leftover and the Amount of edible food leftover, which not has been made during the conceptualisation in chapter 2: The Effect on discarded leftovers has been added. The variables derived from the qualitative analysis in section 2.3.5 are depicted in blue and the extra variables are depicted in green. Variables from another phase do not have a colour.

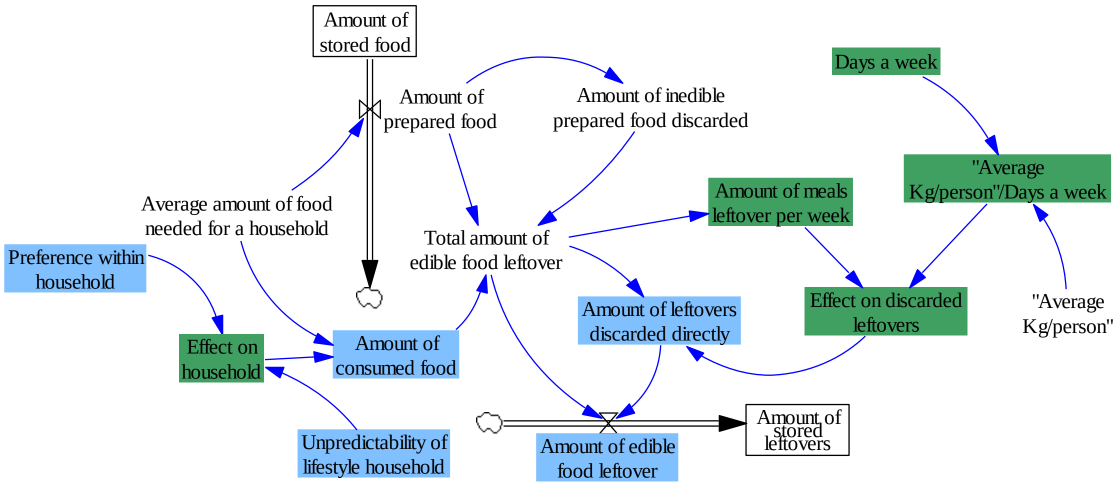


Figure 79: consuming phase sub-model

The value of the Amount of stored food has been discussed in the storing phase. The *Amount of prepared food*, the relation between the Average amount of food needed for a household, and the Amount of inedible prepared food discarded have been discussed in previous section. The Average amount of food needed for a household will be considered in the last phase, the general phase. The value of the *Amount of leftovers stored* will be taken into account during the following phase, the re-using leftover phase. The average Kg per person will be discussed during the general phase. **Based upon figure 79,** the following relations and parameters can be identified for which data is needed in order to generate the desired behaviour:

Parameter values within the consuming phase
Based upon the sub-model identified **by figure 79**, the following parameters can be identified:

- **Preferences within household:** the level of preferences is influencing the amount of food eaten by the households. A household with a high preference will not eat what it ought to eat since its members will dislike a lot of food and therefore not eat it. Since no literature is available on this topic it is assumed that than a household will not eat 1.5% due to the preferences present within a household.
  - $Preferences\ within\ household\ =\ 1.5\%$
    - Dimension: dimensionless

- **Unpredictability lifestyle household**; a life that is predictable will lead to an normal average of food that is being consumed by a household. Having more people within a household that do not have a predictable life will lead to disruptions regarding the consumption of food. It is assumed that the average household does have a missing person due to an unpredictable lifestyle.
  - $Predictability\ lifestyle\ household\ =\ 1.5\%$
    - Dimension: dimensionless

- **Days a week:** is the amount of days needed in order to calculate the average amount of kg is needed per person in a household. This parameter has therefore a value of 7, since there are 7 days in a week and in this model the time unit is 7.
  - $Days\ is\ a\ week\ =\ 7$
    - Dimension: days

Relations within the consuming phase
Based upon the sub-model identified **by figure79**, the following relations can be identified:

- **Amount of consumed food** is influenced by the variables *Effect on household* and *Average amount of food needed for a household*. The variables *Preference within household* and

Unpredictability of lifestyles household have been taken together in the variable *Effect on household*. This value represents an deviation of the normal amount of food that should be eaten, therefore a multiplication is sufficient. In order to calculate the *Amount of consumed food* the *Average amount of food needed for a household* should be compensated by the *Effect on household.* This will result in the following mathematical relation:

- $Amount\ of\ consumed\ food\ = (Average\ amount\ of\ food\ needed\ for\ a\ household) - (Effect\ on\ household\ * Average\ amount\ of\ food\ needed\ for\ a\ household)$
    - Dimension: Kg/Week

- **Effect on household** is a product of the *Unpredictability of lifestyle household* and *Preference within household*. The effect can be calculated by calculating these two parameters together. This will result in the following mathematical relation:
    - $Effect\ on\ household\ = (Predictability\ of\ lifestyle\ household + Preference\ within\ household)$
        - Dimension: dimensionless

- **Amount of leftovers discarded directly** is influenced by the variables *Total amount of edible food leftover* and the *Effect on discarded leftovers directly*. These values can be multiplied by each other in order to calculate the *Amount of leftovers discarded directly*. This will result in the following mathematical relation:
    - $Amount\ of\ leftovers\ discarded\ directly\ = Total\ amount\ of\ edible\ food\ leftover\ * Effect\ on\ discarded\ leftovers$
        - Dimension: Kg/Week

- **Effect on discarded leftovers** is dependent on the variable *Fraction leftover per person*. It is assumed that if not more than 1/3rd of a meal is being left over after dinner, there will be a high probability that more leftover will be thrown away directly. Otherwise, it will be stored and eventually eaten at a later stage**.** In order to represent that relation a look-up graph has been established, which can be found in figure 29. The x-axis represents the *Fraction leftover per person*. The y-axis represents the fraction of the food leftover that will be discarded.
    - $Effect\ on\ discarded\ leftovers\ =$
        - Dimension: dimensionless

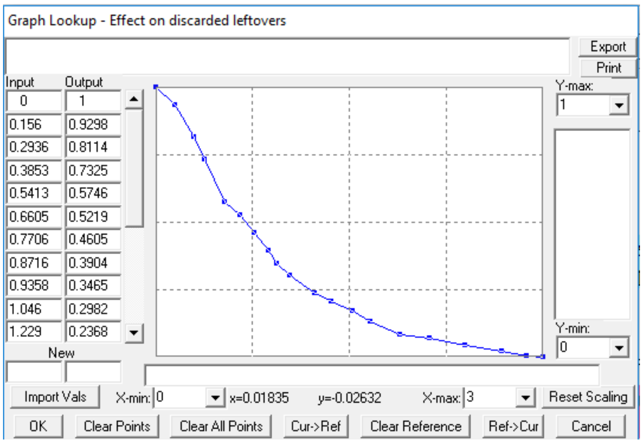


Figure 80; Graph Lookup Effect of discarded leftovers

- **Fraction leftover per person** is a variable of the *Average Kg/person* and the *Average Kg food per day per person.* This value calculates percentage of food that is being leftover per week given the normal amount a person would eat in a day. This variable will be used as input in order to calculate the *Effect on discarded leftovers*. In order to calculate this fraction, the amount of leftovers should be divided by the *Average Kg-Person*. This will result in the following mathematical relation:

- $Fraction\ leftover\ per\ person\ = Total\ amount\ of\ edible\ food\ leftover\ /$ Average Kg/person"
    - Dimension: dimensionless

- **Average Kg food per day per person** is a variable that is dependent on the variables *"Average Kg/person"* and *Days a week.* This variable represents the fraction of a meal for one person a day is being leftover regarding the total amount of leftovers. This value can be calculated by dividing these values. This will result in the following mathematical relation:
  - $Average\ Kg\ food\ per\ day\ per\ person\ = "Average\ Kg/person"/Days\ a\ week$
    - Dimension: Kg/Week

- **Amount of edible food leftover** is influenced by the variables *Total amount of edible food leftover* and *Amount of leftovers discarded directly*. This amount will be used as input for the *Amount of leftovers stored*. The value of this parameter can be calculated by subtracting the *Amount of leftovers discarded directly* of the *Total amount of edible food leftover*. This will result in the following mathematical relation:
  - $Amount\ of\ edible\ food\ leftover\ = Total\ amount\ of\ edible\ food\ leftover\ - Amount\ of\ leftovers\ discarded\ directly$
    - Dimension: Kg/Week

Re-using leftovers

The data that is needed in order to generate the re-using leftover behaviour will be taken into account in this sub-section. The behaviour of interest is that households will or will not use the food that is being leftover, potentially resulting in food waste. The qualitative model for the re-using leftovers phase can be transformed into a Vensim sub-model, which can be found in **figure 81**. In order to take the relation between the Amount of leftovers stored and its effect on the *Amount of leftovers consumed*, two variables are needed, which are not specifically mentioned during the conceptualisation in chapter 2. The variables derived from the qualitative analysis in section 2.3.6 are depicted in blue and the extra variables are depicted in green. Variables from another phase do not have a colour.

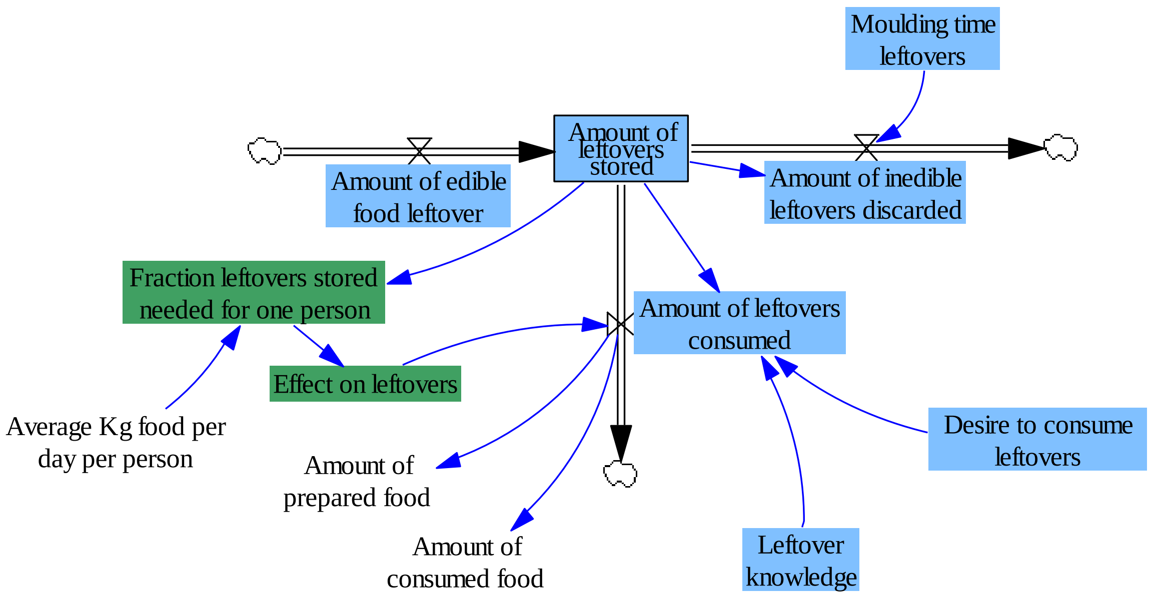


Figure 81; re-suing leftovers phase sub-model

The relation between the Amount of edible food leftover and the *Amount of prepared food* and the *Amount of prepared food* has been taken into account in previous phases, during the preparing phase and during the consuming phase. The *Average Kg/person* will be considered in the last phase, the general phase. Based upon **figure 81,** the following relations and parameters can be identified for which data is needed in order to generate the desired behaviour:

Parameter values within the reusing leftovers phase
Based upon the sub-model identified by **figure 81**, the following parameters can be identified:

- **Desire to consume leftovers**; a higher value represents the willingness to eat leftovers. There is no data available on this topic and therefore it is assumed that a household does have an average value of 0.5. Meaning that 50% of the time, a household is willing to consume leftovers.
    - $Desire\ to\ consume\ leftovers = 0.5$
        - Dimension: Dimensionless

- **Leftover knowledge**; Represents the knowledge on how to re-use leftovers. A higher value will lead to a higher ability of more re-use. No data is available on this topic. It is assumed that a household does have a knowledge of 0.8. Meaning that 80% of the time, a household knows how to re-use food.
    - $Leftover\ knowledge = 0.8$
        - Dimension: Dimensionless

- **Moulding time leftovers**; leftovers will decay fast over time. Therefore a smaller decay time has been chosen regarding the *Used by date* and the *Best before date.* It is also hard to take an average time for leftovers since the time before it decays is dependent on the type of food, therefore a decay time of 3 days has been chosen.
    - $Storing\ time\ leftovers = 3/7$
        - Dimension: Weeks

Relations within the reusing leftovers phase
Based upon the sub-model identified **by figure 81,** the following relations can be identified:

- **Amount of leftover stored** is influenced by the variables, *Amount of edible food leftover, Amount of leftovers consumed,* and *Amount of leftovers discarded*. During the simulation it is assumed than there are no leftovers present within the household at the beginning. Therefore an initial value of zero will be used. This will result in the following mathematical relation:
    - $Amount\ of\ leftover\ stored = (Amount\ of\ edible\ food\ leftover - (Amount\ of\ leftovers\ consumed + Amount\ of\ leftovers\ discarded))$
        - **Initial value:** in this section a value of 0 will be used. However, in order to estimate the correct value, a test will be performed in section 3.5.5
            - Dimension: Kg/Week

- **Amount of leftovers discarded** is influenced by the variables *Amount of leftovers stored* and *Storing time leftovers*. The same approach will be used as during the storage phase, but now, no difference will be made between the *Best before date* and *Used by date*. These will be taken together in a *Storing time of leftovers* variable. This will result in the following mathematical relation:
    - $Amount\ of\ leftovers\ discarded = Amount\ of\ leftovers\ stored / Storing\ time\ leftovers$
        - Dimension: Kg/Week

- **Amount of leftovers consumed** is influenced by the *variables Amount of leftovers stored, Desire to consume leftovers,* and *Leftover knowledge*. The consumption of the leftovers is dependent on the desire and knowledge. Multiplying the desire and the knowledge will result in the fraction that will be eaten of the leftovers. Based upon the amounts of leftovers available, an extra amount will be eaten if a lot of leftovers are being stored. The fraction of the total amount of food that is extra being eaten initially is the *Effect on leftovers.* This will result in the following mathematical relation:

- $Amount\ of\ leftovers\ consumed\ = IF\ THEN\ ELSE(\ Amount\ of\ leftovers\ stored\ >= 0, (Amount\ of\ leftovers\ stored * Desire\ to\ consume\ leftovers * Leftover\ knowledge) + ((Amount\ of\ leftovers\ stored * Desire\ to\ consume\ leftovers * Leftover\ knowledge) * Effect\ on\ leftovers), 0)$
    - As mentioned during the structure assessment in section 5.2.3 if then else function is needed in order to model the decision of the household that they cannot consumed more leftovers than are available in the storage.
        - Dimension: Kg/Week

- **Effect on leftovers** is influenced by the variable *Fraction of leftovers stored needed for one person*. It is assumed that leftovers tend to be eaten faster when bigger portions are available. It is assumed that the behaviour regarding the consumption of leftovers will be according the behaviour illustrated in **figure 82**. An s-shaped relation has been chosen. The x-axis represents the *Fraction of leftovers stored needed for one person* and the y-axis represents the effect on eating leftovers. The effect will be on the fraction of the food leftover that will be eaten extra, based upon the original amount.
    - $Effect\ on\ leftovers\ =$
        - Dimension: Dimensionless

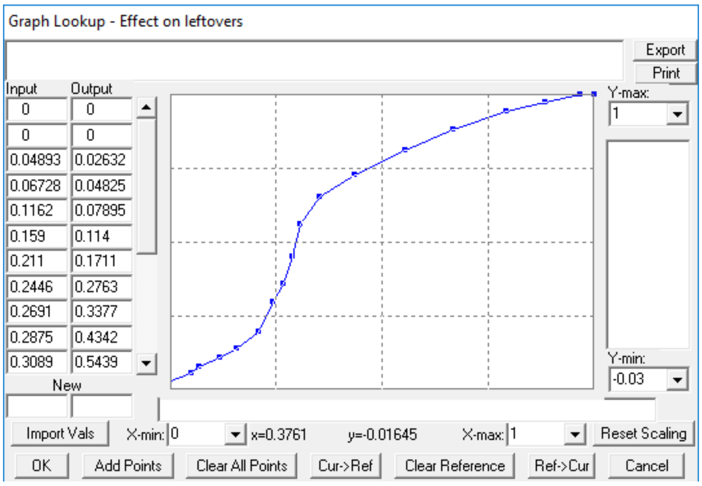


Figure 82; Graph Lookup Effect on leftovers

- **Amount of prepared food** should also be updated with the variable *Amount of leftovers consumed*. The *Amount of leftovers consumed* should be compensated while preparing food for the household. The original mathematical relation has been elaborated during the preparing phase of this section. Adding the *Amount of leftovers consumed* will result in the following updated mathematical relation:
    - $Amount\ of\ prepared\ food\ = (Average\ amount\ of\ food\ needed\ for\ a\ household\ - Amount\ of\ leftovers\ consumed) + ((Average\ amount\ of\ food\ needed\ for\ a\ household - Amount\ of\ leftovers\ consumed) * (Provision\ factor\ + Effect\ of\ stored\ food))$
        - Dimension: Kg/Week

- **Amount of consumed food** is influenced by the variable *Amount of leftovers consumed, Average amount of food needed for a household*, and the *Effect on households*. If leftovers are consumed, then the formula defined in the consuming phase should be updated with the *Amount of leftovers consumed*. This will result in the following updated mathematical relation:
    - $Amount\ of\ consumed\ food\ = (Average\ amount\ of\ food\ needed\ for\ a\ household - Amount\ of\ leftovers\ consumed) - (Effect\ on\ household\ *$

$(Average\ amount\ of\ food\ needed\ for\ a\ household -$
$Amount\ of\ leftovers\ consumed))$

- Dimension: Kg/Week

- **Fraction of leftovers stored for one person** is influenced by the variables *Amount of leftovers stored* and the *Average kg/person*. The fraction can be calculated by dividing the *Amount of leftovers stored by the Average kg/person*. This will result in the following updated mathematical relation:
  - $Fraction\ of\ leftovers\ stored\ for\ one\ person = Amount\ of\ leftovers\ stored\ /$ $"Average\ Kg/person"$
    - Dimension: Dimensionless

General variables data gathering

The parameters and the relations present within the multiple phases described in previous sub-sections should be connected in order to generate the behaviour of the system of a whole rather than phase specific. An overview of all the phases connected to each other can be found in **in chapter 4.** In this section, extra variables have been added that are not explicitly mentioned in qualitative model, chapter 2. These are *Total discarded stored food, Total discarded leftovers, Amount of inedible prepared food discarded, Fraction food thrown away, Total amount of thrown away food, Normal degree of over planning, Normal provision factor, Correctness factor planning, Correctness factor preparing, Effect on Degree of over planning*, and *Effect on provision factor.* The variables derived from the qualitative analysis in section 2.4 are depicted in blue and the extra variables are depicted in green. Variables from another phase do not have a colour.

In this sub-section the different phases will be connected to each other. Besides, general variables will be added. These variables cannot really be connected to one phase specific. The following relations and parameters can be identified for which data is needed in order to generate the desired behaviour,.

Parameter values within the general phase

Based upon the sub-model identified by figure XX, the following parameters can be identified:

- **Average Kg/person needed within household**. The average household in the United Kingdom of 2.4 people purchased around 27 kg of food and drink per week in 2011 (WRAP, 2013). Using this value as reference, resulting in the following amount per person:
  - $Average\ \frac{Kg}{person}\ needed\ withina\ household = 11{,}25$
    - Dimension: Kg/Week

- **Household size**; the average members per households should be taken into account in order to calculate the Amount of food needed for a household. In the Netherlands the average is 2,17 people.
  - $Household\ size = 2.17$
    - Dimension: Number of members

- **Knowledge on consequences food waste;** this variable can be represented by a value between 0 and 1. A value of 0 represents no knowledge at all and a value of 1 represents a total knowledge. Within the Netherlands it is assumed that the average household does have a knowledge level of 0.7. We are pretty well educated and most of the people do actually know what the consequences are regarding the waste of food.
  - $Knowledge\ on\ consequnces\ food\ waste = 0.7$
    - Dimension: Dimensionless

- **Normal degree of over planning;** this variable is needed in order it can be affected by the planning feedback loops. This variable is taken from the planning phase (the *Degree of over planning*). For Dutch households it is assumed to be 10%, resulting in a value of 0.1 for this parameter.

- $Normal\ degree\ of\ over\ planning = 0.1$
  - Dimension: Dimensionless

- **Normal provision factor:** this variable is needed in order to let the provision factor be influenced by the feedback loops regarding the planning behaviour. This variable is taken from the preparing phase (*Provision factor*). It is assumed that the average household will use an additional percentage of 5% above the normal needed amount of food.
  - $Normal\ provision\ factor = 0.05$
    - Dimension: Dimensionless

Relations within the general phase
Based upon the sub-model identified by figure XX, the following relations can be identified:

- **Average amount of food needed for a household** is influenced by the variables *Average Kg/person* and the *Average members household*. The average can be calculated by multiplying these two variables. This will result in the following mathematical relation:
  - $Average\ amount\ of\ food\ needed\ for\ a\ household = "Average\ Kg/person" * Average\ members\ household$
    - Dimension: Kg/Week

- **Total discarded stored food** is influenced by the variables *Amount of edible stored food discarded* and *Amount of inedible stored food discarded***.** Adding these values to each other will result in the *Total discarded stored food*. This will result in the following mathematical relation:
  - $Total\ stored\ food\ discarded = Amount\ of\ edible\ stored\ food\ discarded + Amount\ of\ inedible\ stored\ food\ discarded.$
    - Dimension: Kg/Week

- **Perceived amount of food waste planning** is influenced by the variables *Moral attitude* and the *Total food waste regarding the planning loops*. Wasting food might be seen as negative when the *Moral attitude* is high. However, having no *Moral attitude* and wasting a lot of food will result in a low *Perceived amount of food waste*. In order to have a high *Perceived amount of food waste*, a high *Moral attitude* and a high *Total waste of food* is needed. This will result in the following mathematical relation:
  - $Perceived\ amount\ of\ food\ waste\ planning = Moral\ attitude * Total\ food\ waste\ regarding\ the\ planning\ loops$
    - Dimension: Kg/Week

- **Perceived amount of food waste preparing** is influenced by the variables *Moral attitude* and *Total food waste regarding the preparing loops*. Wasting food might be seen as negative when the *Moral attitude* is high. However, having no *Moral attitude* and wasting a lot of food will result in a low *Perceived amount of food waste*. In order to have a high *Perceived amount of food waste,* a high *Moral attitude* and a high *Total waste of food* is needed. This will result in the following mathematical relation:
  - $Perceived\ amount\ of\ food\ waste\ preparing = (SMOOTHI(\ Moral\ attitude * Total\ food\ waste\ regarding\ the\ planning\ loops, Perceived\ time, Initial\ perceived\ amount\ of\ food\ waste\ planning))$
    - Dimension: Kg/Week

- **Correctness factor planning** is influenced by the variables *Average amount of food needed for a household* and *Perceived amount of food waste planning*. The perceived amount is divided by the *Average amount of food needed for a household*. This will result in the following mathematical relation:
  - $Correctness\ factor\ planning = Perceived\ amount\ of\ food\ waste\ planning / Average\ amount\ of\ food\ needed\ for\ a\ household$
    - Dimension: Dimensionless

- **Correctness factor preparing** is influenced by the variables *Average amount of food needed for a household* and *Perceived amount of food waste preparing*. The perceived amount is divided by the Average amount of food needed for a household. This will result in the following mathematical relation:
    - $\mathit{Correctness\ factor\ preparing} = \mathit{Perceived\ amount\ of\ food\ waste\ prepared} / \mathit{Average\ amount\ of\ food\ needed\ for\ a\ household}$
        - Dimension: Dimensionless

- **Degree of over planning** is influenced by the variables *Effect on degree of over planning* and the *Normal degree of over planning*. The *Degree of over planning* defined will be updated. The *Normal degree of over planning*, which has the same value as the variable defined in section 3.4.1.1 will be affected by the variable *Effect on degree of over planning*. This will result in the following updated formula:
    - $\mathit{Degree\ of\ over\ planning} = \mathit{Effect\ on\ degree\ of\ over\ planning} * \mathit{Normal\ Degree\ of\ over\ planning}$
        - Dimension: Dimensionless

- **Provision factor** is a influenced by the variables *Effect on provision factor* and *Normal provision factor*. The *Provision factor* defined will be updated. The *Provision factor*, which has the same value as the variable defined will be affected by the variable *Effect on Provision factor*. This will result in the following updated formula:
    - $\mathit{Provision\ factor} = \mathit{Effect\ on\ provision\ factor} * \mathit{Normal\ provision\ factor}$
        - Dimension: Dimensionless

- **Effect on degree of over planning** is a dependent on the *Correctness factor planning*. This factor will be used in order to affect the degree of over planning. In order to illustrate the impact of this variable, it has been assumed that the behaviour is according to **figure 83**. Having a bigger *Correctness factor planning* will result in a lower *Degree of over planning*. On the x-axis the *Correctness factor planning* is given, based upon the output will be given on the y-axis, which is the effect on the *Degree of over planning.* This will result in the following look-up function.
    - $\mathit{Effect\ on\ degree\ of\ over\ planning} =$
        - Dimension: Dimensionless

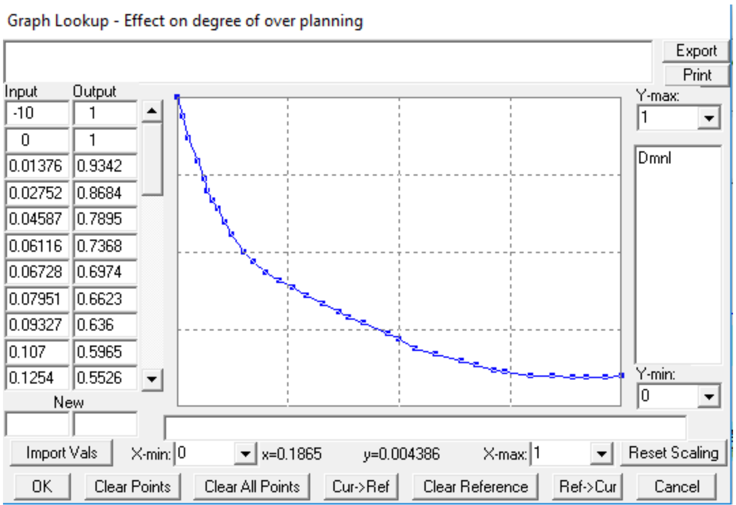


Figure 83; Graph Lookup Effect on degree of over planning

- **Effect on provision factor** is dependent on the variable *Correctness factor prepared*. This factor will be used in order to affect the *Degree of over planning*. In order to illustrate the impact of this variable, it has been assumed that the behaviour is according to **figure 84**.

Having a bigger *Correctness factor prepared*. will result in a lower *Provision factor*. On the x-axis the *Correctness factor preparing* is given, based upon the output will be given on the y-axis, which is the effect on the *Provision factor.* This will result in the following look-up function. This will result in the following look-up graph.

- ○ $Effect\ on\ provision\ factor\ =$
  - ▪ Dimension: Dimensionless

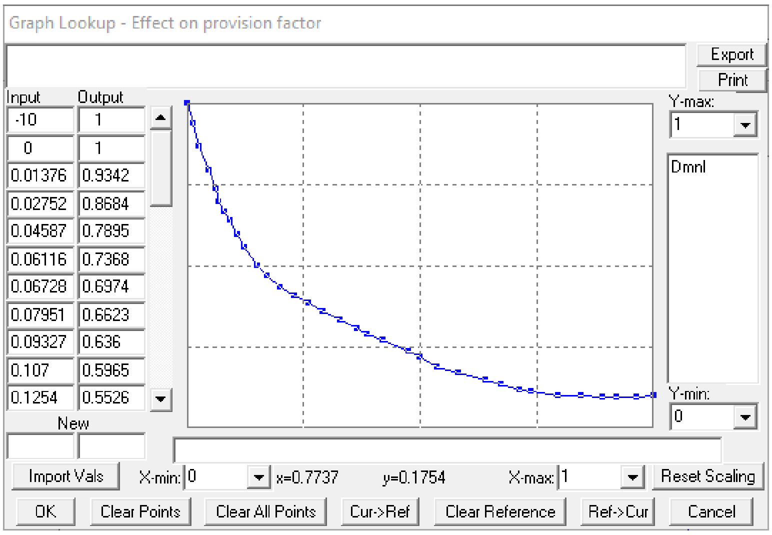


Figure 84; Graph Lookup Effect on provision factor

- **Moral attitude**: the moral attitude is a product of the *Knowledge on consequences food waste*. Attitude is expressed in a number between 0 and 1. A higher *Knowledge on consequences food waste* results in a higher *Moral attitude*. However, knowledge is not the only factor explaining the *Moral attitude*. Therefore a baseline will be chosen, which represents the normal level of *Moral attitude*. For a normal person it is assumed that a base-level of 0.4 moral attitude on average is applicable. This attitude increases when the *Knowledge on consequences food waste* does increase. The x-axis represents the *Knowledge on consequences food waste* and the y-axis represents the *Moral attitude.* The exact assumption regarding the effect of the moral attitude can be seen in figure:
  - ○ $Moral\ attitude\ =$
    - ▪ Dimension: Dimensionless

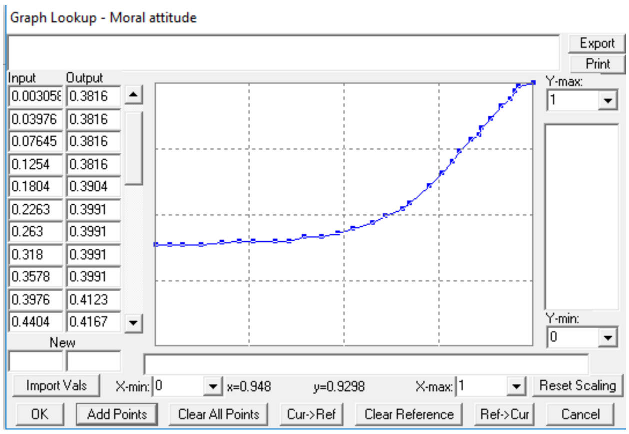


Figure 85: Graph Lookup Moral attitude

- **Total food waste regarding the planning loops** is influenced by the variables *Amount of inedible prepared food discarded*, *Total discarded leftovers*, and *Total discarded stored* *food.* These types wastes will be taken into account for coping with the variable *Degree of overbuying*. This amount can be calculated by adding these wastes to each other. This will result in the following mathematical relation:

- $Total\ food\ waste\ regarding\ the\ planning\ loops\ = Amount\ of\ inedible\ prepared\ food\ discarded\ +\ Total\ discarded\ leftovers\ +\ Total\ discarded\ stored\ food$
  - Dimension: Kg/Week

- **Total food waste regarding the preparing loop** is influenced by the variable *Total discarded leftovers*. Given the preparing loops, the only kinds of food waste that will be taken into account are these dependant on the leftovers. The other food waste variables are not applicable since the result of these food waste are caused by the preparation of food. This will result in the following mathematical relation:
  - $Total\ food\ waste\ regarding\ the\ preparing\ loop\ =\ Total\ discarded\ leftovers$
    - Dimension: Kg/Week

- **Total food waste** is influenced by the variables *Total discarded stored food, Total discarded leftovers,* and *Amount of inedible prepared food discarded.* Adding these values to each other will result in the *Total waste food*. This variable can be summarized by multiplying the *Total food waste* regarding the planning loops and the *Amount of inedible prepared food discarded*. This will result in the following mathematical relation:
  - $Total\ food\ waste\ =\ Total\ food\ waste\ regarding\ the\ planning\ loops\ +\ Amount\ of\ inedible\ prepared\ food\ discarded$
    - Dimension: Kg/Week

- **Total discarded leftovers** are a product of the variables *Amount of Leftovers discarded directly* and the *Amount of inedible leftovers discarded.* Adding these values to each other will result in the *Total leftovers* discarded. This will result in the following mathematical relation:
  - $Total\ leftovers\ discarded\ =\ Leftovers\ discarded\ directly\ +\ the\ Amount\ of\ inedible\ leftovers\ discarded$
    - Dimension: Dimensionless

- **Fraction food thrown away** are a product of the variables *Amount of food bought* and *Total food waste.* dividing these values to each other will result in the *Fraction food thrown away.* This will result in the following mathematical relation:
  - $Fraction\ food\ thrown\ away\ =\ Total\ food\ waste -\ amount\ of\ bought\ food$
    - Dimension: Dimensionless

Appendix C: Vensim-output

This appendix provides an overview of the parameters and relations used in the System Dynamics model. Per phase, an overview is given on the value or the mathematical relation and the dimensions used in the System Dynamics model.

- Spoilage knowledge = 0.5 ~ Dmnl
- Degree of using shopping list = 0.7 ~ Dmnl
- Fraction leftovers stored of needed for one person = Amount of leftovers stored/Average Kg food per day per person ~ Week*Person*Days
- Correctness factor planning = Perceived amount of food waste planning/Average amount of food needed for a household ~ Dmnl
- Knowledge consequences food waste = (0.7) ~ Dmnl
- Fraction of inventory remebered by household= 0.8 ~ Dmnl/Week
- Degree of inventory checking = 0.5 ~ Dmnl
- Effect of economies of scale and discounts =0.1 ~ Dmnl
- Effect on household = 0.03 ~ Dmnl
- Degree of appropriate amount of food = 0.0627 ~ Dmnl
- Used by date = 1 ~ Week
- Affected use by date = Used by date+(Used by date*Effect storing conditions on used by date) ~ Week
- Effect of using a shopping list= WITH LOOKUP (Degree of using shopping list, ([(0,0)-(1,0.1)] , (0,0.1) , (0.0504587, 0.0929825) , (0.0825688, 0.0850877) , (0.122324, 0.0798246) , (0.155963, 0.0723684) , (0.198777 ,0.0640351), (0.227829,0.0561404), (0.249235,0.0491228), (0.278287,0.0421053), (0.302752,0.0368421), (0.340979,0.0298246), (0.374618,0.0263158), (0.409786,0.0219298), (0.464832,0.0171053), (0.524465,0.0109649), (0.553517,0.00921053), (0.597859,0.00745614), (0.648318,0.00614035), (0.712538,0.00482456), (0.743119,0.00438596), (0.813456,0.00219298), (0.883792,0.00175439), (0.955657,0), (0.990826,-0.000438597), (1,0))) ~ Dmnl
- Perceived time =2 ~ Week
- Initial perceived amount of food waste prepared =0.3971 ~ Kg/Week
- Perceived amount of food waste planning = (SMOOTHI(Moral attitude*Total food waste regarding the planning loops, Perceived time, Initial perceived amount of food waste planning)) ~ Kg/Week
- Correctness factor preparing = Perceived amount of food waste prepared/Average amount of food needed for a household ~ Dmnl
- Initial perceived amount of food waste planning = 1.235 ~ Kg/Week
- Amount of prepared food = IF THEN ELSE (Amount of stored food >= 0, (Average amount of food needed for a household - Amount of leftovers consumed) + ((Average amount of food needed for a household - Amount of leftovers consumed) * (Provision factor + Effect of stored food)),0) ~ Kg/Week
- Effect on discarded leftovers = WITH LOOKUP (Amount of meals leftover per week, ([(-100,0)-(100, 1)], (-100, 1),(0,1), (0.155963,0.92), (0.211009,0.872807), (0.293578,0.81), (0.385321,0.73), (0.440367, 0.662281), (0.541284, 0.57), (0.623853, 0.517544), (0.743119, 0.434211), (0.834862, 0.390351), (0.93578, 0.34), (1.04587, 0.29), (1.22936, 0.23), (1.36697, 0.2), (1.52294, 0.16), (1.66972, 0.12), (1.88991, 0.083), (2.11927, 0.065), (2.3945, 0.039), (2.6789, 0.021), (2.87156, 0.004), (3, 0), (100, 0), (100, 0))) ~ Dmnl
- Days a week = 7 ~ Days
- Amount of meals leftover per week = Total amount of edible food leftover/Average Kg food per day per person ~ Person*Days

- Average Kg food per day per person = "Average Kg/person"/Days a week ~ Kg/(Week*Person*Days)
- Provision factor= (Effect on provision factor)*Normal provision factor ~ Dmnl
- Effect on provision factor= WITH LOOKUP (Correctness factor preparing, ([(-0, 0)-(1, 1)], (-10, 1), (0, 1), (0.0137615, 0.934211), (0.0275229, 0.868421), (0.0458716, 0.789474), (0.0611621, 0.736842), (0.0795107, 0.662281), (0.0932722, 0.635965), (0.107034,0.596491), (0.125382, 0.552632), (0.14526, 0.52193), (0.172783, 0.469298), (0.200306, 0.429825), (0.229358, 0.403509), (0.259939, 0.381579), (0.29052, 0.359649), (0.328746, 0.333333), (0.366972, 0.302632), (0.399083, 0.289474), (0.437309, 0.258772), (0.475535, 0.236842), (0.538226, 0.188596), (0.639144, 0.144737), (0.740061, 0.114035), (0.844037, 0.100877), (0.963303, 0.0964912), (1, 0.1), (10, 0.1))) ~ Dmnl
- Degree of over planning = (Effect on degree of over planning)*Normal Degree of over planning ~ Dmnl
- Normal provision factor = 0.05 ~ Dmnl
- Normal Degree of over planning= 0.1 ~ Dmnl
- Effect on degree of over planning= WITH LOOKUP (Correctness factor planning, ([(-0, 0)-(20, 1)], (-10, 1), (0, 1), (0.0137615, 0.934211), (0.0275229, 0.868421), (0.0458716, 0.789474), (0.0611621, 0.736842), (0.0795107, 0.662281), (0.0932722, 0.635965), (0.107034, 0.596491), (0.125382, 0.552632), (0.14526, 0.52193), (0.172783, 0.469298), (0.200306, 0.429825), (0.229358, 0.403509), (0.259939, 0.381579), (0.29052, 0.359649), (0.328746, 0.333333), (0.366972, 0.302632), (0.399083, 0.289474), (0.437309, 0.258772), (0.475535, 0.236842), (0.538226, 0.188596), (0.639144, 0.144737), (0.740061, 0.114035), (0.844037, 0.100877), (0.963303, 0.0964912), (1, 0.1), (10, 0.1), (20, 0.1))) ~ Dmnl
- Amount of inedible leftovers discarded = Amount of leftovers stored/Storing time leftovers~ Kg/Week
- Amount of consumed food = (Average amount of food needed for a household-Amount of leftovers consumed)-(Effect on household*(Average amount of food needed for a household-Amount of leftovers consumed))~ Kg/Week
- Amount of leftovers consumed = IF THEN ELSE(Amount of leftovers stored >= 0, (Amount of leftovers stored*Desire to consume leftovers*Leftover knowledge)+((Amount of leftovers stored*Desire to consume leftovers*Leftover knowledge)*Effect on leftovers), 0)~ Kg/Week
- Perceived amount of food waste prepared = SMOOTHI(Moral attitude*Total food waste regarding the preparing loops, Perceived time, Initial perceived amount of food waste prepared)~ Kg/Week
- Total consumption = Amount of consumed food + Amount of leftovers consumed~ Kg/Week
- Fraction food thrown away = (Total food waste/Amount of bought food)~ Dmnl
- Perceived amount of inventory = Fraction of inventory taken into account*(Amount of stored food + Amount of leftovers stored)~ Kg/Week
- Effect on leftovers = WITH LOOKUP (Fraction leftovers stored of needed for one person, ([(-10, 0)-(10, 1)], (-10, 0), (0, 0), (0, 0), (0.0489297, 0.0263158), (0.0672783, 0.0482456), 0.116208, 0.0789474), (0.159021, 0.114035), (0.211009, 0.171053), (0.244648, 0.276316), (0.269113, 0.337719), (0.287462, 0.434211), (0.308868, 0.54386), (0.35474, 0.640351), (0.434251, 0.719298), (0.553517, 0.802632), (0.666667, 0.877193), (0.795107, 0.938596), (0.88685, 0.969298), (0.966361, 0.995614), (1, 1), (10, 1))) ~ Dmnl
- Total food waste = Total food waste regarding the planning loops + Amount of inedible prepared food discarded~ Kg/Week
- Total food waste regarding the preparing loops = Total discarded leftovers~ Kg/Week

- Effect storing conditions on used by date = Effect of storing conditions*Fraction storing effect on used by date ~ Dmnl
- Fraction storing effect on used by date = 0.1 ~ Dmnl
- Amount of inedible stored food discarded = ((Amount of stored food/(Affected use by date))*(Spoilage knowledge effect on the used by date)) ~ Kg/Week
- Spoilage knowledge effect on the used by date = 1-Spoilage knowledge effect ~ Dmnl
- Adjusted amount of planned food = (Amount of planned food with over planning*Effect of using a shopping list)+Amount of planned food with over planning ~ Kg/Week
- Fraction of inventory taken into account = Fraction of inventory remembered by household+((1-Fraction of inventory remembered by household) *Degree of inventory checking) ~ Dmnl/Week
- Amount of planned food with over planning = Amount of planned food+(Degree of over planning*Amount of planned food) ~ Kg/Week
- Amount of planned food = IF THEN ELSE(Perceived amount of inventory> = Average amount of food needed for a household, 0.1, (Average amount of food needed for a household-Perceived amount of inventory))~ Kg/Week
- Moral attitude = WITH LOOKUP (Knowledge consequences food waste, ([(0.7, 0)-(1, 1)], (-1, 0.38), (0.0030581, 0.381579), (0.0397554, 0.381579), (0.0764526, 0.381579), (0.125382, 0.381579), (0.180428, 0.390351), (0.2263, 0.399123), (0.262997, 0.399123), (0.318043, 0.399123), (0.357798, 0.399123), (0.397554, 0.412281), (0.440367, 0.416667), (0.48318, 0.429825), (0.522936, 0.447368), (0.574924, 0.469298), (0.611621, 0.491228), (0.657492, 0.52193), (0.672783, 0.539474), (0.724771, 0.609649), (0.75841, 0.657895), (0.862385, 0.824561), (0.88685, 0.864035), (0.917431, 0.912281), (0.960245, 0.986842), (1, 1), (1.01223, -0.0219298)))~ Dmnl
- Fraction food stored of needed for household = Amount of stored food/Average amount of food needed for a household ~ Week
- Effect of stored food = WITH LOOKUP (Fraction food stored of needed for household, ([(-100, 0)-(150, 0.1)], (-100, 0), (0, 0), (0.0856269, 0.00219298), (0.171254, 0.00394737), (0.269113, 0.00482456), (0.302752, 0.00701754), (0.345566, 0.00964912), (0.388379, 0.0131579), (0.434251, 0.0153509), (0.48318, 0.0214912), (0.51682, 0.029386), (0.553517, 0.0372807), (0.608563, 0.0403509), (0.654434, 0.0421053), (0.75841, 0.0447368), (0.847095, 0.0473684), (0.948012, 0.05), (1, 0.05), (150, 0.05))) ~ Dmnl
- Amount of edible stored food discarded = (Amount of stored food/Affected best before date)*Spoilage knowledge effect ~ Kg/Week
- Affected best before date = (Best before date*Effect of storing conditions)+Beste before date ~ Week
- Leftover knowledge = 0.5 ~ Dmnl/Week
- Amount of leftovers discarded directly = Total amount of edible food leftover*Effect on discarded leftovers ~ Kg/Week
- Effect of storing conditions = WITH LOOKUP (Storing conditions, ([(0, -0.1)-(1, 0.1)], (0, -0.1), (0.0642202, -0.0947368), (0.0917431, -0.0921053), (0.12844, -0.0868421), (0.16208, -0.0850877), (0.207951, -0.0789474), (0.250765, -0.0736842), (0.281346, -0.0684211), (0.324159, -0.0614035), (0.382263, -0.054386), (0.474006, -0.0394737), (0.513761, -0.0307018), (0.544343, -0.0201754), (0.562691, -0.00701754), (0.58104, 0.00438596), (0.602446, 0.0140351), (0.642202, 0.0280702), (0.669725, 0.0385965), (0.706422, 0.0491228), (0.755352, 0.0587719), (0.807339, 0.0675439), (0.850153, 0.0754386), (0.899083, 0.0833333), (0.948012, 0.0894737), (1, 0.1))) ~ Dmnl
- Amount of bought food = (Adjusted amount of planned food*Degree of overbuying*"Price-awareness")+Adjusted amount of planned food ~ Kg/Week
- Amount of edible food leftover = Total amount of edible food leftover-Amount of leftovers discarded directly ~ Kg/Week

- Amount of inedible prepared food discarded = Amount of prepared food-(Cooking skills*Amount of prepared food) ~ Kg/Week
- Amount of stored food = INTEG (Amount of bought food-Amount of edible stored food discarded-Amount of inedible stored food discarded -Amount of prepared food, 1.6) ~ Kg
- Average amount of food needed for a household = "Average Kg/person"*Average members household~ Kg/Week
- "Average Kg/person" = 7~ Kg/Person/Week
- Average members household = 2.17~ Person
- Best before date = 3~ Week
- Cooking skills = 0.975~ Dmnl
- Storing time leftovers = (3/7)~ Week
- Total amount of edible food leftover = IF THEN ELSE(((Amount of prepared food-Amount of inedible prepared food discarded)- Amount of consumed food) > = 0, (Amount of prepared food-Amount of inedible prepared food discarded)-Amount of consumed food, 0)~ Kg/Week
- Degree of overbuying = ((Effect of economies of scale and discounts + Degree of appropriate amount of food)*(Effect of the frequency of shopping))+(Effect of economies of scale and discounts + Degree of appropriate amount)~ Dmnl
- Total discarded stored food = Amount of edible stored food discarded + Amount of inedible stored food discarded~ Kg/Week
- Desire to consume leftovers = 0.8~ Dmnl
- Frequency of shopping = 3~ Dmnl
- Effect of the frequency of shopping = WITH LOOKUP (Frequency of shopping, ([(1, 0)-(15, 0.2)], (1, 0.15), (1.1609, 0.136493), (1.3442, 0.124171), (1.56823, 0.108057), (1.73116, 0.0938389), (1.91446, 0.0777251), (2, 0.075), (2.09776, 0.0663507), (2.21996, 0.0578199), (2.36253, 0.0492891), (2.64766, 0.0388626), (2.81059, 0.0274881), (3.07536, 0.0180095), (3.31976, 0.014218), (3.60489, 0.0085308), (3.95112, 0.00473933), (5, 0), (5.41752, 0), (6, 0), (10, 0), (14, 0), (15, 0)))~ Dmnl
- Amount of leftovers stored = INTEG (Amount of edible food leftover-Amount of inedible leftovers discarded-Amount of leftovers consumed, 0.1566)~ Kg
- Storing conditions = 0.7~ Dmnl
- "Price-awareness" = 0.95~ Dmnl
- Spoilage knowledge effect = WITH LOOKUP (Spoilage knowledge, ([(0, 0)-(1, 1)], (0, 0.33), (0, 0.33), (0.0733945, 0.337719), (0.143731, 0.342105), (0.244648, 0.350877), (0.336391, 0.350877), (0.406728, 0.372807), (0.458716, 0.425439), (0.486239, 0.473684), (0.510703, 0.508772), (0.527495, 0.582938), (0.541752, 0.663507), (0.574924, 0.754386), (0.620795, 0.807018), (0.675841, 0.850877), (0.755352, 0.885965), (0.850153, 0.903509), (0.94501, 0.895735), (1, 0.909953)))~ Dmnl
- Total food waste regarding the planning loops = Amount of inedible prepared food discarded + Total discarded leftovers + Total discarded stored food~ Kg/Week
- Total discarded leftovers = Amount of inedible leftovers discarded + Amount of leftovers discarded directly~ Kg/Week

****
.Control
***~
Simulation Control Parameters
|
FINAL TIME = 78
~ Week
~ The final time for the simulation.
|

INITIAL TIME = 0
~ Week
~ The initial time for the simulation.
|
SAVEPER =
TIME STEP
~ Week [0,?]
~ The frequency with which output is stored.
|
TIME STEP = 0.0078125
~ Week [0,?]
~ The time step for the simulation.
|

Appendix D: Dimensions analysis

This appendix shows the results of the dimension check available in Vensim Pro x32. The units of the variables are given in previous appendix, appendix D. The most important insights are concluded in dimension consistency in section 5.2. No errors are identified, but mainly warnings resulted, as shown below:

****

Warning: units in equation for - Effect of stored food
Lookup -#Effect of stored food#- used with dimensioned argument
Week

****

Warning: units in equation for - Effect on discarded leftovers
Lookup -#Effect on discarded leftovers#- used with dimensioned argument
Person*Days

****

Warning: units in equation for - Effect on leftovers
Lookup -#Effect on leftovers#- used with dimensioned argument
Week*Person*Days

Appendix E: Extreme condition test

This appendix presents the result of the extreme condition test as described in section 5.3.1. Situations are simulated and given per phase in this appendix. Per phase, the parameters are given, after which the results of the simulations based upon are illustrated. In this appendix, two situations are simulated during the planning, purchasing, storing, preparing, consuming, re-using leftover, and general phase. During the simulations, a runtime of 20 weeks, a time step of 0.0078125, and the Runge-Kutta auto integration method are used. The most important conclusions are drawn and elaborated on in section 5.3.1.

Planning phase

The results are given on the food waste variables first and on the main process variables secondly. The following situations are simulated with the according parameter settings that will be used for the planning phase:

- **No inventory checking + over planning**. The following parameter values have been used:
  - *Degree of over planning* = 100%
  - Fraction of inventory remembered by household = 0%
  - *Degree of inventory checking* = 0%

- **Full inventory checking + no over planning.** The following parameter values have been used:
  - *Degree of over planning* = 0%
  - Fraction of inventory remembered by household = 100%
  - *Degree of inventory checking* = 100%

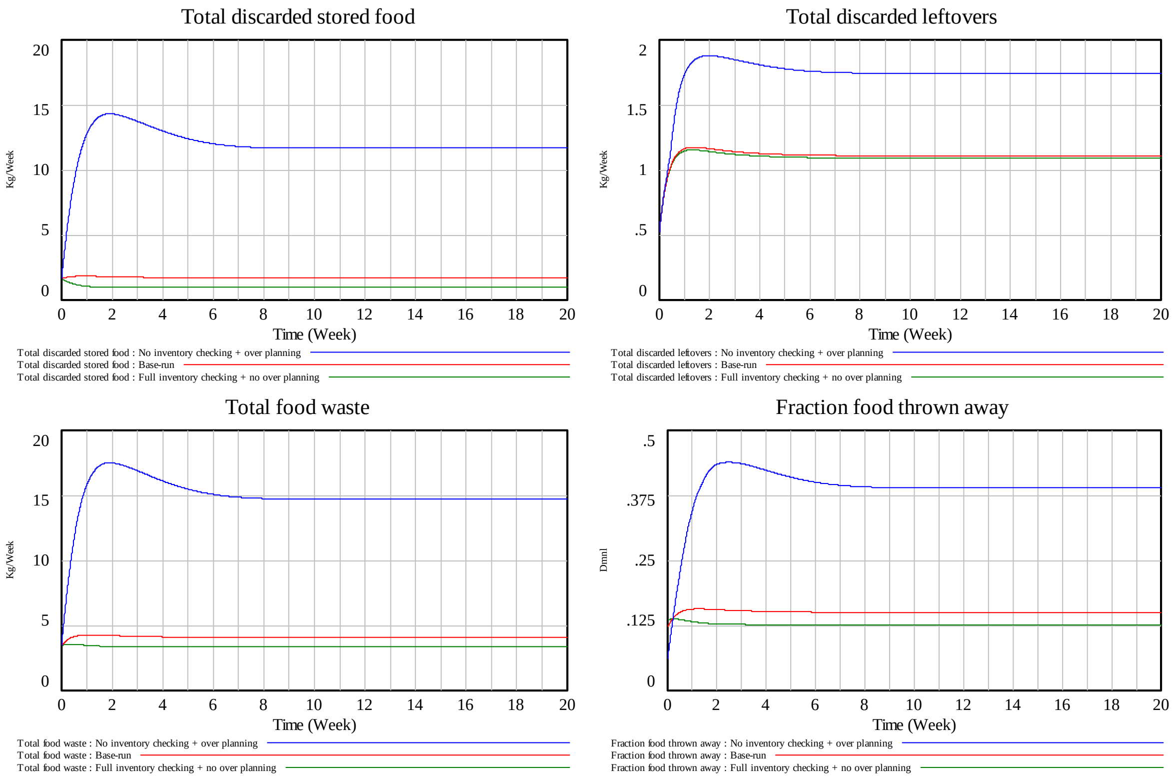


Figure 86: results of extreme condition test planning phase (i/ii)

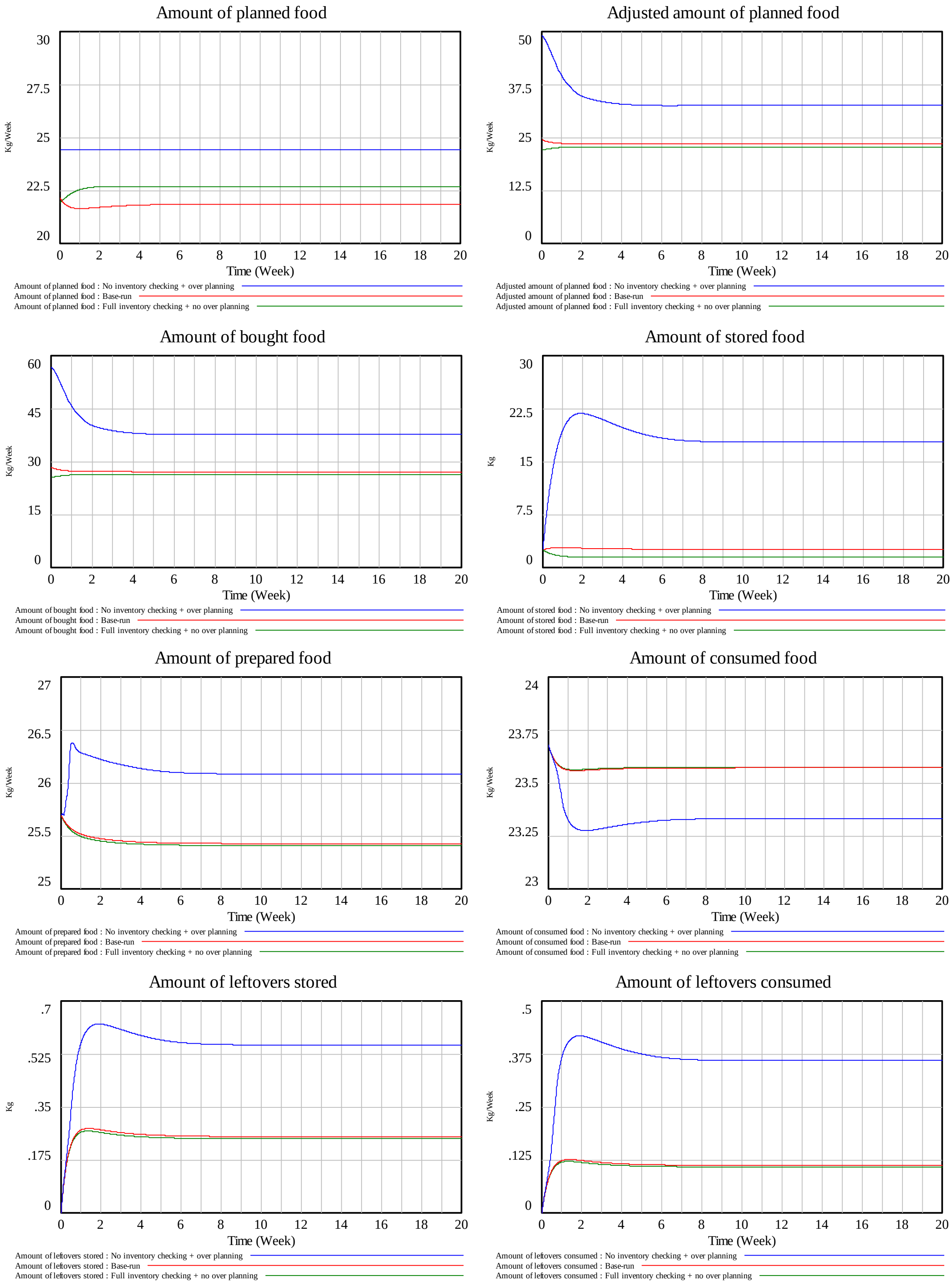


Figure 87: results of extreme condition test planning phase (ii/ii)

In both situations, as can be seen, sensible behaviour occurred. All the effects have also been tested singular, which also resulted in the desired behaviour. All the equations responded plausibly. The model reacted realistic to the changes.

Purchasing phase
The results are given on the food waste variables first and on the main process variables secondly. The following situations are simulated with the according parameter settings that will be used for the purchasing phase:

- **No price-awareness + many trips + overbuying.** The following parameter values have been used:
    - Price-awareness = 0%
    - Price/KG ratio = 100%
    - Degree of appropriate amount of food = 100%
    - Frequency of shopping = 14 trips per week

- **Full price-awareness + one trip + no overbuying.** The following parameter values have been used:
    - Price-awareness = 100%
    - Price/KG ratio = 0%
    - Degree of appropriate amount of food = 0%
    - Frequency of shopping = 1 trip per week

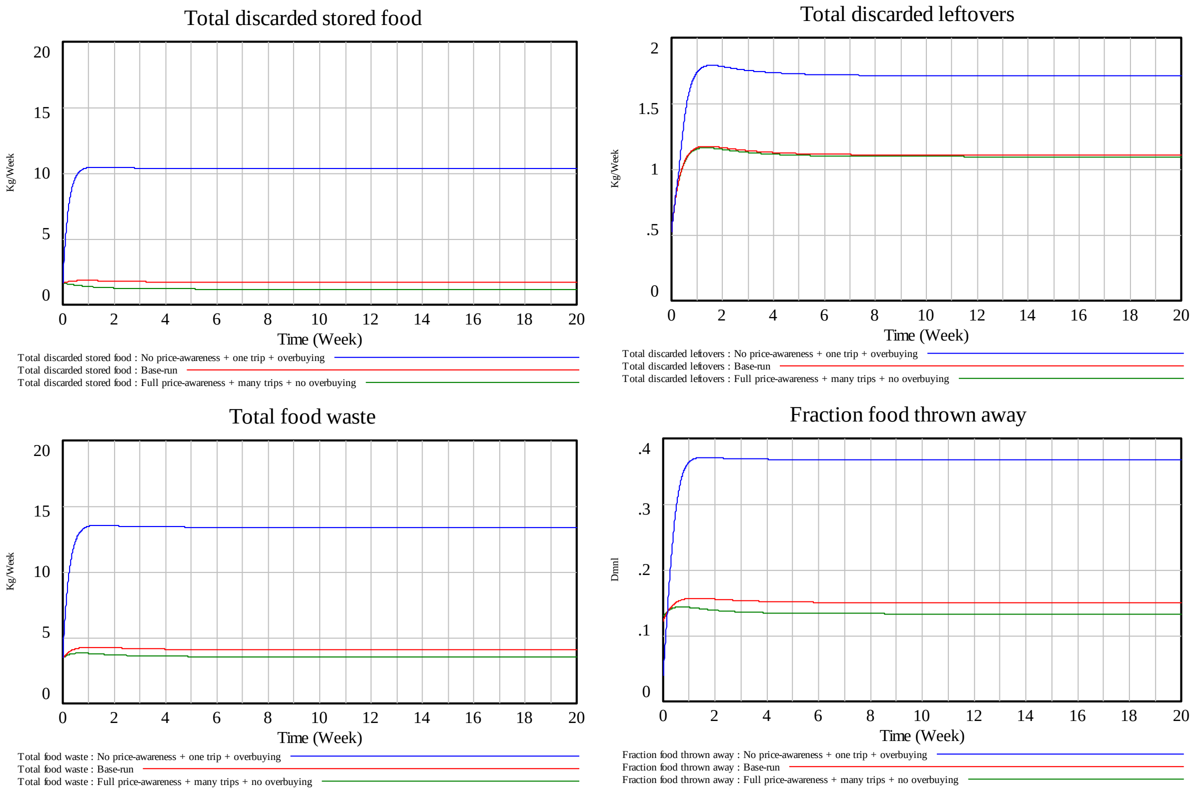


Figure 88: results of extreme condition test purchasing phase (i/ii)

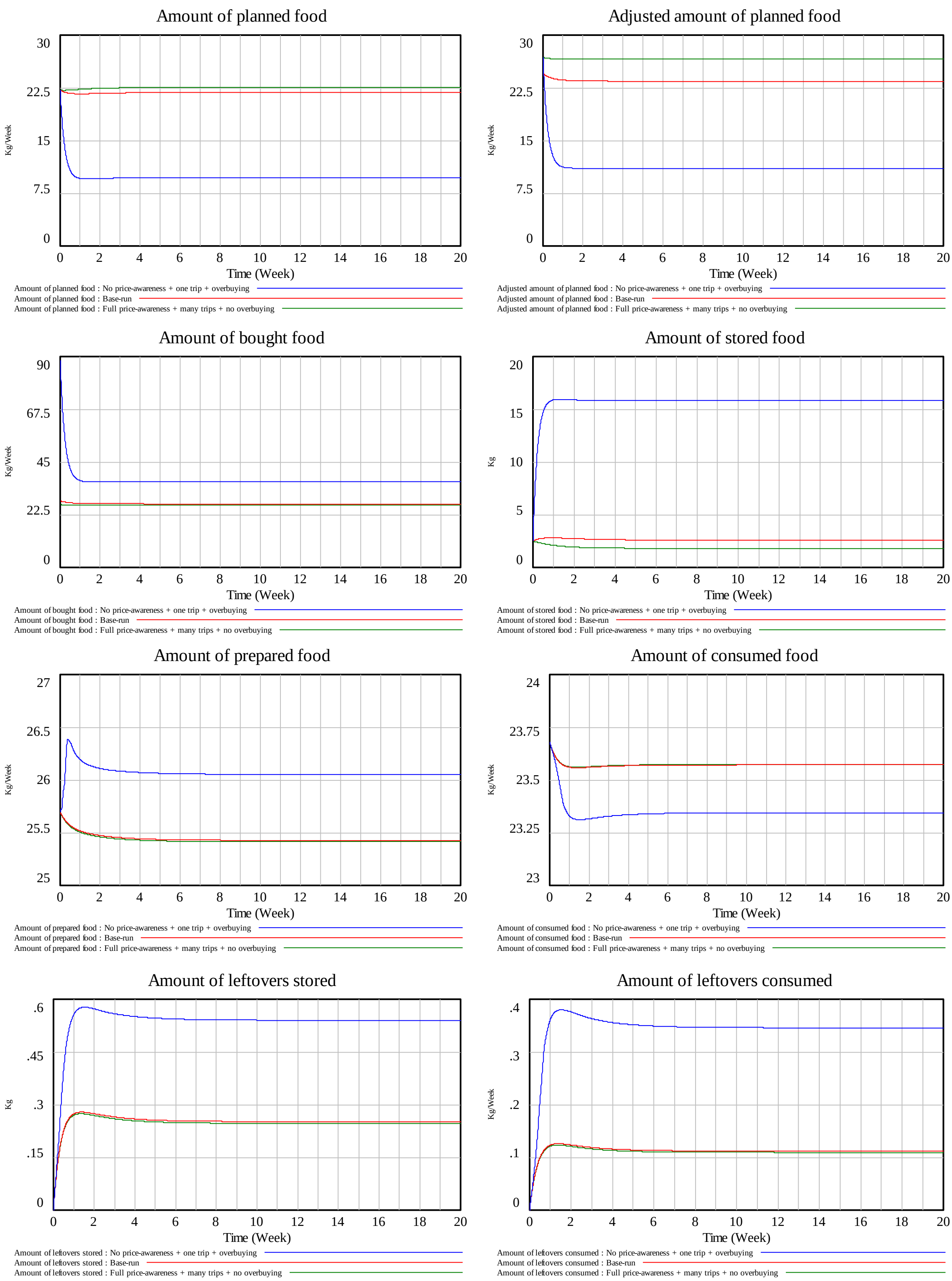


Figure 89 results of extreme condition test purchasing phase (ii/ii)

In both situations, as can be seen, sensible behaviour occurred. All the effects have also been tested singular, which also resulted in the desired behaviour. All the equations responded plausibly. The model reacted realistic to the changes.

Storing phase

The results are given on the food waste variables first and on the main process variables secondly. The following situations are simulated with the according parameter settings that will be used for the storing phase:

- **No knowledge and storing conditions + short used by dates and best before dates + a lot of storage.** The following parameter values have been used:
    - Storing conditions = 0%
    - Spoilage knowledge = 0%
    - Best before date = 1/7th week
    - Best used by date = 3/7th week
    - Initial value = 100

- **Full knowledge and storing conditions + long used by and best before date**. The following parameter values have been used:
    - Storing conditions = 100%
    - Spoilage knowledge = 100%
    - Best before date = 78 weeks
    - Best used by date = 26 weeks
    - Initial value = 0

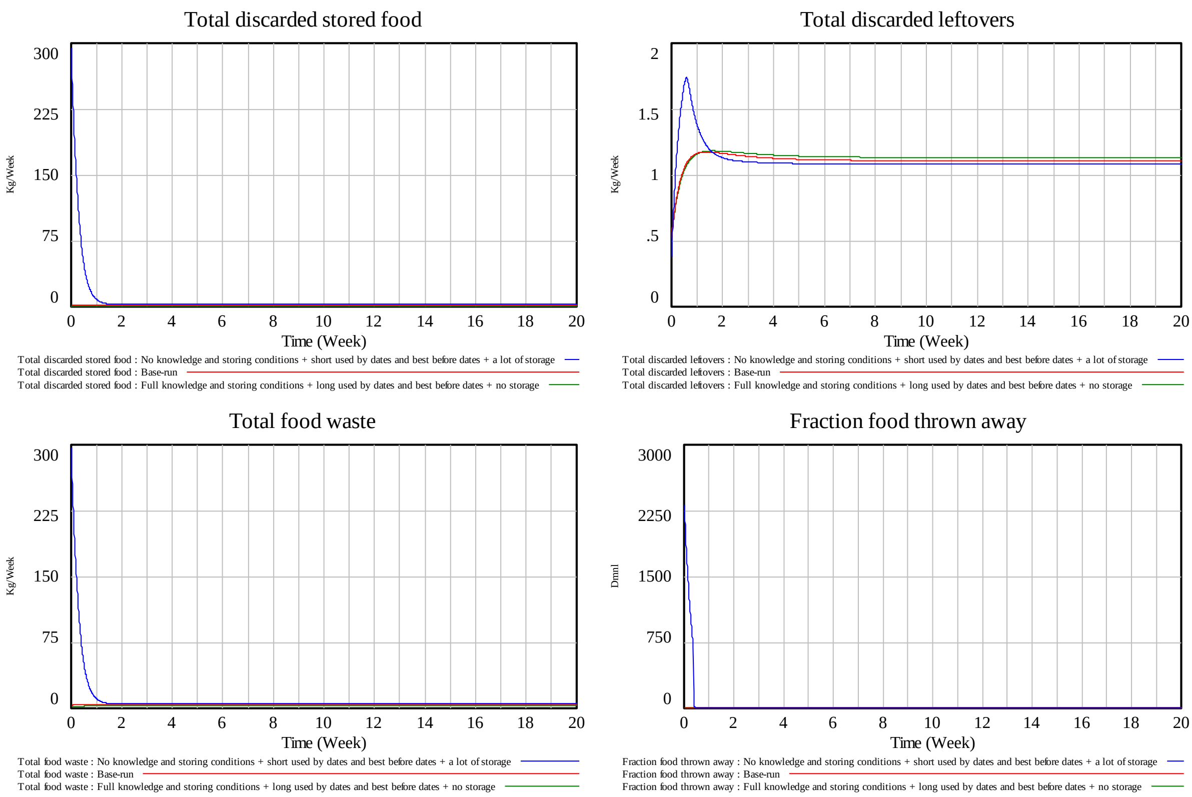


Figure 90: results of extreme condition test storing phase (i/ii)

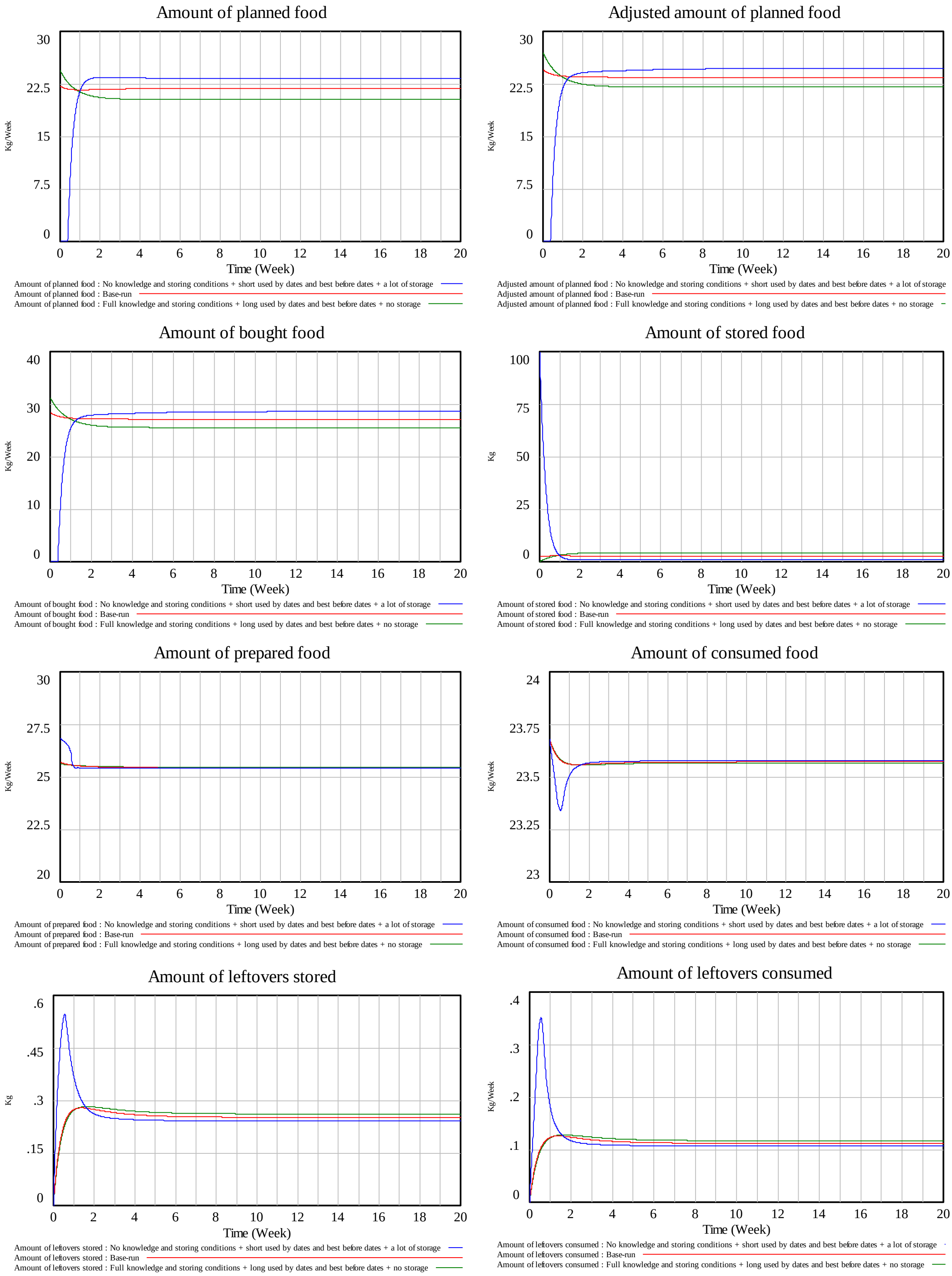


Figure 91: results of extreme condition test storing phase (ii/ii)

In both situations, as can be seen, sensible behaviour occurred. All the effects have also been tested singular, which also resulted in the desired behaviour. All the equations responded plausibly. The model reacted realistic to the changes.

Preparing phase

The results are given on the food waste variables first and on the main process variables secondly. The following situations are simulated with the according parameter settings that will be used for the preparing phase:

- **No provision and a perfect cooking skills.** The following parameter values have been used:
    - Provision factor = 1%
    - Cooking skill = 100%

- **High provision and low cooking skills.** The following parameter values are used.
    - Provision factor = 25%
    - Cooking skill = 50%

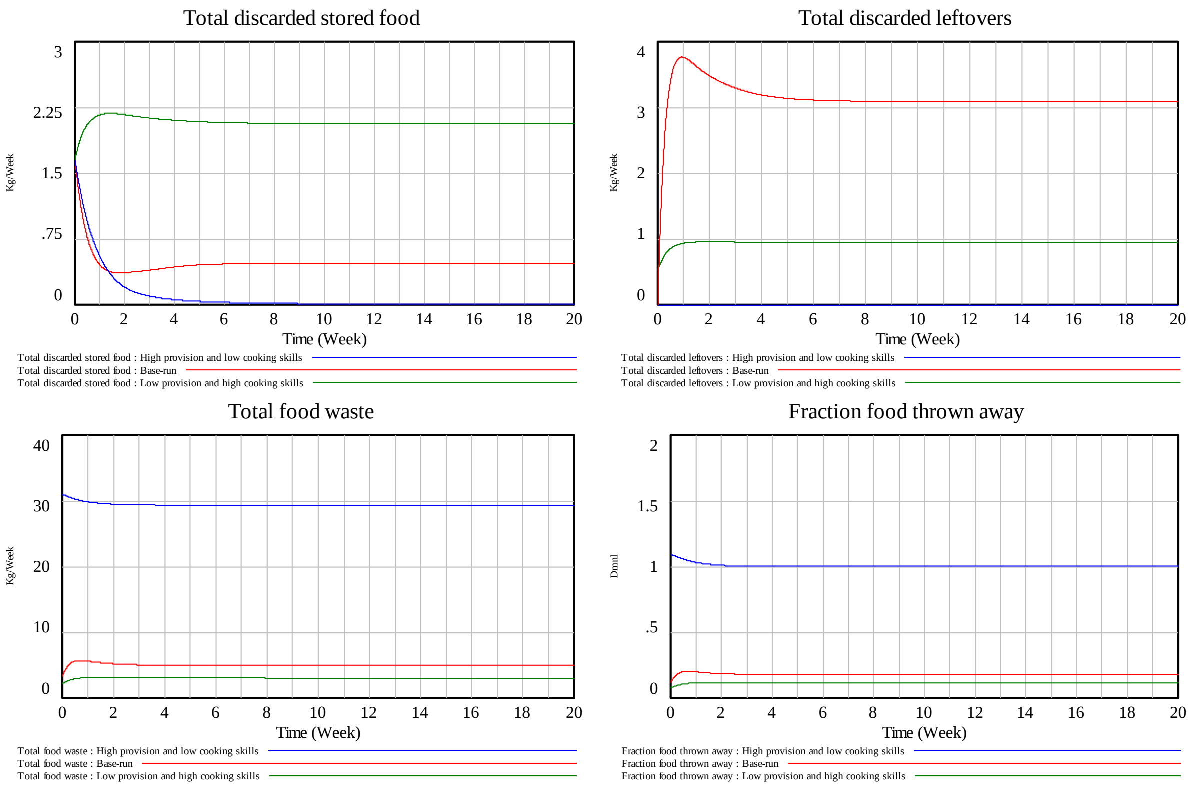


Figure 92: results of extreme condition test preparing phase (i/ii)

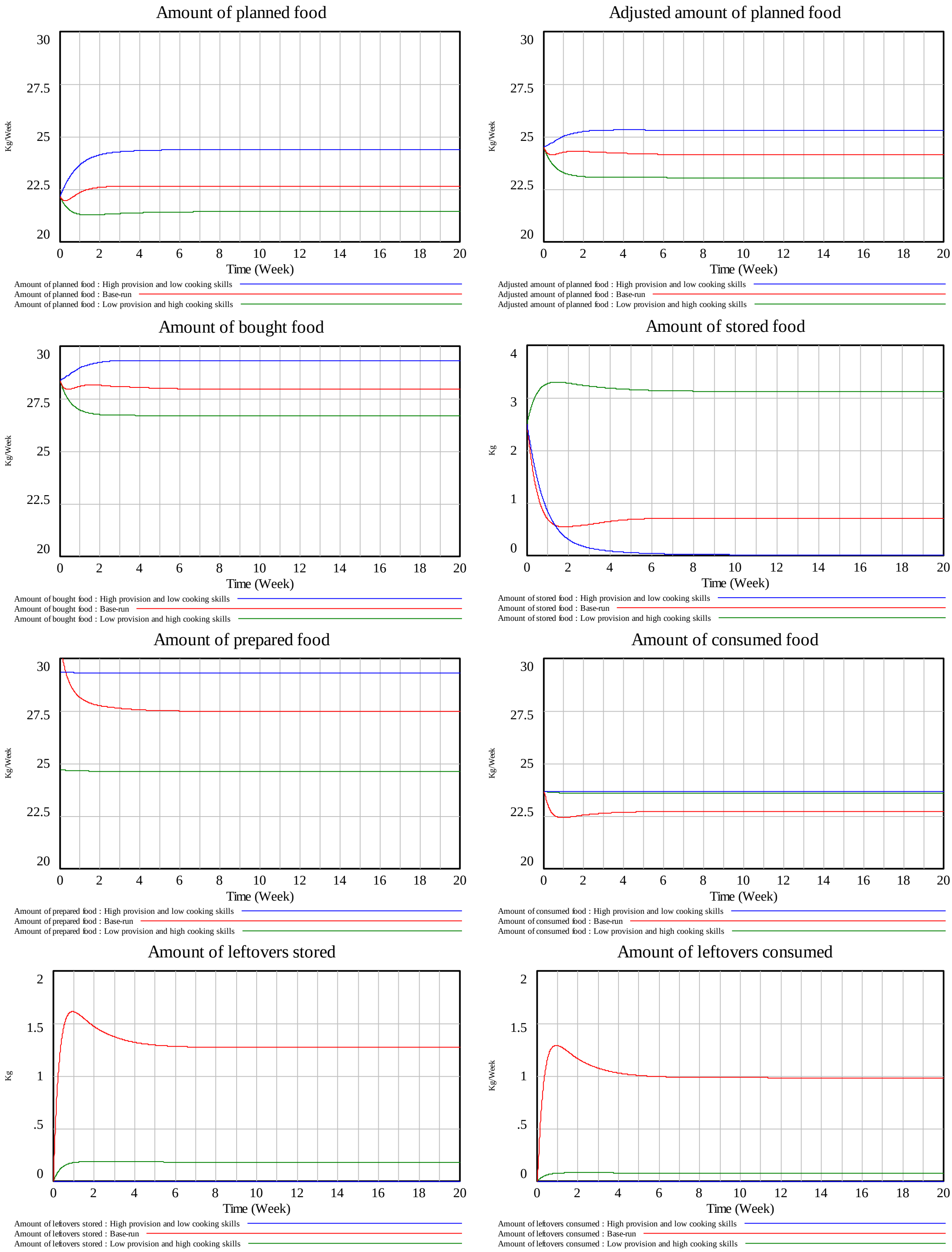


Figure 93: results of extreme condition test storing phase (ii/ii)

In both situations, as can be seen, sensible behaviour occurred. All the effects have also been tested singular, which also resulted in the desired behaviour. All the equations responded plausibly. The model reacted realistic to the changes. However, using a higher provision factor did not result in the desired and anticipated behaviour. Multiple errors resulted, resulting in an important limitation of the System Dynamics model, which is described in more detail in section 5.3.1.

Consuming phase

The results are given on the food waste variables first and on the main process variables secondly. The following situations are simulated with the according parameter settings that will be used for the consuming phase:

- **A predictable household.** In this situation it is assumed that more food waste will occur, all Amounts of food will increase and that the Amounts of leftovers will increase slightly and the Amount of leftovers consumed will increase. The following parameter values have been used:
    - Preference within household = 0%
    - Unpredictability of lifestyle household = 0%

- **An unpredictable household.** The following parameter values have been applied in the simulation model:
    - Preference within household = 100%
    - Unpredictability of lifestyle household = 100%

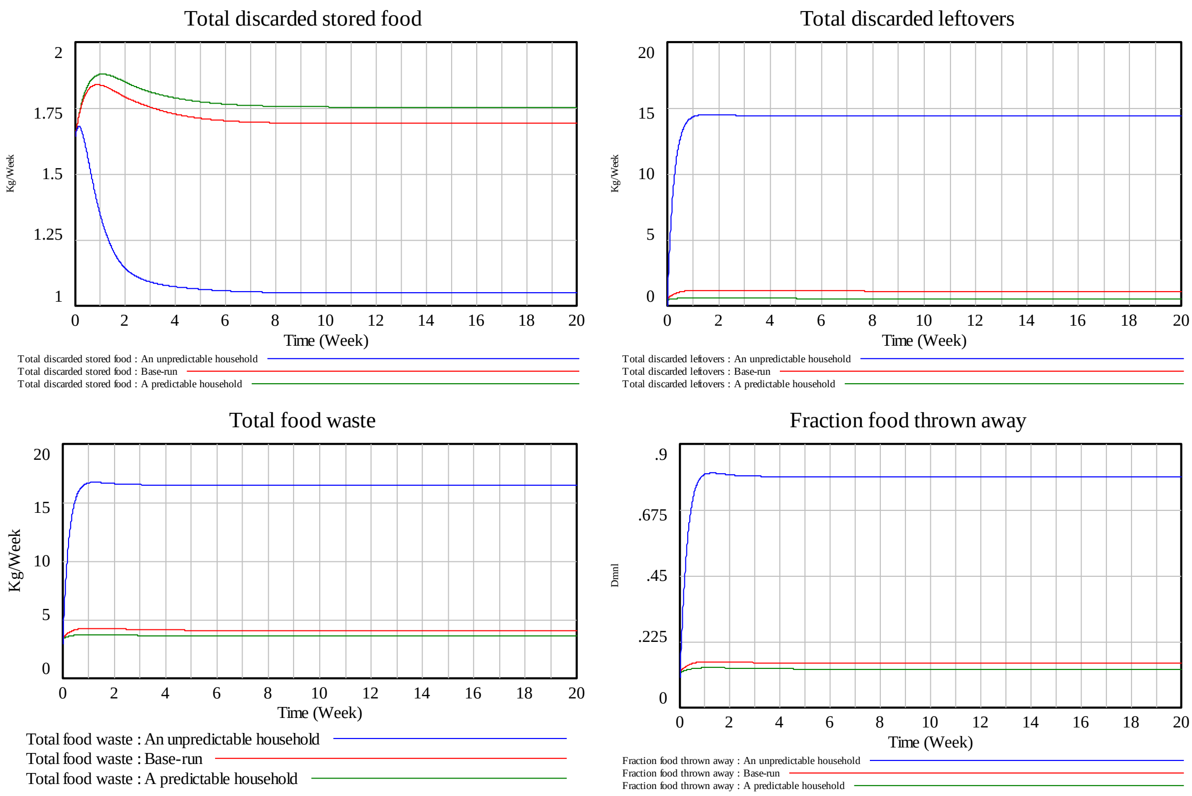


Figure 94: results of extreme condition test consuming phase (i/ii)

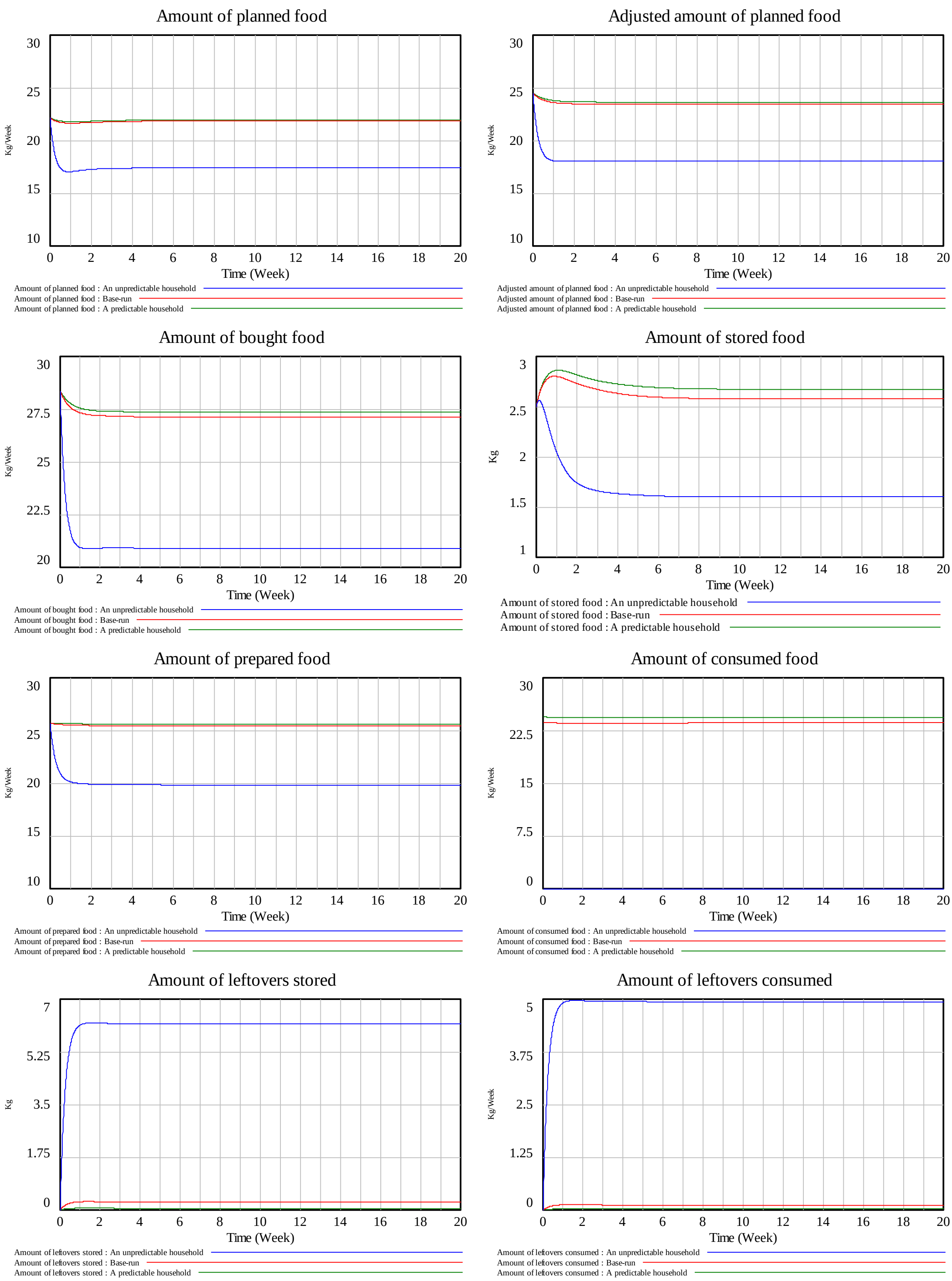


Figure 95: results of extreme condition test consuming phase (ii/ii)

In both situations, as can be seen, sensible behaviour occurred. All the effects have also been tested singular, which also resulted in the desired behaviour. All the equations responded plausibly. The model reacted realistic to the changes.

Re-using leftover phase

The results are given on the food waste variables first and on the main process variables secondly. The following situations are simulated with the according parameter settings that will be used for the re-using leftovers phase:

- **Long storing time + full desire and knowledge.** The following parameter values have been used:
  - Desire to consume leftovers = 100%
  - Leftover knowledge = 100%
  - Storing time leftovers = 52 weeks

- **Short storing time + no desire and knowledge.** The following parameter values have been applied in the simulation model:
  - Desire to consume leftovers = 0%
  - Leftover knowledge = 0%
  - Storing time leftovers = 1 day

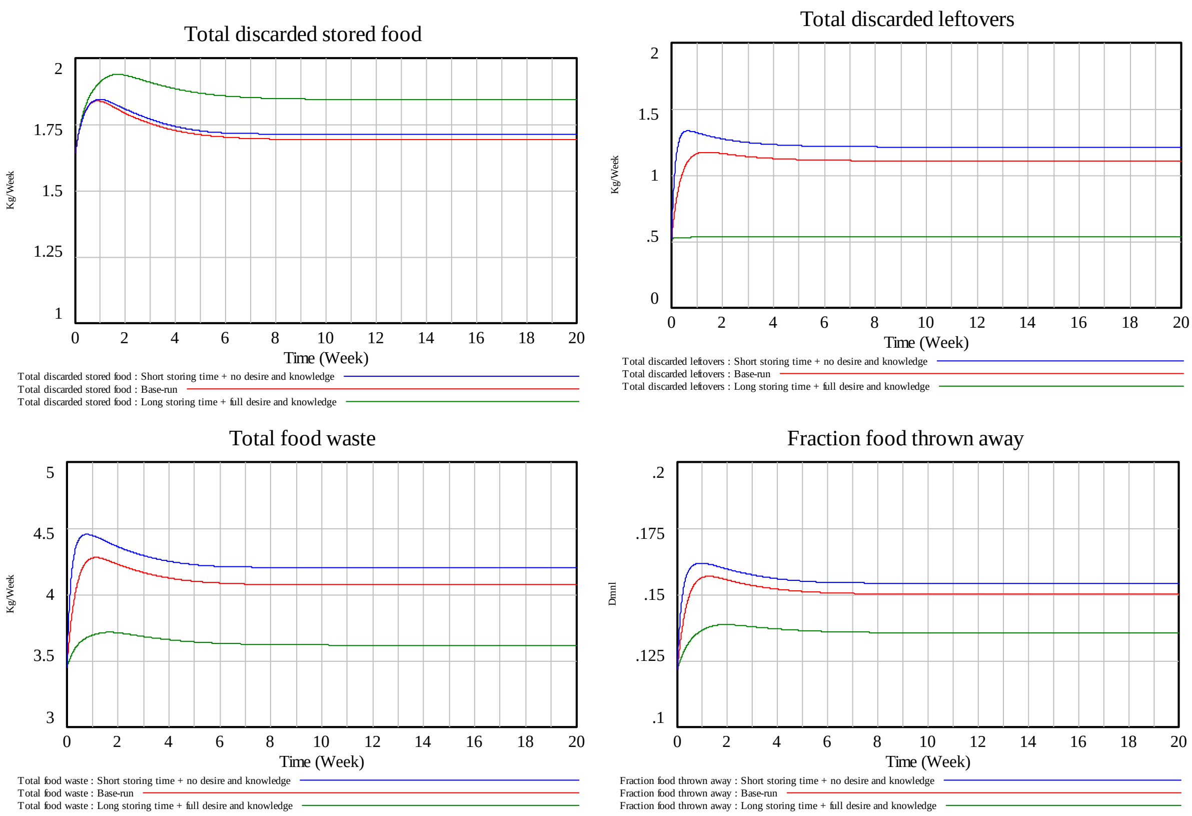


Figure 96: results of extreme condition test re-using leftover phase (ii/ii)

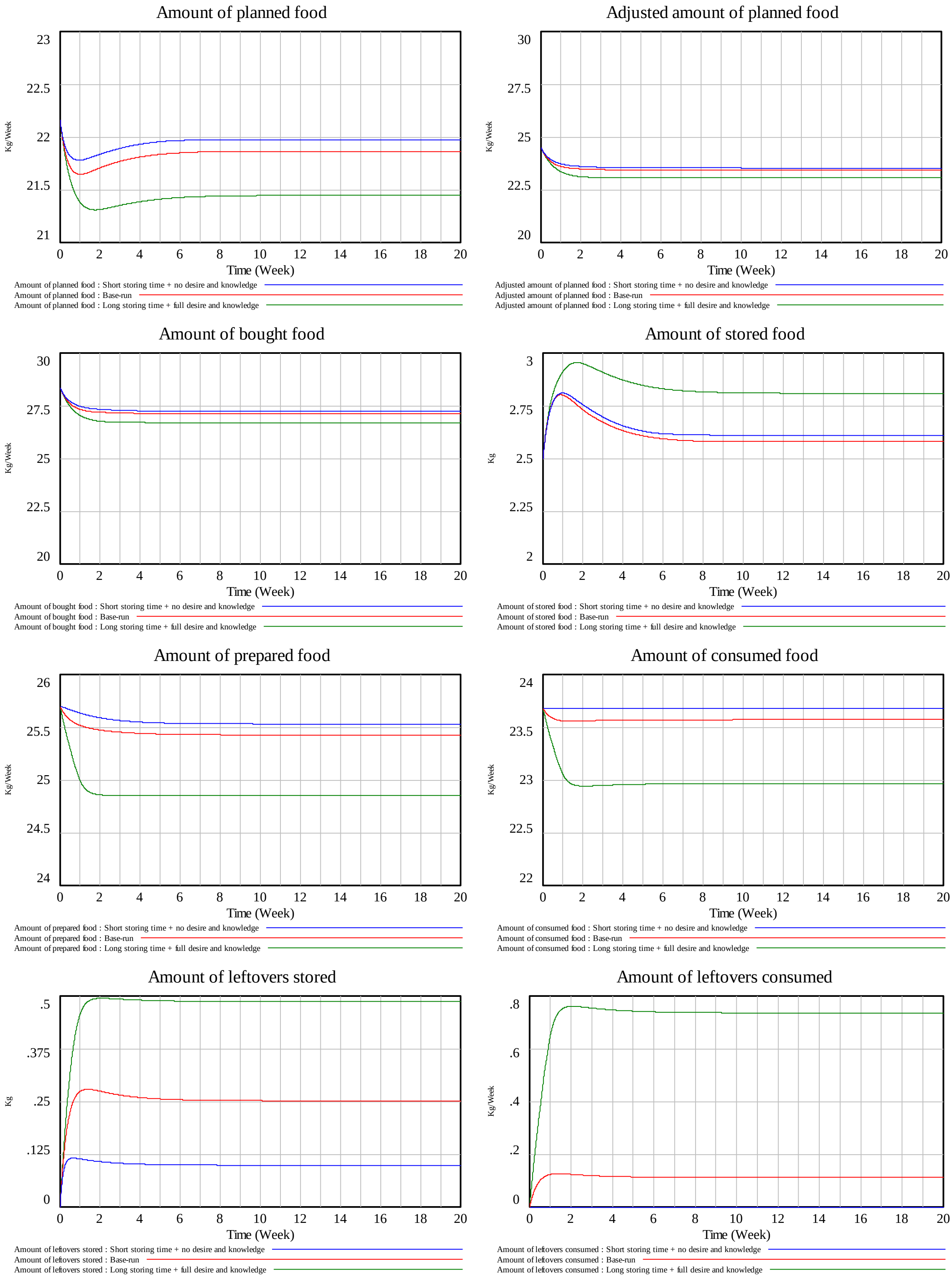


Figure 97: results of extreme condition test re-using leftover phase (ii/ii)

In both situations, as can be seen, sensible behaviour occurred. All the effects have also been tested singular, which also resulted in the desired behaviour. All the equations responded plausibly. The model reacted realistic to the changes.

The food waste system on the level of a household

The results are given on the food waste variables first and on the main process variables secondly. The following situations are simulated with the according parameter settings that will be used for the general phase:

- **Long storing time + high desire and knowledge.** The following parameter values have been used:
  - Desire to consume leftovers = 100%
  - Leftover knowledge = 100%
  - Storing time leftovers = 52 weeks
- **Short storing time + no desire and knowledge.** The following parameter values have been applied in the simulation model:
  - Desire to consume leftovers = 0%
  - Leftover knowledge = 0%
  - Storing time leftovers = 1 day

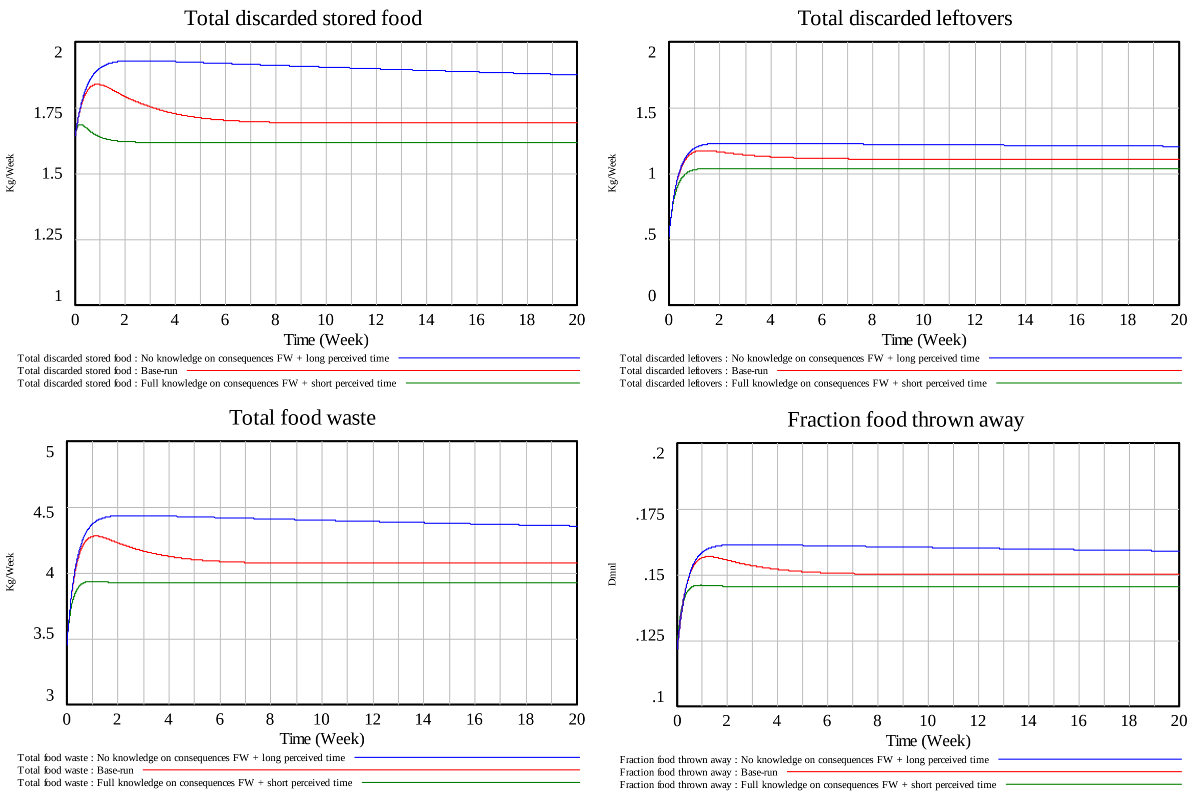


Figure 98: results of extreme condition test general phase (ii/ii)

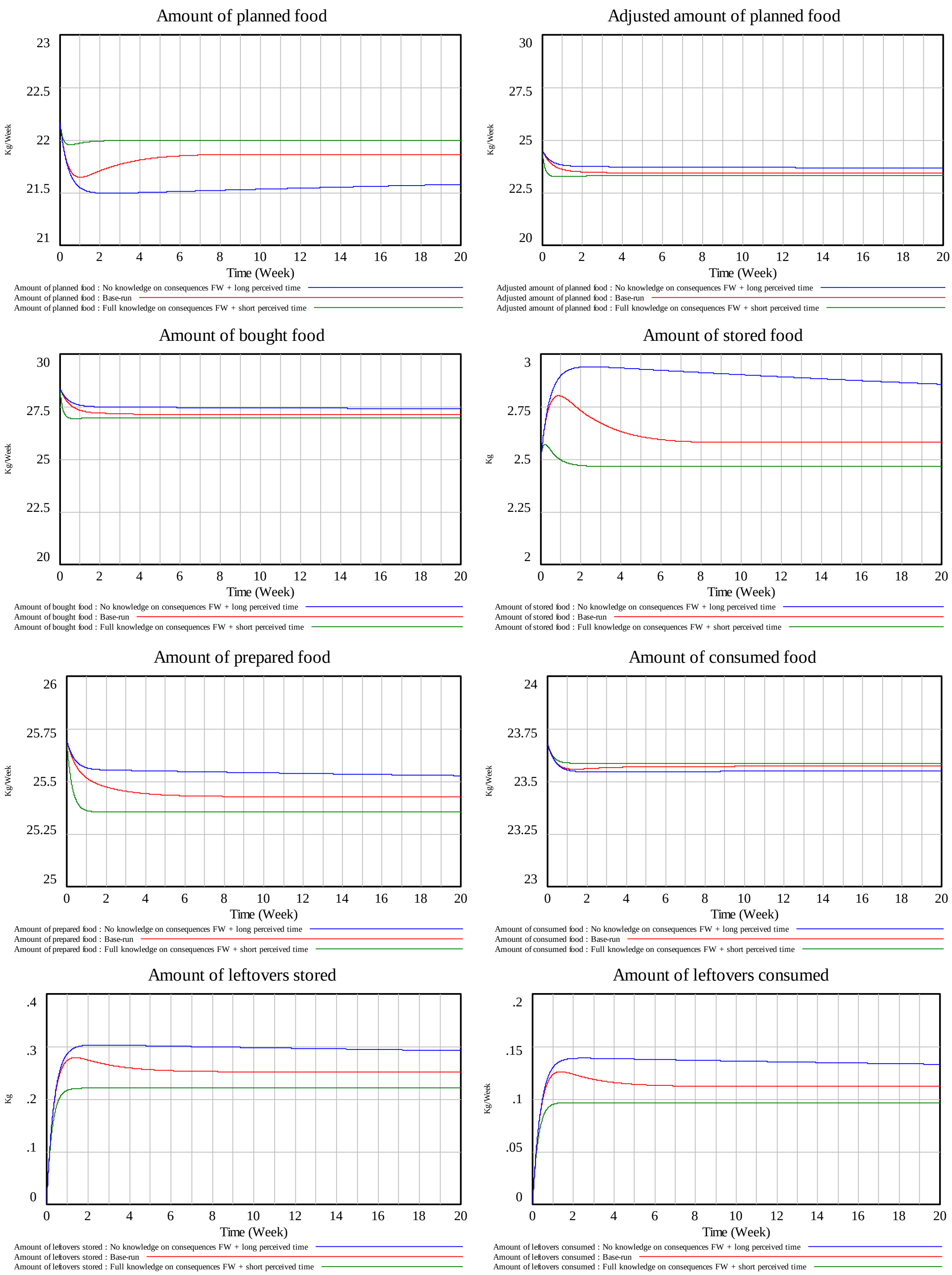


Figure 99: results of extreme condition test general phase (ii/ii)

In both situations, as can be seen, sensible behaviour occurred. All the effects have also been tested singular, which also resulted in the desired behaviour. All the equations responded plausibly. The model reacted realistic to the changes.

Appendix F: Sensitivity analysis

This appendix gives the results of the sensitivity analysis as described in section 5.3.2. The model showed expected behaviour and to illustrate this behaviour, therefore three examples are varied over a +/- 10% range in this appendix. All parameters are tested and to illustrate the process a limited number of parameters are documented in this appendix. During the simulations, a runtime of 20 weeks, a time step of 0.0078125, and the Runge-Kutta auto integration method are used. The parameters *Degree of over planning*, *Effect of economies of scale and discounts*, and *Average Kg/person* are considered while performing the sensitivity analysis.

Degree of over planning

This parameter present within the planning phase is varied over a +/- 10% range. A value of 10% is estimated during appendix C. Varying the range of this value results in the following parameter values used during the simulation:

- -10% = *Degree of over planning* of 9% represented by a value of 0.09 in the System Dynamics model
- +10% = *Degree of over planning* of 11% represented by a value of 0.11 in the System Dynamics model
    - The results of this simulation are presented on the main structure variables in **figure 100** and on the food waste variables in **figure 101**.

Effect of economies of scale and discounts

This parameter present within the purchasing phase is varied over a +/- 10% range. A value of 10% is estimated during appendix C. Varying the range of this value results in the following parameter values used during the simulation:

- -10% = *Effect of economies of scale and discounts* of 9% represented by a value of 0.09 in the System Dynamics model
- +10% = *Effect of economies of scale and discounts* of 11% represented by a value of 0.11 in the System Dynamics model
    - The results of this simulation are presented on the main structure variables in **figure 102** and on the food waste variables in **figure 103**.

Average Kg/person

This parameter present within the general phase is varied over a +/- 10% range. A value of 11.25 kilogram is estimated during appendix C. Varying the range of this value results in the following parameter values used during the simulation:

- -10% = *Average Kg/person* of 10.125 kilogram is used in the System Dynamics model
- +10% = *Average Kg/person* of 12.375 kilogram is used in the System Dynamics model
    - The results of this simulation are presented on the main structure variables in **figure 104** and on the food waste variables in **figure 105**.

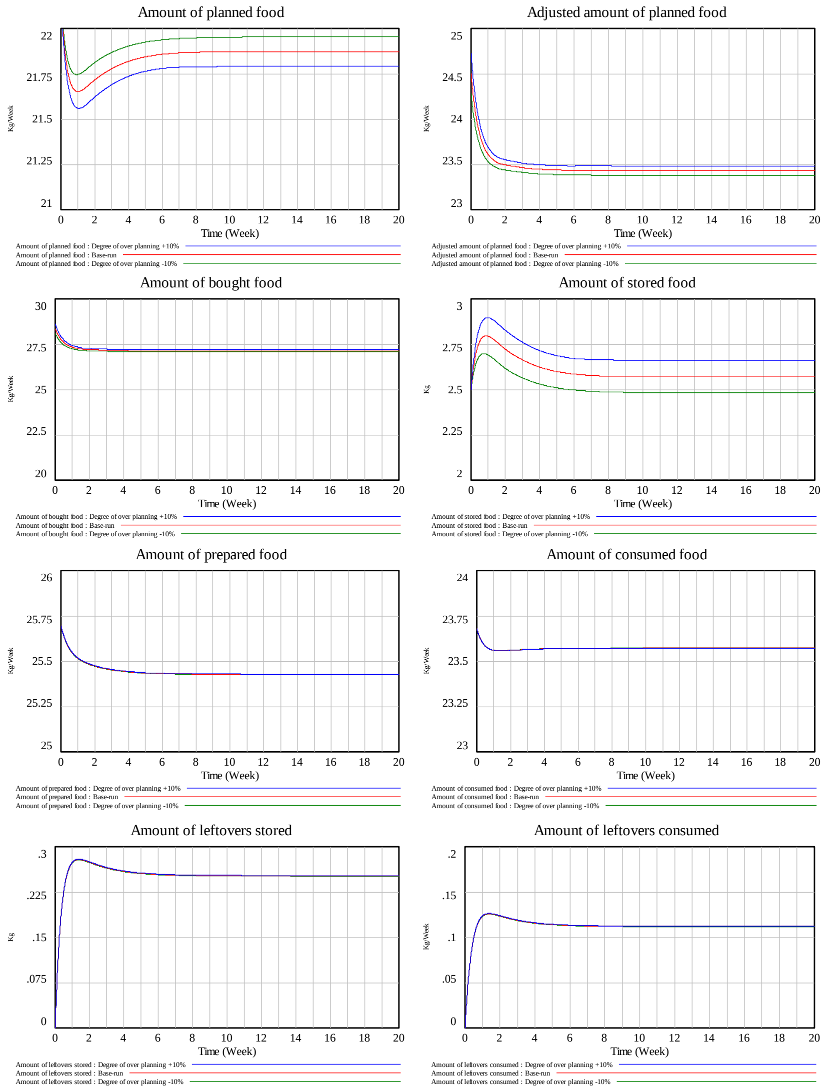


Figure 100: overview results sensitivity analysis Degree of over planning (i/ii)

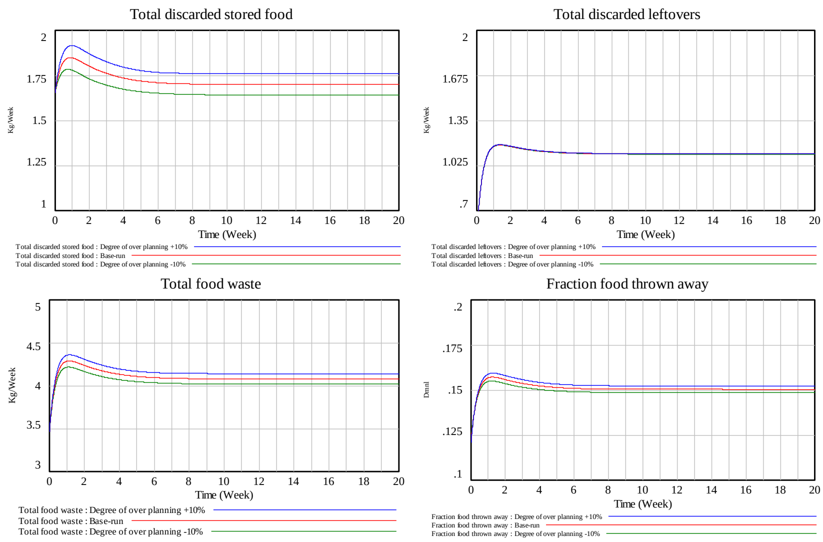


Figure 101: overview results sensitivity analysis Degree of over planning (ii/ii)

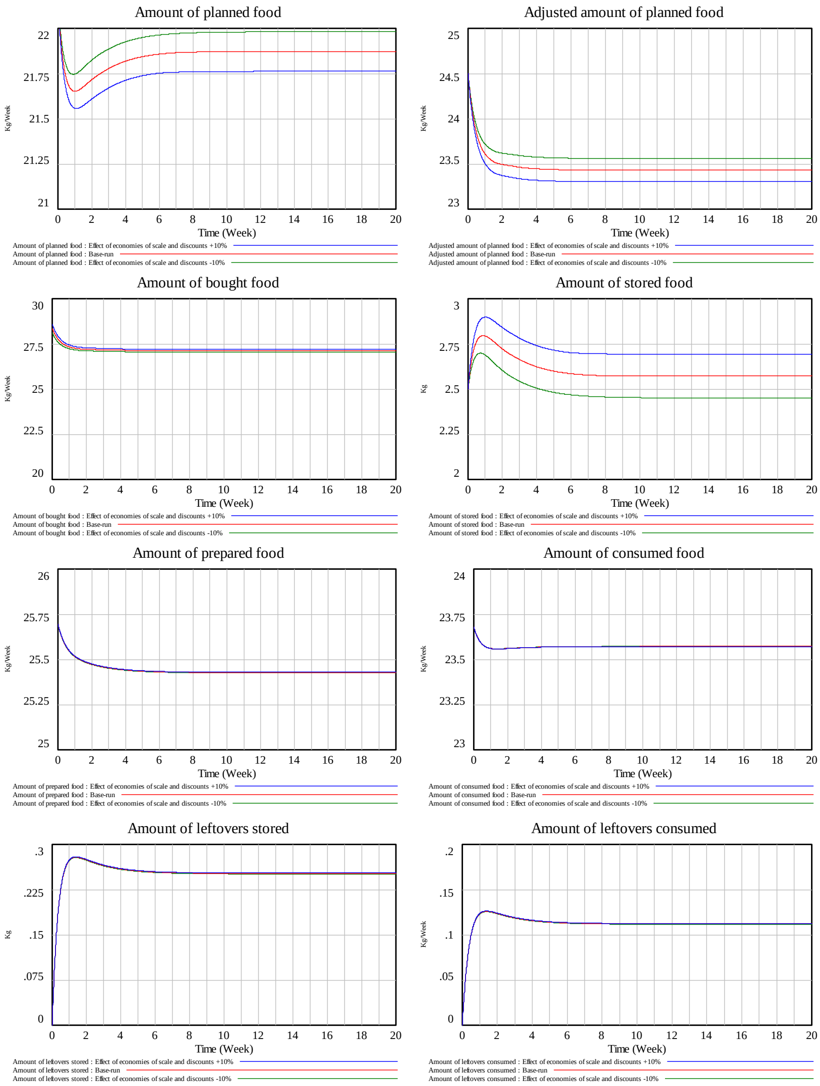


Figure 102: overview results sensitivity analysis Effect of economies of scale and discounts (i/ii)

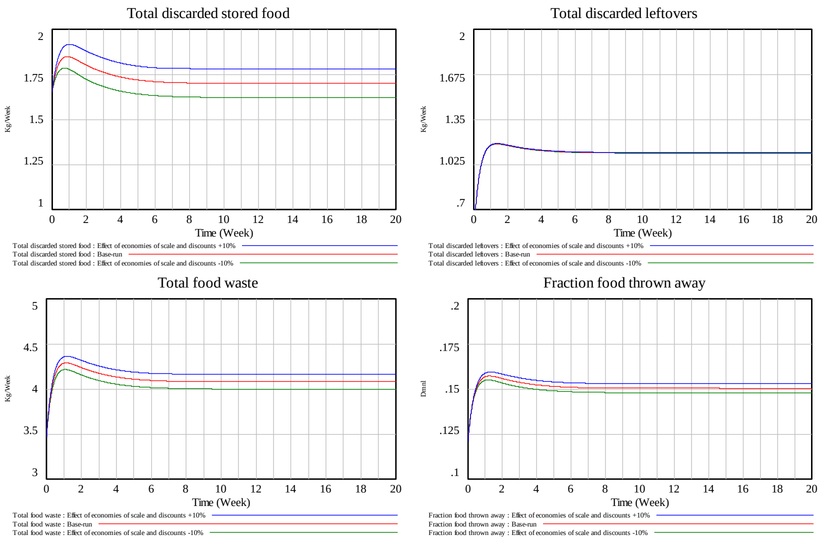


Figure 103: overview results sensitivity analysis Effect of economies of scale and discounts (ii/ii)

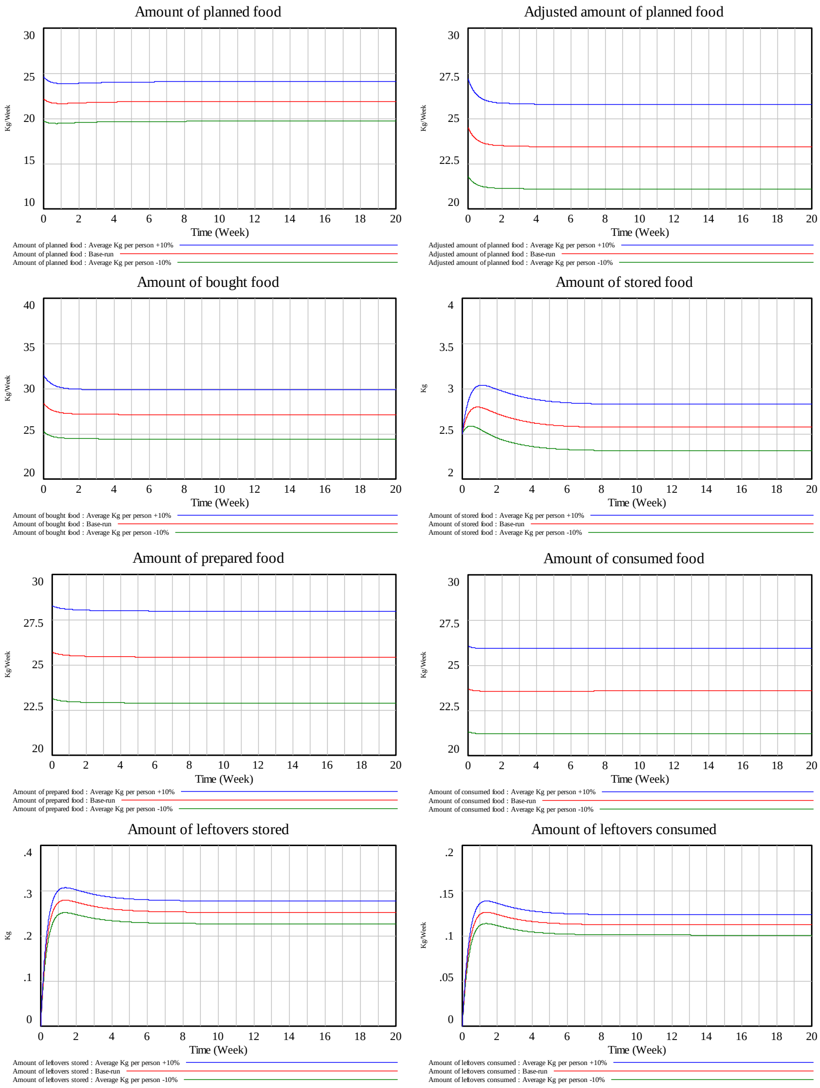


Figure 104: overview results sensitivity analysis Average KG/Person (i/ii)

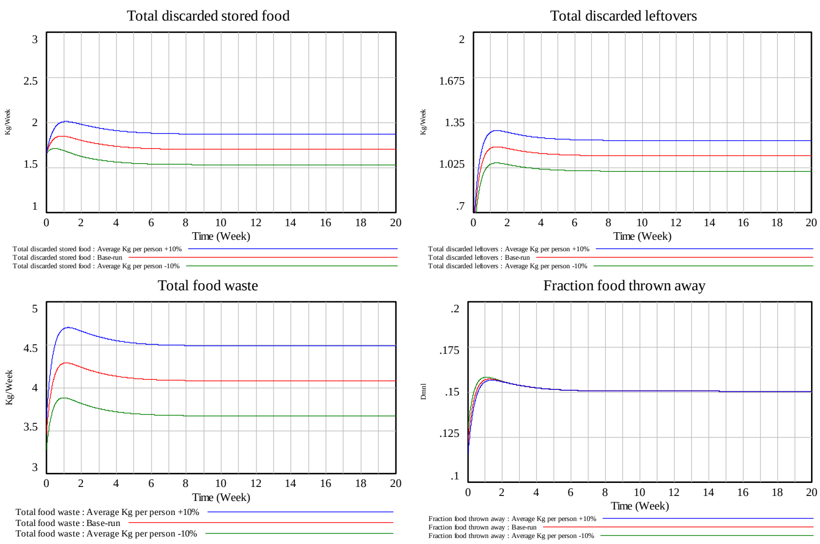


Figure 105: overview results sensitivity analysis Average KG/Person (ii/ii)

Appendix G: Output validation

This appendix gives the results of the output validation as described in section 5.3.3. As shown in previous appendix, changing the value of the *Average Kg/person* within the System Dynamics model does not affect the behaviour of the system (considering the fact that the initial value of the stock *Amount of prepared food* does not change). In this appendix, the System Dynamics model is simulated while changing the value of the *Average Kg/person* from 11.25 kilogram to 7.0 kilogram. The most important conclusions are drawn and elaborated on in section 3.5.3. During the simulations, a runtime of 20 weeks, a time step of 0.0078125, and the Runge-Kutta auto integration method are used. The results of changing the *Average Kg/person* on the food waste variables is illustrated in **figure 106** and on the main process variables in **figure 107.**

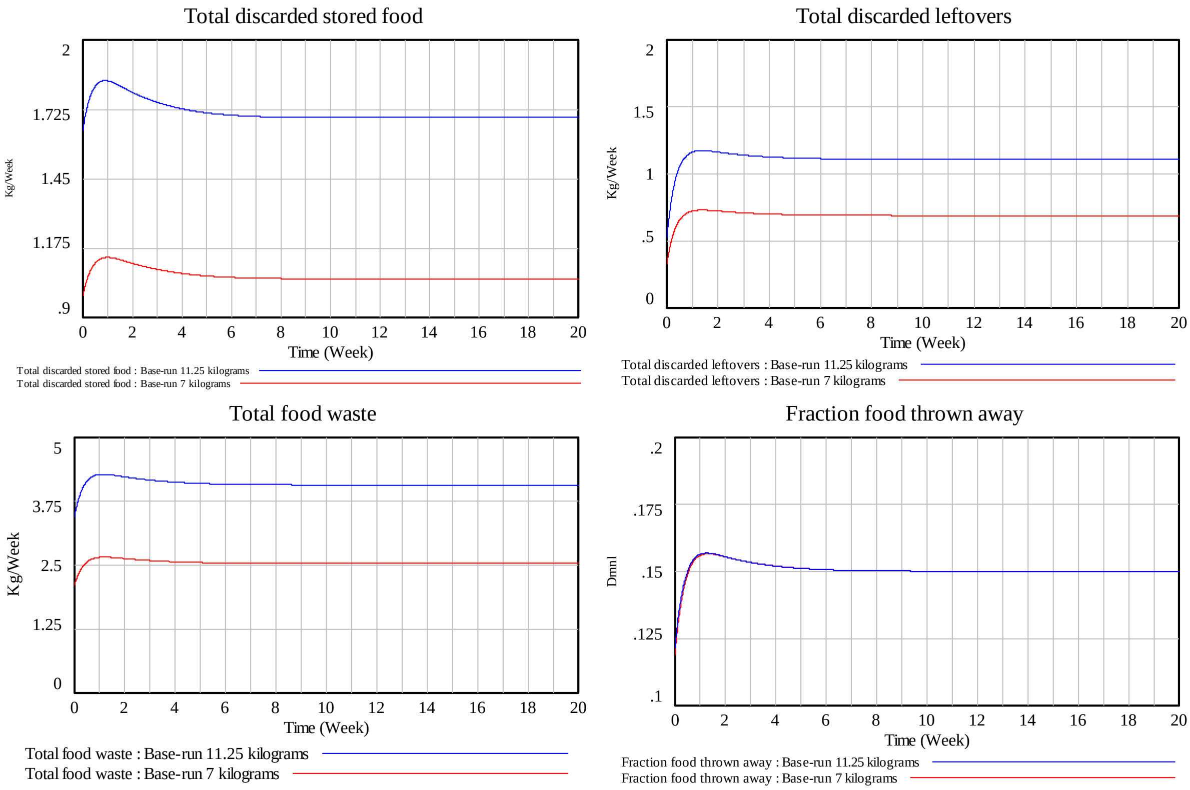


Figure 106: overview results changing the value Average Kg/person on the food waste variables

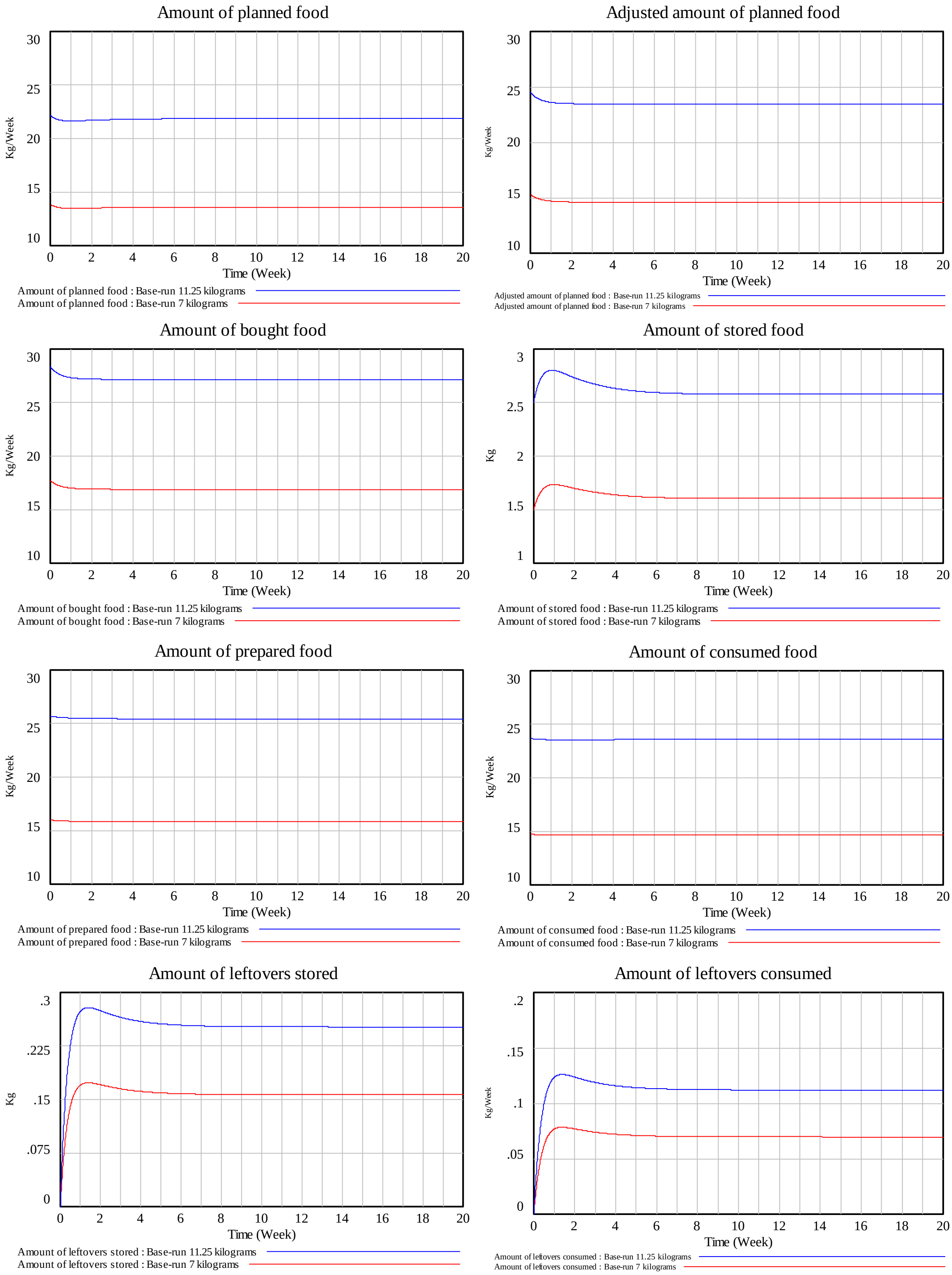


Figure 107: overview results changing the value Average Kg/person on the main process variables

Appendix H: Individual model results

This appendix gives the results of the individual simulations as described in section 6.3.4. The behaviour of the simulations are compared with the base-run results illustrated in section 6.2. The most important figures are presented, conclusions are drawn and elaborated on in section in 6.3.4. The results are presented per intervention. Note that the appendixes are not simulated in equilibrium, however, the results on the longer term do not differ and are therefore comparable. During the simulations, a runtime of 78 weeks, a time step of 0.0078125, and the Runge-Kutta auto integration method are used. The results in the main text are given in equilibrium as described and tested in section 5.3.5.

Individual intervention 1: FridgeCam

The parameters are adjusted according to the following:

- *Degree of using a shopping list;* in chapter 4, it is argued that the within 70% of all households use some kind of shopping lists. As stated in section 3.5.1, using a FridgeCam is assumed to increase this the usage of a shopping list within a household. However, it is not investigated to what degree. To consider the effect on the *Degree of using a shopping list,* a range is applied during the simulation with a maximum increase 15%, resulting in the following a base-run input of 70% and a maximal intervention input of 85%. As stated sub-section 6.3.1, the *Effect of an intervention in general* is also considered, resulting in the following formulas for the *Degree of using a shopping list:*
    - $Degree\ of\ using\ a\ shopping\ list\ =\ 0.7\ +\ (0.15\ *\ Effect\ on\ intervention\ general\ *\ FridgeCam)$

- *Degree of inventory checking;* in chapter 4, it is assumed that 80% of the inventory is remembered while planning to buy new food. The resulting 20% is checked by the household. It is assumed that 50% of the times when a planning is made, the household checks the available food present within a household. In total, the inventory is taken for 90% during the base-run. As stated in chapter 3, having the FridgeCam increases the *Degree of inventory checking.* To consider the effect on *Degree of inventory checking,* a range is applied during the simulation with a maximum increase of 50%, going from 50 to 100%. As stated sub-section 6.3.1, the *Effect of an intervention in general* is also considered, resulting in the following formulas for the *Degree of inventory checking:*
    - $Degree\ of\ inventory\ checking\ =\ 0.5\ +\ ((0.5\ *\ Effect\ on\ intervention\ general)\ *\ FridgeCam)$

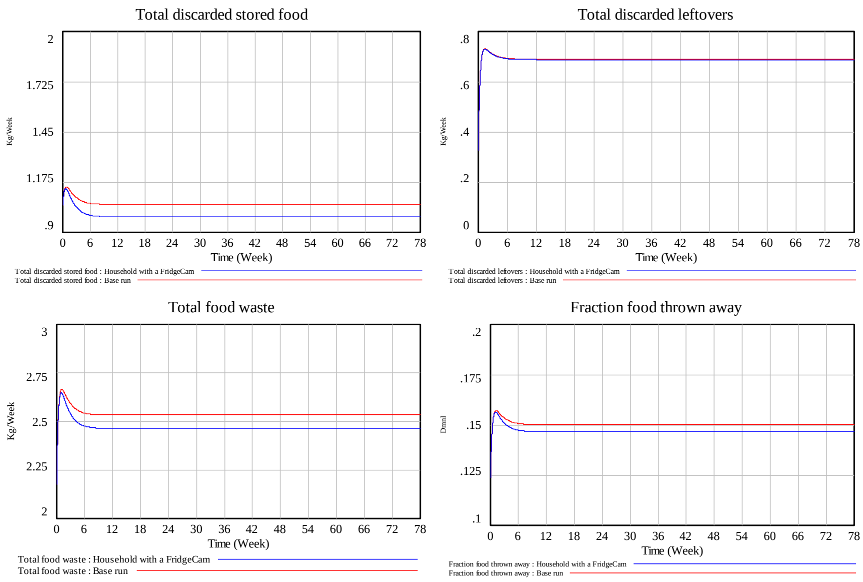


Figure 108: results of simulating the CamFridge intervention on the food waste variables

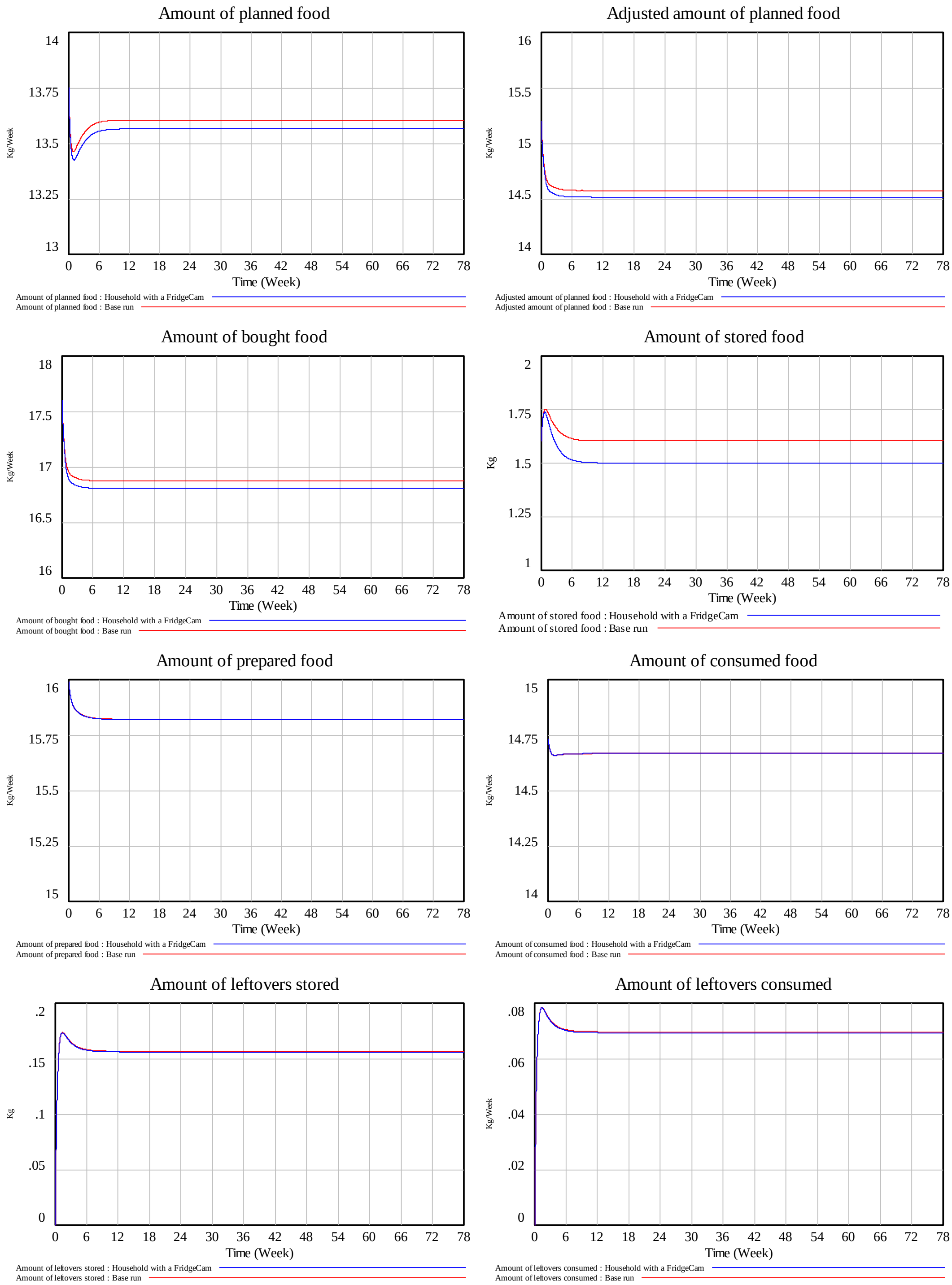


Figure 109: results of simulating the CamFridge intervention on main process variables

Individual intervention 2: No discounts and economies of scale
The parameters are adjusted according to the following:

- *Effect of economies of scale and discounts*; in chapter 4 it is assumed that having no discounts and no economies of scale results in a lower *Degree of overbuying.* Regarding this intervention, it is assumed that removing all the economies of scale and discounts by providing one price per kilogram results in a lower *Degree of overbuying.* A low effect of this intervention is given in the base-run, which is no effect at all. A big effect is given by the intervention where the *Effect of economies of scale and discounts* is totally removed. This results in the following accumulated fraction of overbuying: As stated sub-section 6.3.1, the *Effect of an intervention in general* is also considered, resulting in the following formulas for the *Effect of economies of scale and discounts.*
    - $Degree\ of\ discounts\ and\ economy\ of\ scale = 0.1 - (0.1 * Tailored\ made\ intervention * Effect\ on\ intervention\ general)$

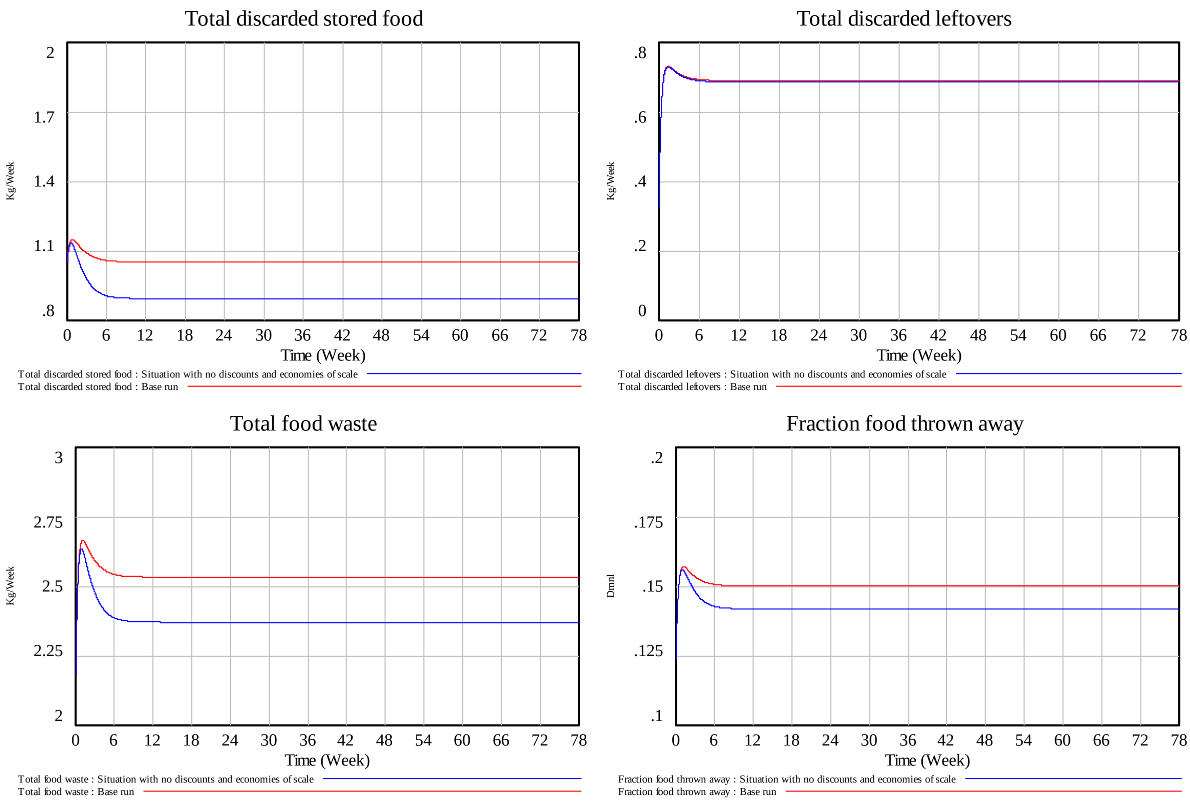


Figure 110: results No discount and economies of scale intervention on food waste variables

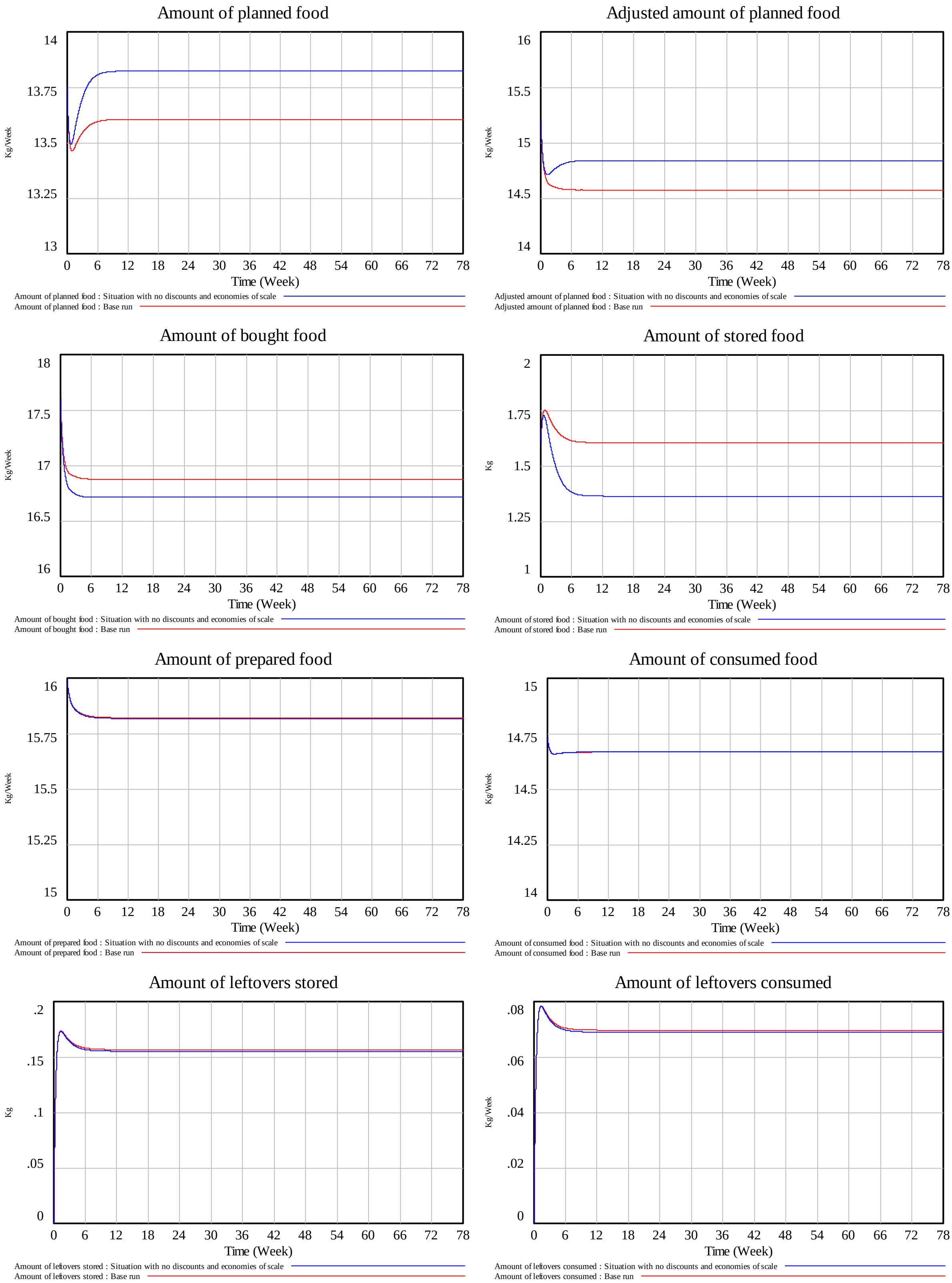


Figure 111: results No discount and economies of scale intervention on main process variables

Individual intervention 3: Spoilage knowledge campaign
The parameters are adjusted according to the following:

- *Spoilage knowledge*: in chapter 4 it is assumed that an average spoilage level of 50% is applicable within households. With the Awareness campaign on the best-by and best before date, the level of knowledge is assumed to increase, but again also over time people adopt this knowledge and people forget it on the longer term. Therefore, the same time-based function is assumed used during previous intervention given in **figure 48** and described in section 6.3.2. Regarding the *Spoilage knowledge* it is assumed that level of knowledge increases with a maximum of 20%. No change at all is illustrated by the base-run. As stated sub-section 6.3.1, the *Effect of an intervention in general* is also considered, resulting in the following formulas for the *Spoilage of knowledge:*
    - $Spoilage\ knowledge = 0.5 + (((0.1 * Awareness\ campaign\ on\ Best\ before\ Best\ used\ by\ dates * Effect\ on\ intervention\ general) + (0.1 * Big\ campaign\ effect)) * \text{"}Time - based\ effects\text{"})$

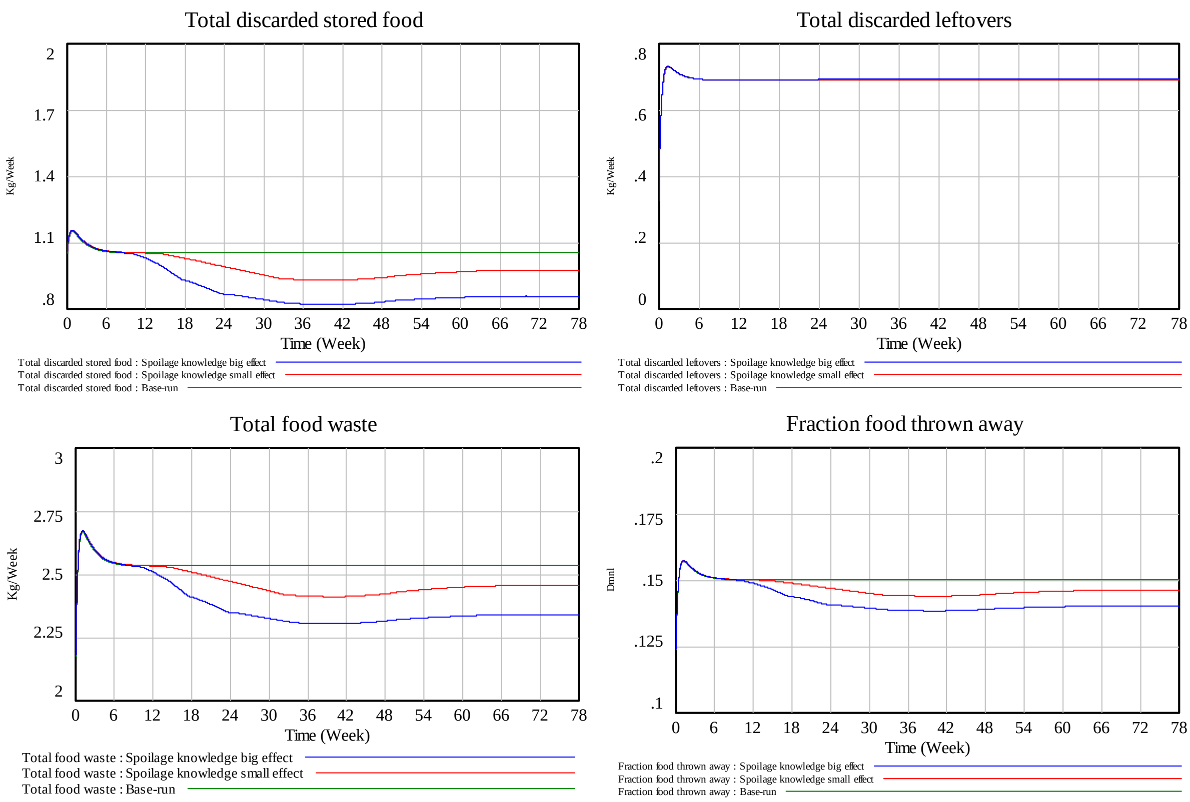


Figure 112: results Spoilage knowledge campaign on food waste variables

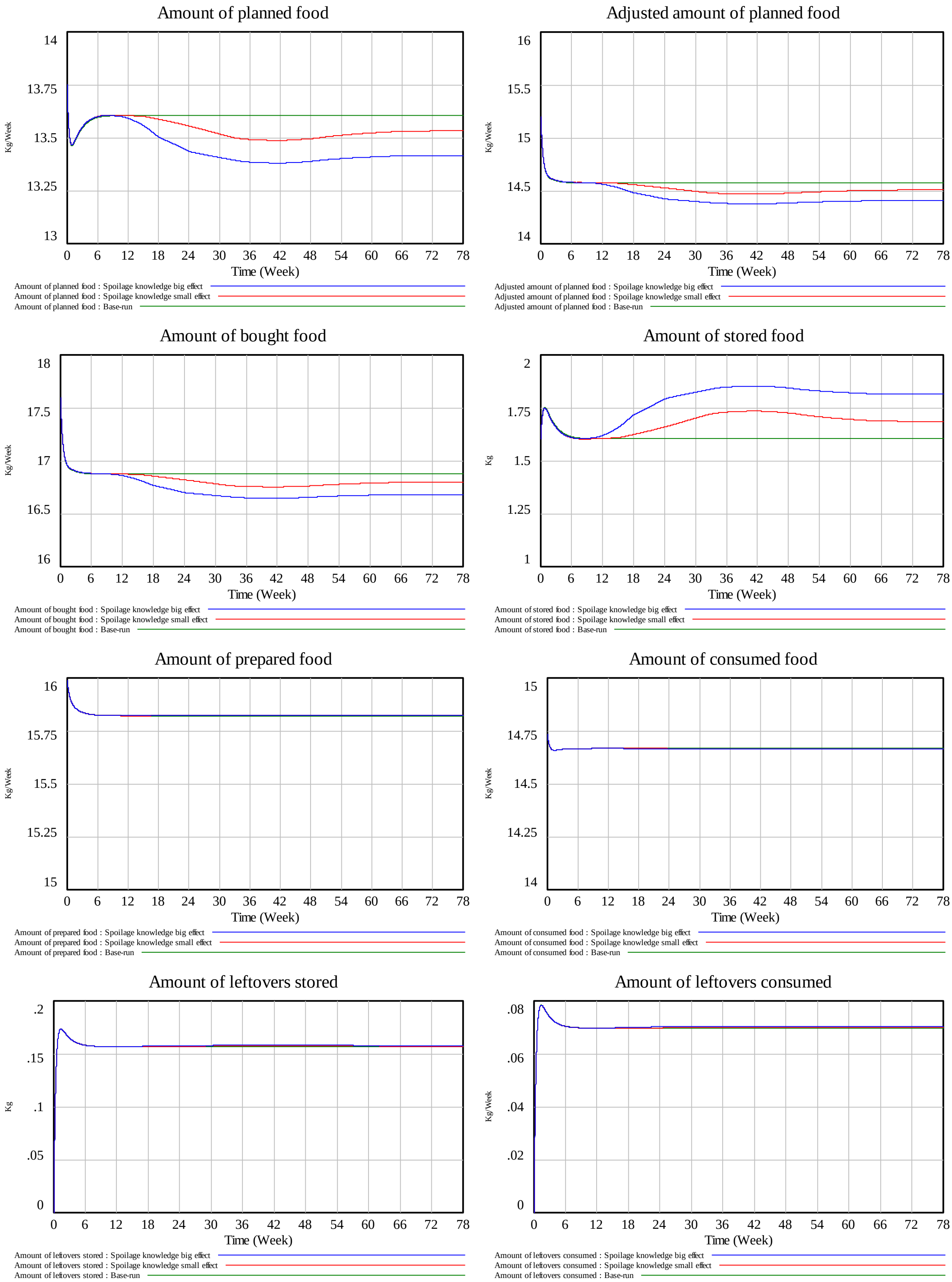


Figure 113: results Spoilage knowledge campaign on main process variables

Individual intervention 4: Knowledge consequences food waste campaign
The parameters are adjusted according to the following:

- *Knowledge on consequences food waste:* in chapter 4 it is argued that on average households know what the results are of wasting food. However, improvements are possible, which may increase by means of an awareness campaign on the consequences of food waste. The average knowledge on the consequences of food waste is assumed to be 70%. Increasing the knowledge with a campaign results in an average increase of 10% varying to 20%. As stated sub-section 6.3.1, the *Effect of an intervention in general* is also considered, resulting in the following formulas for the K*nowledge on consequences food waste:*

    - $Knowledge\ on\ consequences\ food\ waste\ =\ 0.7\ +\ (((0.1\ *\ Awareness\ campaign\ on\ consequences\ food\ waste)\ +\ (0.1\ *\ Big\ campaign\ effect))\ *\ "Time-based\ effects")$

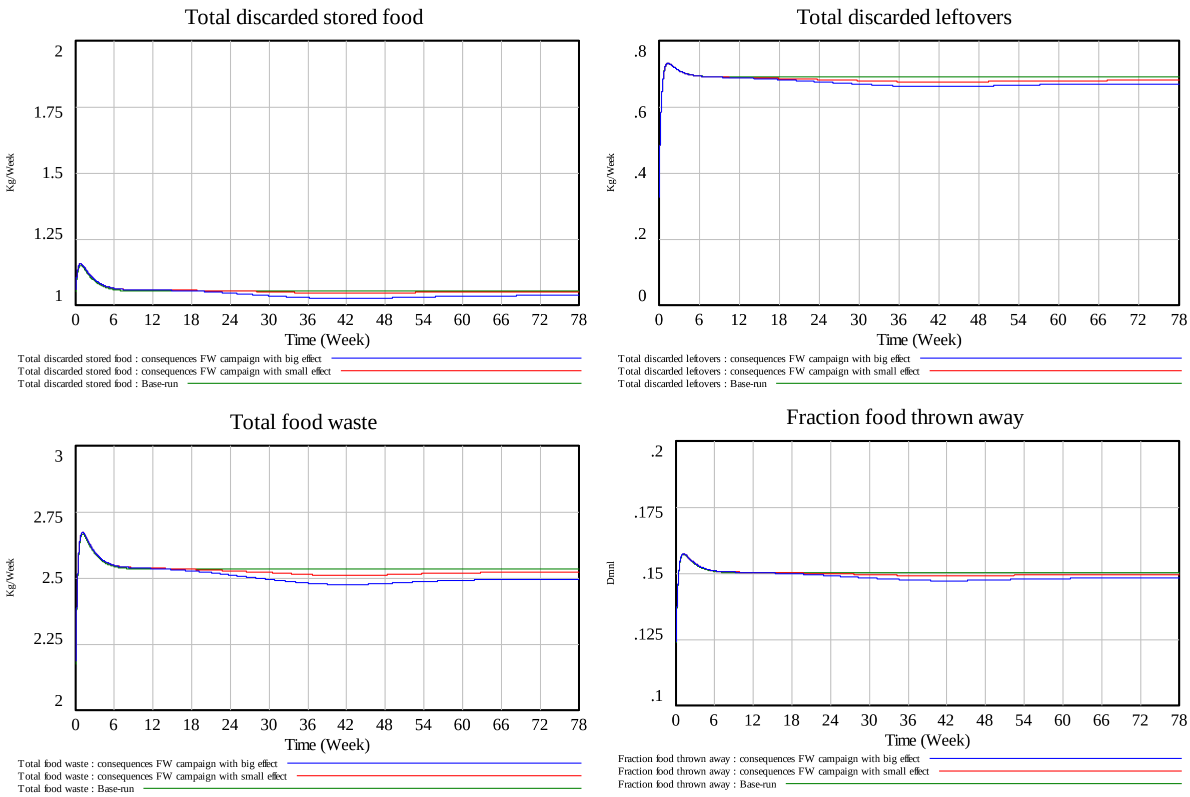


Figure 114 : results Knowledge on consequences food waste campaign on food waste variables

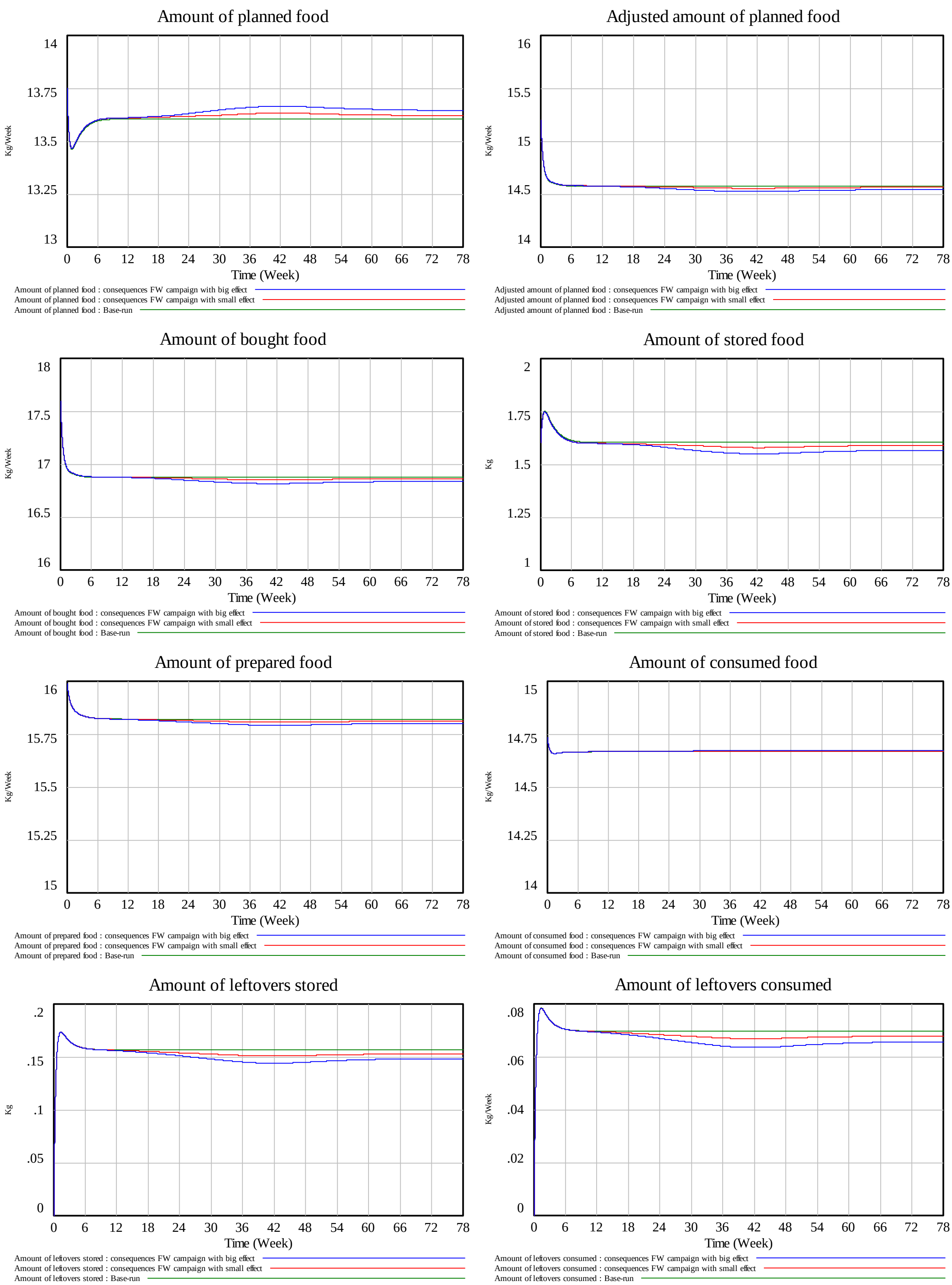


Figure 115 results Knowledge on consequences food waste campaign on main process variables

Appendix I: Combined model results

This appendix gives the results of the combined simulations as described in section 6.4. The behaviour of the simulations are compared with the base-run results illustrated in section 6.2 and the individual effects of the interventions as described in appendix J. The most important figures are presented, conclusions are drawn and elaborated on in section in 6.4. The results are presented per intervention strategy. Note that the appendixes are not simulated in equilibrium, however, the results on the longer term do not differ and are therefore presented. Besides, during in this appendix, difference is made between different adoption rates of campaigns. In section 6.4, only the big impacts are considered to provide a total overview of the potential effect of combining these interventions. During the simulations, a runtime of 78 weeks, a time step of 0.0078125, and the Runge-Kutta auto integration method are used. The results in the main text are given in equilibrium as described and tested in section 5.3.5.

Intervention strategy 1: No discount and economies of scale & Knowledge on consequences food waste campaign

The results of the simulating the intervention strategy are given on the food waste variables and on the main process variables. The most important conclusions are drawn in section 6.5.1. Important is the difference between the different adoption rates used in this appendix. The adoption rates used in chapter 6 are based upon the big effects of the Knowledge on consequences food waste campaign.

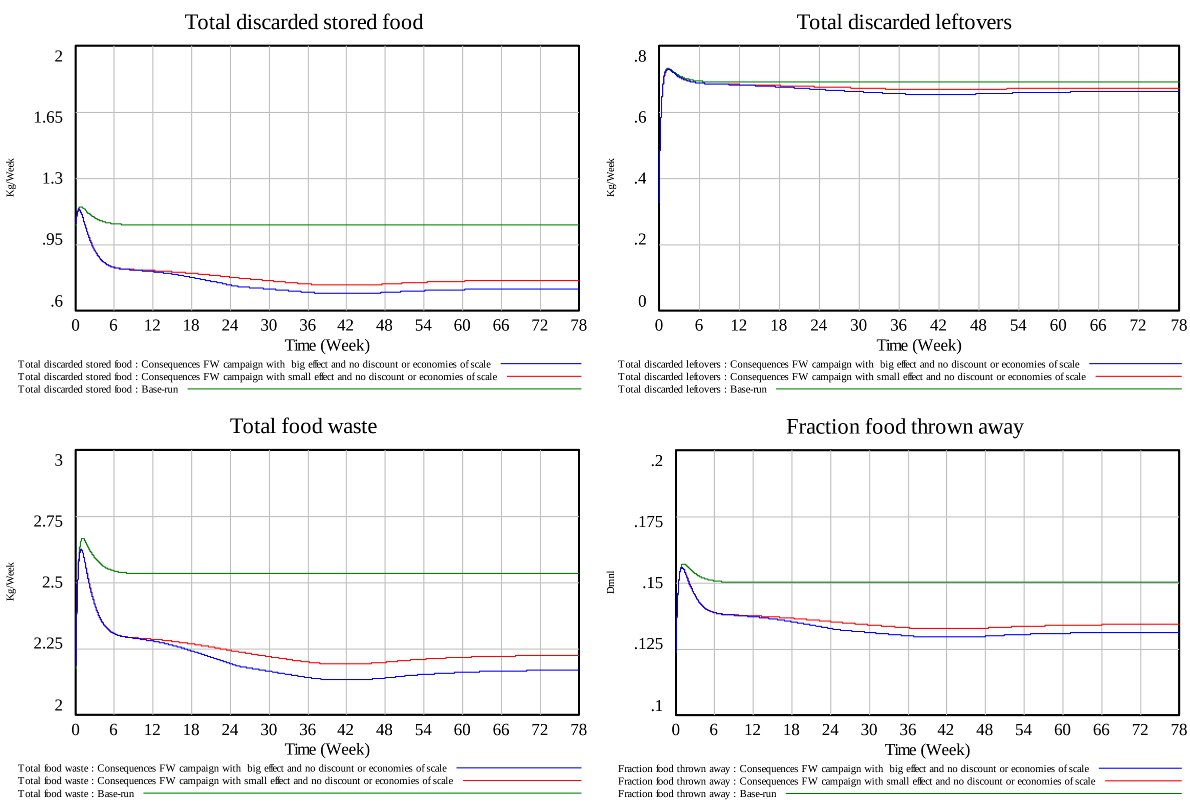


Figure 116: results of intervention 1 strategy on food waste variables

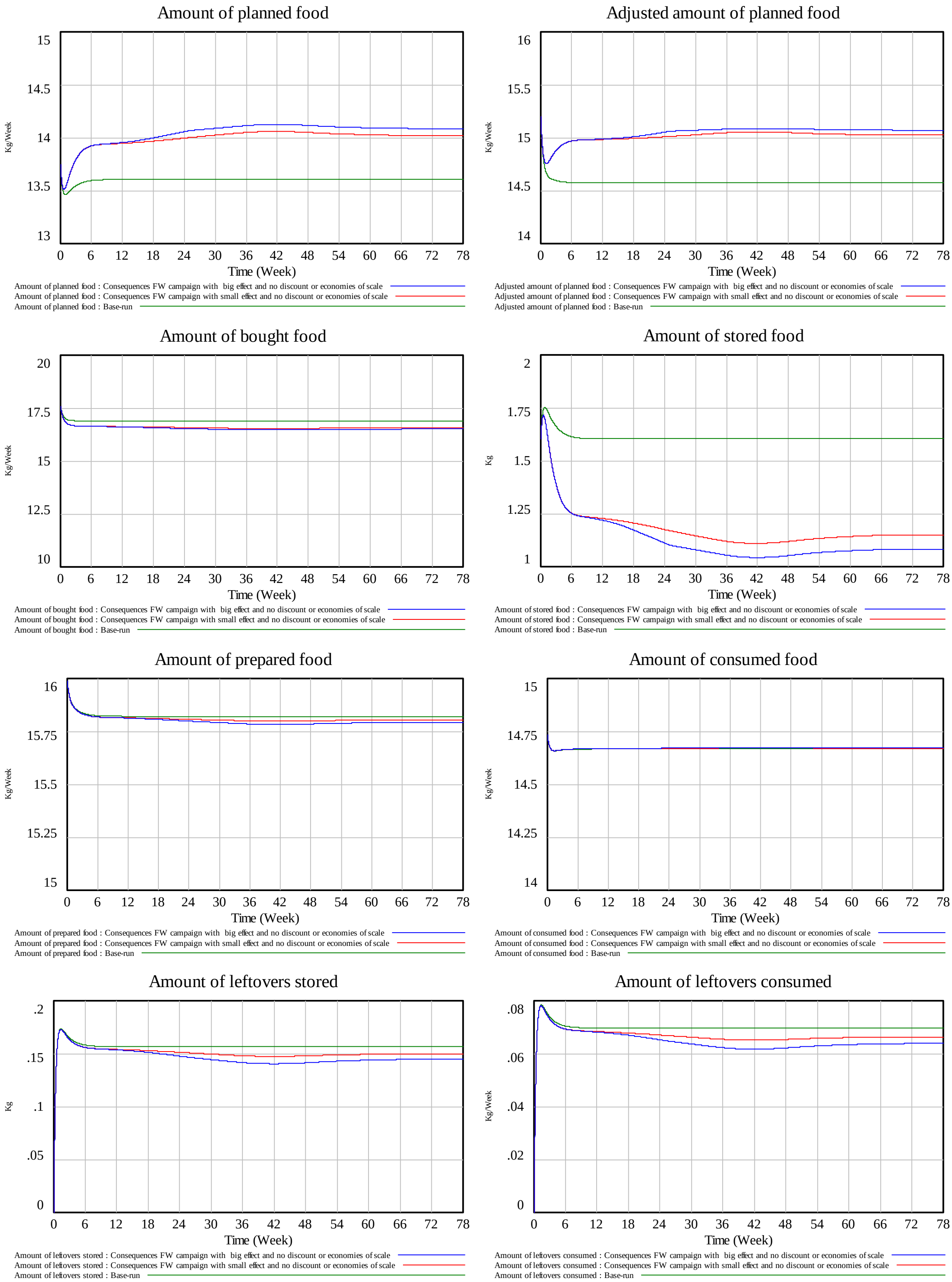


Figure 117: results of intervention strategy 1 on main process variables

Intervention strategy 2: Spoilage knowledge campaign & Knowledge on consequences food waste with a Spoilage knowledge with a small effect

The results of the simulating the intervention strategy are given on the food waste variables and on the main process variables. The most important conclusions are drawn in section 6.5.2. Important is the difference between the different adoption rates used in this appendix. The Spoilage knowledge campaign with a big effect in this appendix is used as the Spoilage knowledge campaign in section 6.5.2. The adoption rates used in chapter 6 are based upon the big effects of the Knowledge on consequences food waste campaign.

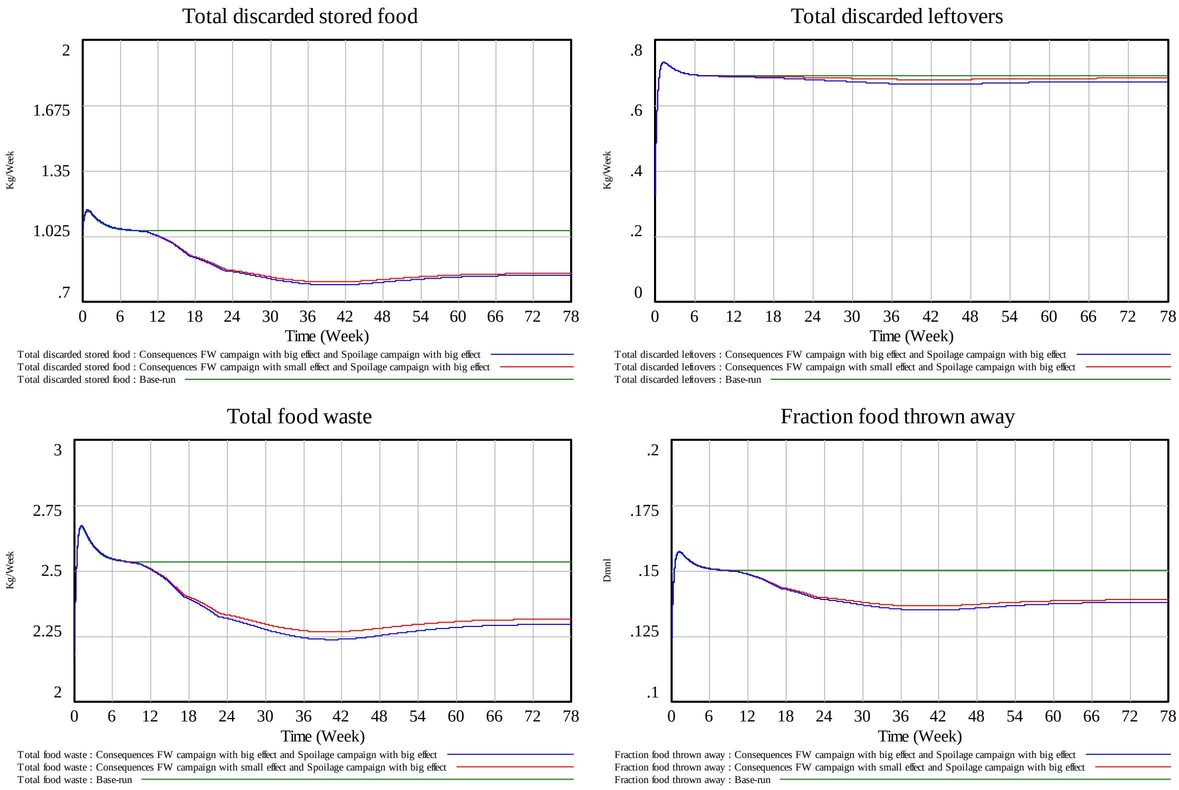


Figure 118: results of intervention strategy 2 on food waste variables

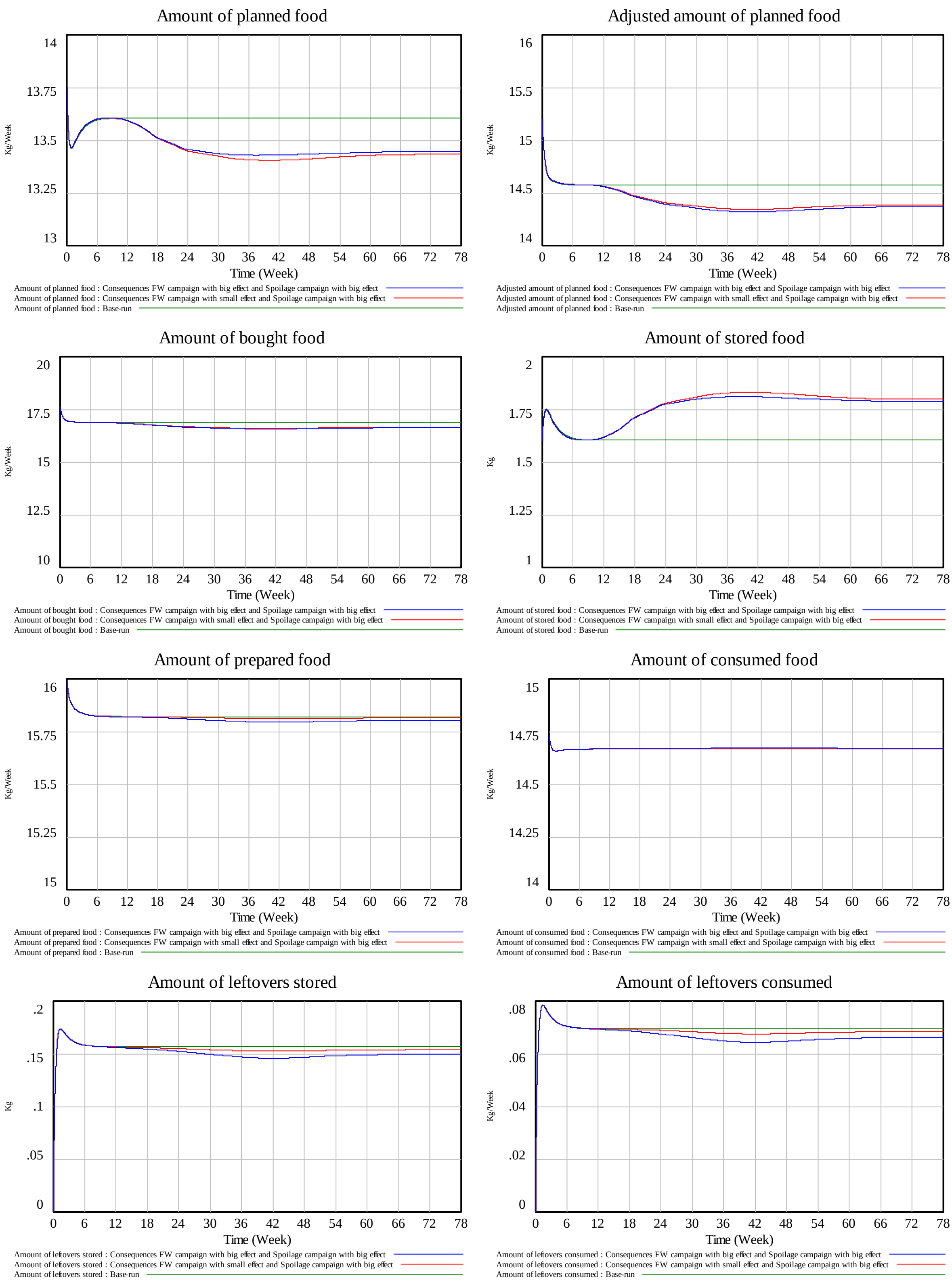


Figure 119: results of intervention strategy 2 on main process variables

Appendix J: Uncertainty analysis

The results of the uncertainty analysis are presented in this section. Based upon these results, the most important insights are considered in section 6.6. In this appendix, first the test is elaborated on. In chapter 4, 11 parameters are identified that are uncertain, which are discussed and simulated univariate in the second section of this appendix. Based upon the simulated individual impact of the uncertain parameters on the *Fraction food thrown away*, multiple important parameters are considered during the multivariate analysis. During the simulations, a runtime of 78 weeks, a time step of 0.0078125, and the Runge-Kutta auto integration method are used.

Uncertainty analysis

This uncertainty analysis aims to test the impact of multiple uncertain parameters on the combined System Dynamics model. In previous chapter, important uncertain parameters are identified. These parameters are simulated over a plausible range to determine the impact on the system as a whole. The results of this analysis are given in this **appendix.** The parameters that are most influential on the system are considered during the simulation the robustness test.

Factors identified during the data-gathering

Degree of over planning is considered as an uncertain variable during the planning phase. From the purchasing phase, the parameter *Effect of economies of scale and discounts* is taken further into account. From the storing phase, the parameters *Use by date, Best before date, Spoilage knowledge* and *Storing conditions* are considered during the uncertainty analysis. From the preparing phase, the *Provision factor* is taken further into account. From the consuming phase, the combined effect of the *Preference within household* and *Unpredictability lifestyle households is* considered during the uncertainty analysis. From the re-using leftover phase, the *Leftover knowledge* and *Desire to consume leftovers* are taken further into account. From the general phase, the variable *Knowledge on consequences food waste* is considered. As mentioned before, the *Degree of over planning* and *Provision factor* are mentioned as uncertain. However, these are replaced by the variables *Normal degree of over planning* and the *Normal provision factor.* The latter two are considered in the uncertainty analysis, doing this incorporates the feedback mechanism into the uncertainty analysis performed in next chapter. For every uncertain variable, a lower and upper bound is given and summarised in **table XX.**

Table 16: overveiw uncertain parameters

Uncertain variable	Lower bound	Average value	Upper bound
Degree of over planning	0.05	0.1	0.15
Effect of economies of scale and discounts	0.05	0.1	0.15
Use by date	0.5	1	1.5
Best before date	2	3	4
Spoilage knowledge	0.25	0.5	0.75
Storing conditions	0.5	0.7	0.9
Provision factor	0.025	0.05	0.075
Preference within household & Unpredictability lifestyle households	0.015	0.03	0.045
Leftover knowledge	0.25	0.5	0.75
Desire to consume leftovers	0.6	0.8	1
Knowledge consequences food waste	0.5	0.7	0.9

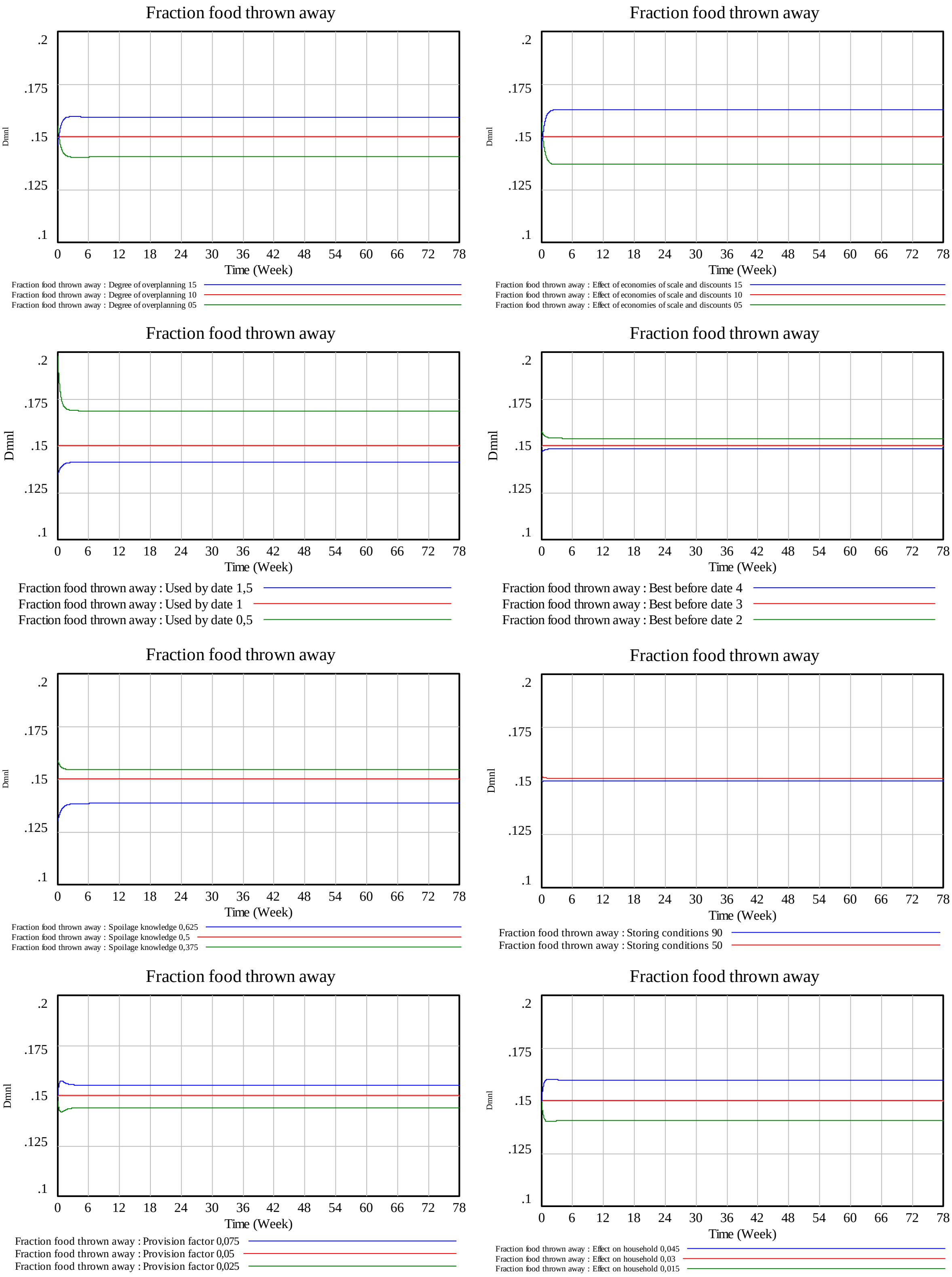


Figure 120: overview univariate testing (i/ii)

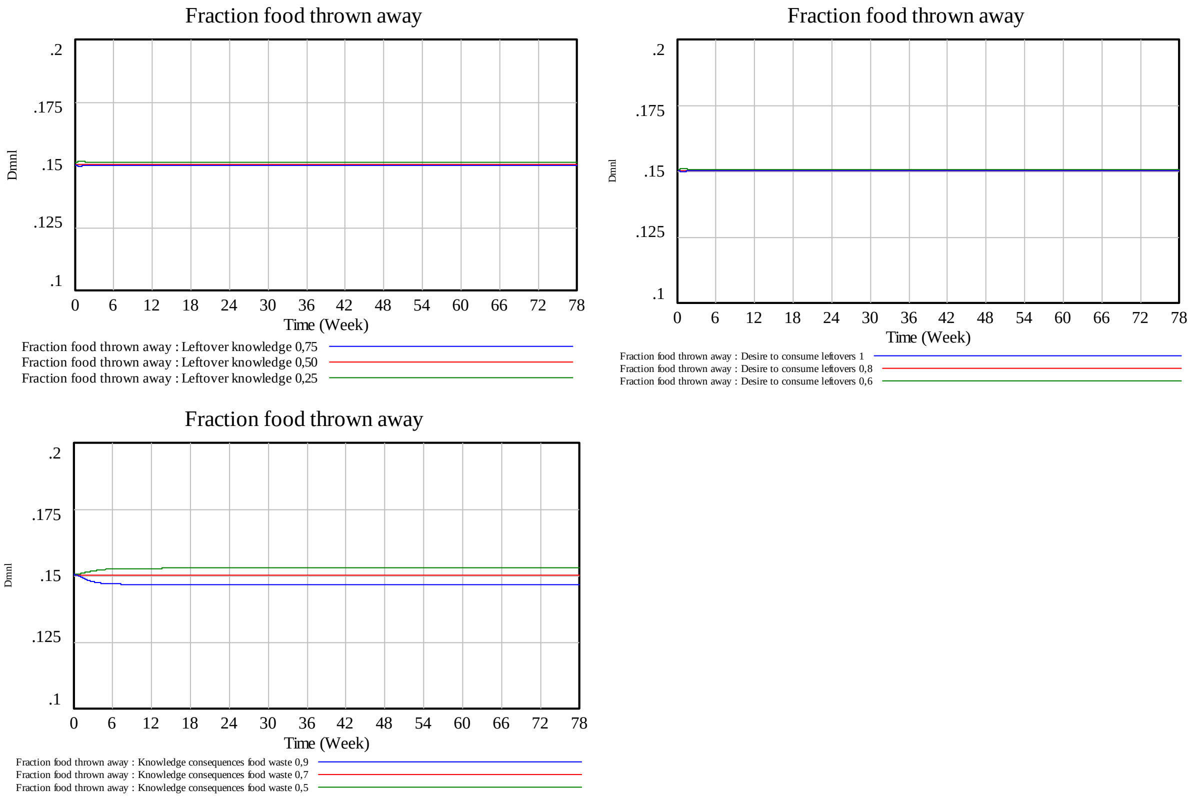


Figure 121: overview univariate testing (ii/ii)

Parameter 1: Degree of over planning (0.05-0.15)
Parameter 2: used by date (0.5 -1.5)
Parameter 3: Provision factor (0.05-0.15)
parameter 4: combined effect on Effect on households (0.00 – 0.06)

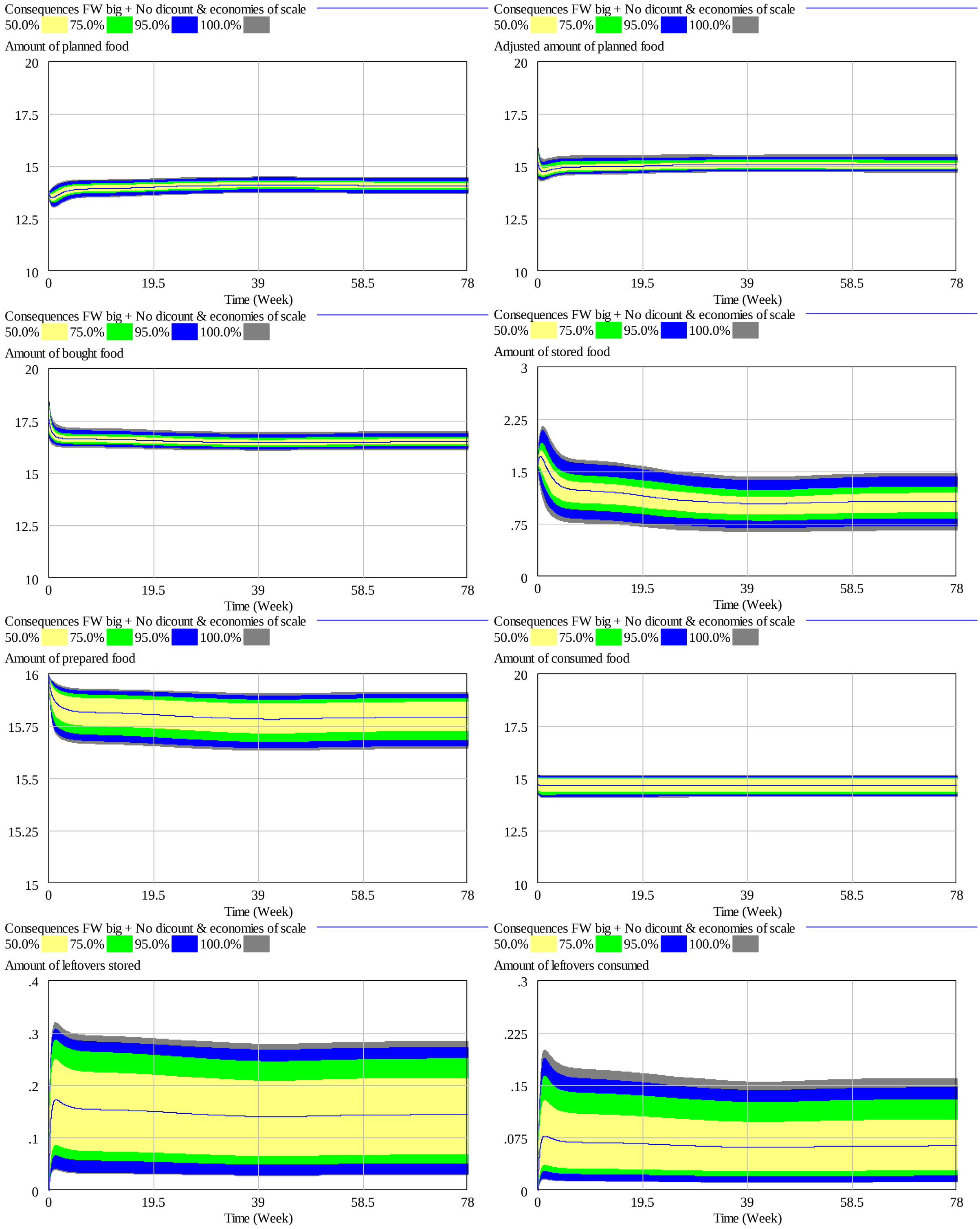


Figure 122: overview multivariate testing (i/ii)

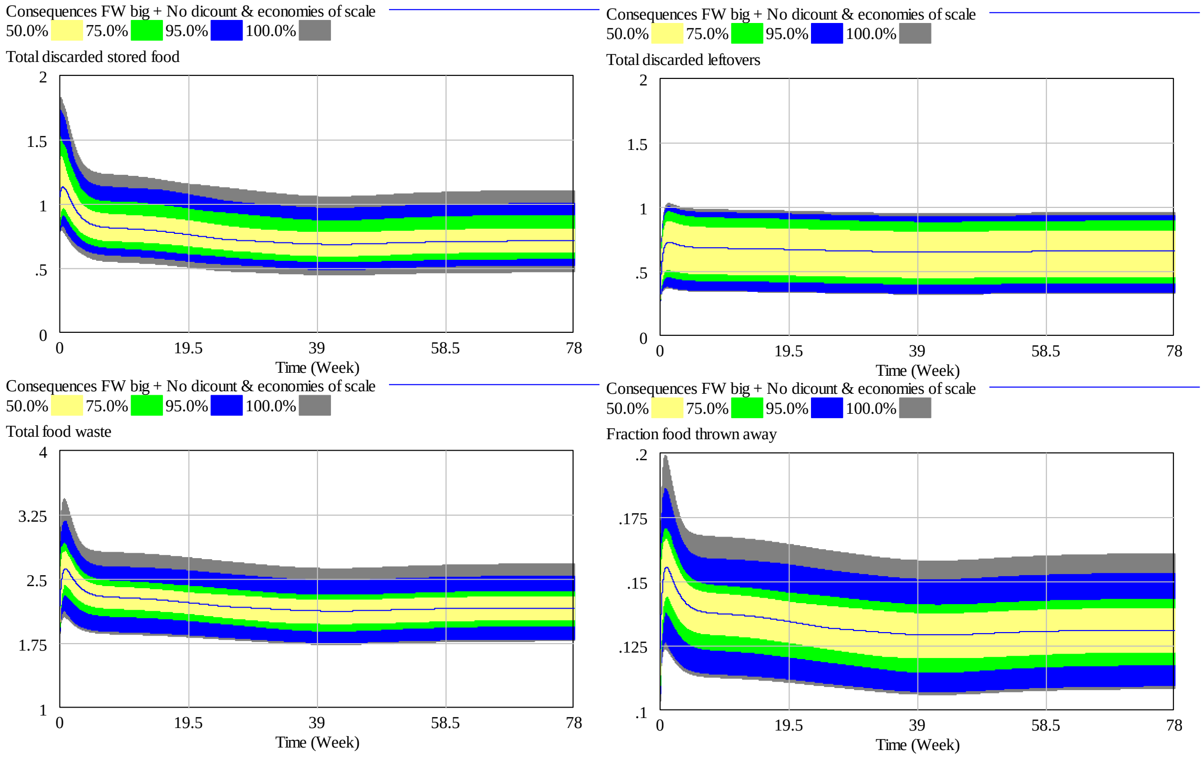


Figure 123: : overview multivariate testing (ii/ii)

Decrease food waste on the level of a household by means of synergies
A System Dynamics study towards food waste interventions

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15-09-2017

Abstract: *Within the Netherlands, households are the major contributors to the waste. There are negative environmental and financial consequences regarding the waste of food. In this article a System Dynamics approach is used to analyse the food waste system on a level of a household and to simulate the potential effects of interventions. Based upon simulating the interventions individually, it is concluded that the waste of food is fragmented generated. The waste of food caused in multiple phases (planning, purchasing, storing, preparing, consuming, and re-using leftovers phase). Affecting the waste of food in one phase has a limited effect on reducing the waste of food in total. Simulating the interventions combined may have an increasing or decreasing effect on each other. It is important to consider the knowhow and the willingness within a household. Focusing only on the knowhow results in a decreasing effect. Only focusing on the willingness has little impact. However, synergies are created by combining interventions that do affect the willingness and the knowhow within a household.*

Keywords: Food waste, Households, Interventions, Potential effects, System Dynamics

1. Introduction

The importance of wasting food is increasing at a national (Quested et al., 2013), European (Reisinger et al., 2011), and a global level (Foley et al., 2011). In developed countries like the Netherlands, households are the major contributor to the waste of food (Griffin et al., 2009; Parfitt et al., 2010; Gustavsson et al., 2011; Koivupuro et al, 2012; Silvennoinen et al., 2014). It is estimated that on average a person wastes around 41 kilograms food per year In the Netherlands in 2016. This waste of food was avoidable. It is indicated that within the Netherlands, 14% of all the food bought by a household is unnecessarily discarded (Crem, 2017).

There are negative consequences of wasting food. The world population is constantly increasing and meeting society's growing demand of food is a challenge (Foley et al., 2011). Feeding this growing demand is consequential; it sacrifices Earth's biodiversity, it increases the production of greenhouse gas emission due to the extra needed production, and it reduces the water supplies (Muir et al., 2010). Wasting less food results in a decrease of these negative environmental consequences. Besides, there is also a financial aspect regarding the waste of food. The waste of food in 2011 is estimated to be associated with a global cost of €715 billion (Schader et al. 2013).

Households do not decrease the waste of food by themselves. Multiple actors can influence this food wasting behaviour of households. However, these actors may have different conflicting perspectives on the waste of food (Halloran et al., 2014). There is little evidence, as to what interventions do reduce the amount of food wasted by a household and what interventions do not work (Sharp et al., 2010). In this article, the focus is on interventions that have a potential influence on the avoidable amount of food wasted on the level of a household from a multi-actor perspective.

The aim of this article is to investigate the behaviour of the generation of food waste on the level of a household and the potential effects of interventions on reducing this food waste in the Netherlands. This article is structured by the following research question: "*What are the potential effects of interventions on the waste of food generated by a household within the Netherlands?*" This article is based upon a System Dynamics study performed by de Waal (2017).

This article is structured as follows; the next section elaborates on the qualitative model of the food waste system by describing the main feedback mechanisms that are present within the food waste system on the level of a household. Besides, a set of interventions from multiple actors perspectives during this study is described. Section 3 elaborates on this qualitative model and the potential impact of the interventions on this system. The effects of these interventions, based on simulations of the System Dynamics model, are discussed in Section 4. Important insights are summarized and discussed in section 5 and 6 respectively.

2. Conceptual model of food waste system on the level of a household

This section conceptualizes the food waste system on the level of a household and is based upon a more extensive study (de Waal, 2017). A causal relation diagrams is designed by means of reviewing existing literature and two expert interviews. The result of this section is an aggregated causal diagram that represents the food waste system on the level of a household and an overview of the interventions that are considered during the model simulations.

2.1 defining food waste

To scope the study, the following definition of food waste is used in this article:

"All the avoidable food that is discarded during the storing of food, preparation of food, and the leftovers that are discarded within a household, either before or after it spoils, by the human members within a household"

2.2 conceptualisation of the food waste system

In scientific literature, it is argued that the generation of food waste is a product of the process as a whole (Quested et al., 2013a; Parizeau et al., 2015; Principato et al., 2015; Roodhuyzen et al., 2017). It is argued by Quested et al. (2011) that: the waste of food generated within a househould is not a behaviour in itself, but it is the agregrated result of the various behaviours in the food consumption chain. These are related to planning, shoppping, storage, perparation and consumption of food In addition to these behaviours, the practices related to storing and consuming of leftovers are considered during conceptualisation.

Based upon the behaviours the following phases are identified: a planning, purchasing, storing, preparing, consuming, and re-using leftover phase. A *planning phase* in which households plan to buy too much food, a *purchasing phase* in which households buy more food than planned, which are eventually stored during the storing phase. Following this food is prepared during *the preparing phase*, after which the members of the household consume it during the *consuming phase*. The amounts of food leftover are stored and consumed *re-using leftover phase*. Based upon, an aggregated causal relation diagram is identified, which is illustrated in figure 1.

As illustrated in figure 1, in the aggregated causal model food waste occurs during the *storing phase*, the *preparation phase*, via the

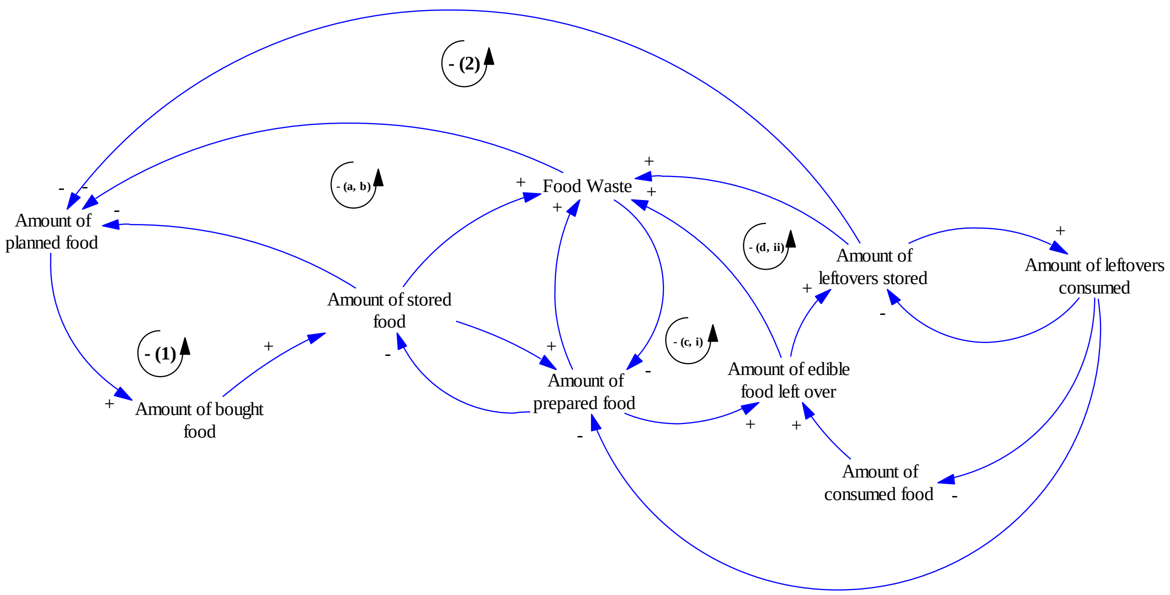

Figure 124: aggregated causal relation diagram food waste system on the level of a household

Amount of edible food leftover, the *consuming phase*, and the *leftover phase*. Edible and inedible stored food are both discarded during the storing phase due the moulding process the inability of a household to determine if food is still edible, or a misinterpretation of the used by or best before day (Ganglbauer et al., 2013; Evans, 2012; Parizeau et al., 2015; Silvennoinen, 2014 Williams et al., 2012; Jörissen et al., 2015). Inedible food prepared is wasted during the preparation of food due to a lack of cooking skills (Parizeau et al., 2015). Leftovers are discarded because households either do not know how (Cappellini & Parsons, 2012), or do not desire to re-use them (Farr-Wharton et al., 2014; Evans, 2012).

2.2 Feedback mechanisms

Within the causal relation diagram, which represents the food waste system, two main feedback mechanisms are identified. One mechanism is identified via the storage of food and leftovers and one mechanism is identified via the waste of food. Counter clockwise arrows depict the feedback loops with a negative sign within in figure 1**.**

The *Amount of stored food* and the *Amount of leftovers stored* are considered while a household determines the new *Amount of planned food* (Quested et al., 2013; Ganglbauer et al., 2013; Farr-Wharton et al., 2014). Considering the stored amounts of food and leftovers while a household determines its *Amount of planned food* results in negative feedback loops; i.e. the awareness of current *Amount of stored food* and *Amount of leftovers stored* limits or decreases the *Amount of planned food.*

Via the waste of food mechanisms, multiple feedback loops can be identified. It is assumed that wasting a lot of food results in adapting the planning and preparing behaviour within a household. Planning to buy too much food results in wasting food during the storing, consuming, and re-using leftovers phase. These food wastes are considered while making a new planning; wasting a lot of food results in a decrease of the *Amount of planned food*, illustrated by a negative feedback loop. Wasting food during the leftover phase is assumed to affect the preparing behaviour; wasting food during this phase results in a lower *Amount of prepared food*, which is illustrated by a negative feedback loop.

Based upon the aforementioned feedback mechanisms that are present within the defined aggregated causal relation diagram, multiple negative feedback loops are identified, which have a balancing nature. Loop 1 and 2 represent the feedback loops via the stored amounts. Loop a, b, and c are de feedback loops regarding the food waste related the planning behaviour. Feedback loop i and ii present the loops regarding the waste of food and the preparing behaviour within a household.

2.3 defining an intervention

To scope the study, the following definition of an intervention is used in this article: *"Measures that are used for reducing the amount of food waste that occur the preparation of food, and the food and leftovers that are discarded, either before or after it spoils, by the human members within a household."*

2.4 interventions for reducing the waste of food

Multiple interventions are applicable for influencing the waste of food. The effects of the interventions on the conceptual model are illustrated in figure 2. The following interventions are considered:

- *FridgeCam*. The 'FridgeCam' is an application installed on a mobile device and the secured on the inside of a fridge. This application is able to take several photos, which are approachable, online by the members of a household (Farr-Wharton et al., 2014). A 'FridgeCam' enables households to better consider what they have at home while doing groceries. This application from an industry perspective affects the planning phase, resulting in a consequently in a lower *Amount of planned food*, and thereby a lower *Amount of stored food*, finally resulting in a less stored food discarded.
- *No discount and economies of scale intervention.* This intervention entails a situation where no discounts and economies of scale are present in a supermarkets (Delley & Brunner, 2017). This intervention from a supermarkets perspective affects the purchasing phase, resulting in a lower *Amount of bought food* and thereby a lower *Amount of stored food*, consequential in less stored food discarded.
- *Spoilage knowledge campaign.* This spoilage campaign provides information to increase the overall spoilage knowledge within a household. It entails information of the difference between the "best before" date and the "use by" of products (Delley & Brunner, 2017). Understanding the difference contributes to a reduction of the waste of food (Vittuari et al. 2015). Besides, a better spoilage knowledge within a household may result in a better skill of determining the edibility of food, even if it has surpassed the best before date. This intervention from a governmental perspective affects the storing phase, resulting in a less food discarded.
- *Knowledge on consequences food waste campaign*. As mentioned before, it is assumed that the planning and preparing behaviour are influenced by the *Total amount of food waste*. Besides, it is assumed that the planning and preparing behaviour of a household are influenced by a *Moral attitude.* To account for this behaviour, the variable *Perceived food waste* is added, which is a product of the *Moral attitude* and the *Food waste*. This is illustrated in figure 2. This intervention from a governmental perspective is affects the *Moral attitude* within a household by providing information and education on the consequences of food waste. Thereby planning and preparing related behaviour is affected via the *Perceived food waste,* resulting in less stored food and leftovers discarded.

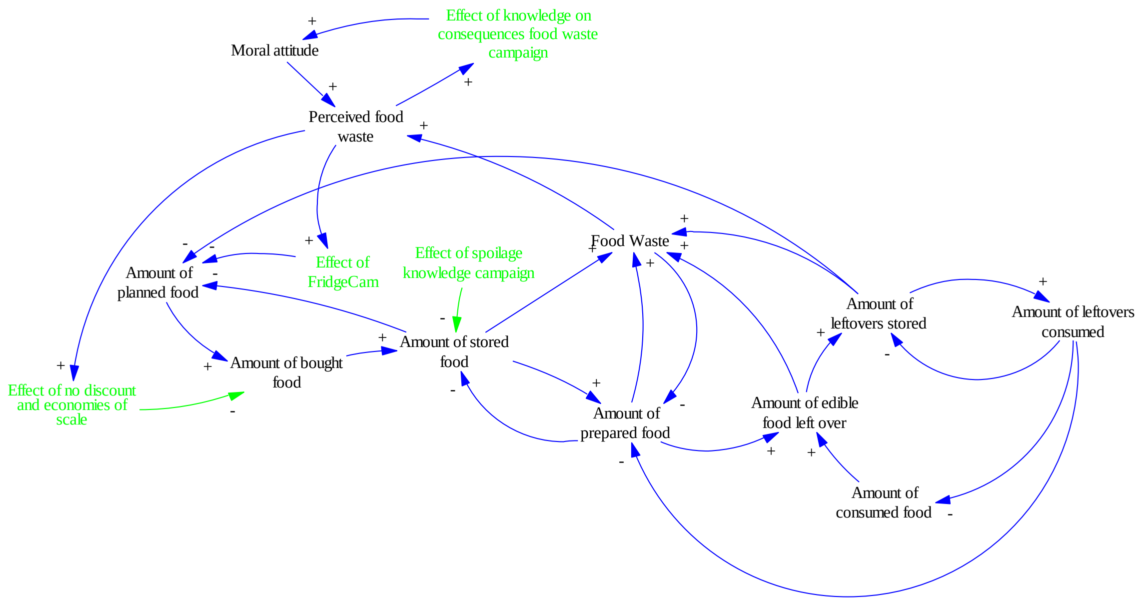

Figure 2: overview aggregated causal relation diagram with interventions included

Besides, the aforementioned mechanisms, there is also another mechanism included while applying interventions. The effect of an intervention is also dependent on the to reduce the food wasted (Stefan et al., 2013; Graham-Rowe, et al., 2014; Principato et al., 2015). Through this mechanism, temporary feedback loops are created while applying an intervention. All these interventions have a negative nature, resulting in more balancing loops present in the conceptual model.

3. Specification of the food waste system on the level of a household

The System Dynamics model is designed based on the combined causal relation diagram identified in previous section by means of literature review, expert interviews and educated guesses. A more detailed specification is elaborated on in the study of de Waal (2017). The result of this section is an overview of the uncertainties surrounding the System Dynamics model and the tests that are performed to improve the model.

3.1 Uncertainties regarding the data

This sub-section aims to elaborate on the uncertainties surrounding the specification *Perceived food waste* present within a household and illustrated in figure 2. A household that produces a lot of *Food waste* and has a high *Moral attitude* is more willing of the model. Little research is done toward causal relations regarding the waste of food on the level of a household (Roodhuyzen et al. 2017). Also, different definitions of food waste are used ranging for example from food waste, food loss, avoidable, possibly avoidable, and spoilage (Parfitt et al., 2010; Schneider, 2013). These different definitions result in different approaches used for on how food waste is studied, measured, and presented. This finally results in a domain of which the results are hard to compare (Koivupuro et al., 2012; Parfitt et al., 2010; Silvennoinen et al., 2014). Data is therefore lacking and assumptions are inevitable. To cope with these uncertainties, multiple uncertain parameters are identified and incorporated considered a robustness analyses, which is discussed in next section

3.2 static and dynamic tests

To improve the model and to identify its limits, multiple test are performed. Respectively, the approach by Sterman (2000, ch. 21) is used and the following three static tests are performed; Boundary adequacy, Dimension consistency, and Structure assessment. Regarding the dynamic tests, the following tests are used: Extreme condition test, Sensitivity analysis, Output validation, Initialisation, and Face validation. The System Dynamics model is adjusted and improved according to the outcomes of these tests.

4. Model results

The interventions identified in section 2 are simulated and the results of the simulations are discussed in this section. The results on the variable *Fraction food thrown away* is given in this section. This variable is the fraction food thrown away regarding the food that is bought by a household.

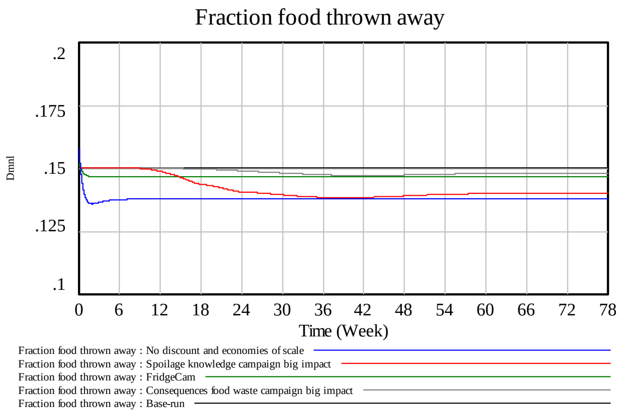

Figure 3: individual effects of the interventions based upon the System Dynamics model

4.1 Individual effects

The simulated individual effects of the intervention are illustrated in figure 3. All interventions do reduce the fraction food thrown away. None of the interventions do have a big individual effect on reducing the waste of food within a household, which indicates that the generation of food waste is segmented. Effective reducing the amount of food waste demands affecting the food waste system on multiple phases. The intervention 'No discount and economies of scale intervention' seems to reduce the *Fraction food thrown away* the most. This intervention is combined with the 'Knowledge on consequences food waste campaign' and with the 'Spoilage knowledge campaign' in next section to simulate its combined potential.

4.2 Combined effects

The simulated combined effect of the first intervention strategy where the 'No discount and economies of scale intervention' is combined with 'Knowledge on consequences food waste campaign' and the second intervention strategy where the 'No discount and economies of scale intervention' is combined with 'Spoilage knowledge campaign' are illustrated in figure 4. The first intervention is illustrated on the left and the second intervention strategy is illustrated on the right in figure 4.

Based upon combining the interventions 'No discount and economies of scale intervention' and the 'Knowledge on consequences food waste campaign', an enlarging effect can be identified. The combined results of these interventions is bigger than the individual effects accumulated. This is explained, as mentioned in end of section 2, by the mechanism that the 'Knowledge on consequences food waste campaign' has a positive effect on the *Moral attitude,* and thereby a positive effects on 'No discount and economies of scale' intervention via the increased *Perceived food waste*. Besides, the planning and preparing behaviour within a household are also affected. A decrease of the *Amount of planned food* and *Amount of prepared food* results, which also finally results in a decrease of the discarded stored food and leftovers within a household.

However, the 'No discount and economies of scale intervention' intervention combined with the 'Spoilage knowledge campaign' results in a accumulated decreasing effect. This decrease can be explained by the fact that decreasing the waste of food via an intervention

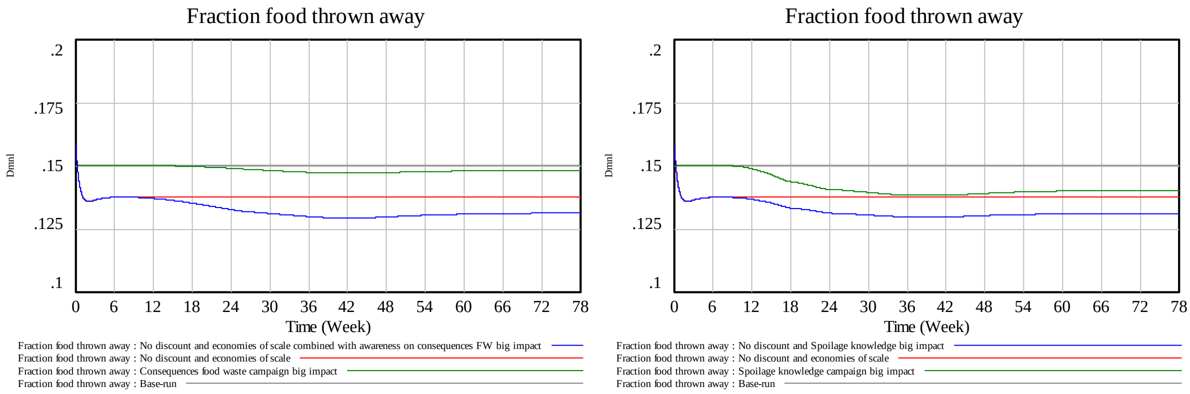

Figure 4: effect of combining interventions compared with the individual effect first intervention strategy (left) and the second intervention strategy (right)

on the waste of food. If a household is able to reduce the waste of food by the use of one intervention, the effect of another intervention decreases since the urgency to reduce the waste of food is decreased within the household.

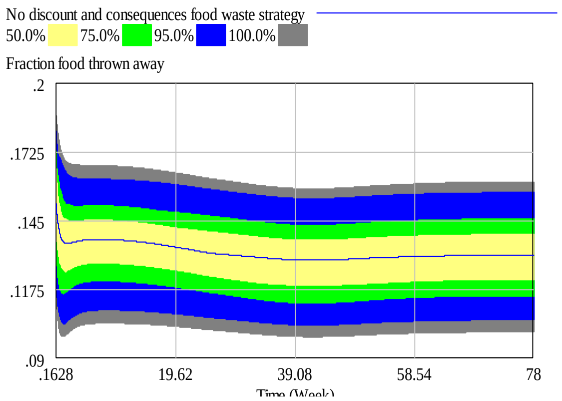

Figure 5: simulating the intervention strategy while varying parameters multivariate

4.3 Robustness

The intervention strategy where the interventions 'No discount and economies of scale intervention' and the 'Knowledge on consequences food waste campaign' are combined is tested on its robustness in this section. Multiple important uncertain parameters, are varied over a plausible range. These are varied univariate and multivariate while simulating the first intervention strategy. The effect of changing these parameters on the behaviour on the *Fraction food thrown away* is illustrated in figure 5.

Based on the result of the robustness analysis, it is concluded that the effect of the intervention strategy is robust but the actual size of the effect is uncertain.

5. Conclusion

This article considered the following question: "*What are the potential effects of interventions on the waste of food generated by a household within the Netherlands?*" To do so, a System Dynamics model is developed to understand and explore the behaviour regarding the waste of food generated by households and the potential effects of interventions on reducing the amount of waste generated by households. Multiple feedback mechanisms are identified within the food waste system on the level of a household. Storage feedback mechanisms are identified: planning to buy more food results in a higher amount of stored food. This amount is considered while making a new planning, resulting in a decrease of the amount of planned food. Food waste feedback mechanisms are identified; wasting a lot food results in affecting the planning and preparing behaviour within a household, which finally results in a lower amount of food wasted. The storage and food waste mechanisms are of a negative nature; multiple balancing loops are present within the food waste system on the level of a household. Besides these mechanisms, there are also temporary feedback mechanisms present. Applying an intervention results in a temporary feedback loop.

The actual impact of these interventions based on the simulation cannot be considered due to the uncertainties surrounding the results. However, they provide rough indications on potential effects. The results of the individual simulations illustrate the segmented process in which food is wasted on the level of a household. This waste of food is generated on multiple places in multiple phases. This suggests that an effective approach demands multi-phase affecting intervention strategy. Combining interventions can have an enlarging or decreasing effect. Within a household there are two components that are important to consider while effectively reducing the amount of food waste. Households should know how to reduce the waste of food and households should be willing to reduce the amount of food waste. A lot of measures can be taken, but focussing multiple interventions on the knowhow results in a decreasing combined effect. Focusing only on the willingness does not have a big impact. Combining an intervention that provides know how with an intervention that increases the willingness within a household results in a synergy; their combined effect is greater than the sum of their separate effects

6. Discussion

There are a lot of uncertainties regarding the simulated effects on the food waste on the level of a household. As mentioned before, different definitions of food waste are used. Different ways of measuring food waste are used. Different ways of presenting the waste of food are used, which troubles comparing the outcomes of the studies. Besides, little data was available regarding the values of the parameters of the System Dynamics model and the potential effects of the interventions. Therefore, assumptions are inevitable. The aggregation level of the model considered has also implications. No distinction is made between different kinds of food and households due to a lack of data. The potential effects of the interventions are also lacking. Therefore, potential effects are assumed. To cope with the resulting assumptions, the most important uncertain parameters are considered while testing the robustness of on an intervention. Even though the behaviour of the interventions seemed to be robust, the actual impacts of the interventions are hard to consider due to the uncertainties; they provide rough indications. The underlying mechanisms are important and interesting to consider.

Further research should focus on the causal mechanisms within the food waste system on the level of a household rather than on statistical significance. Incorporating causality in these studies could increase the quality and the usability of this research. Considering causal mechanisms may identify the factors that truly are responsible for the generation of food waste and relations between these factors may become more realistic; meaningful insights can be derived. Consider causal mechanisms would also improve the quality of the estimation of possible effects of interventions. Potential effects are estimated better or even unexpected results might be identified, providing better designs.

Besides the causal mechanisms, also applying simulations models may increase the quality of the research regarding the field of food waste on the level of a household. Other modelling methods can equally describe the system and derive meaningful insights. Combining multiple simulation methods would also increase the quality of the model representing the waste of food on the level of a household. Also, the resulting uncertainties could be further explored.

References

Cappellini, B., & Parsons, E. (2012). Practising Thrift At Dinnertime: Mealtime Leftovers, Sacrifice And Family Membership. *Sociological Review*, *60*(2), 121–134. http://doi.org/10.1111/1467-954X.12041

Crem. (2017). *Bepaling voedselverspilling in huishoudelijk afval Nederland 2016*.

Delley, M., & Brunner, T. A. (2017). Foodwaste within Swiss households: A segmentation of the population and suggestions for preventive measures. *Resources, Conservation and Recycling*, *122*(December 2012), 172–184. http://doi.org/10.1016/j.resconrec.2017.02.008

Evans, D. (2011). Blaming the consumer – once again : the social and material contexts of everyday food waste practices in some English households. *Critical Public Health*, *21*(4), 429–440. http://doi.org/10.1080/09581596.2011.608797

Farr-Wharton, G., Foth, M., & Choi, J. H. J. (2014). Identifying factors that promote consumer behaviours causing expired domestic food waste. *Journal of Consumer Behaviour*, *13*, 393–402. http://doi.org/10.1002/cb

Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., … Zaks, D. P. M. (2011). Solutions for a cultivated planet. *Nature*, *478 (7369)*, 337–342. http://doi.org/10.1038/nature10452

Ganglbauer, E., Fitzpatrick, G., & Comber, R. (2013). Negotiating food waste: Using a practice lens to inform design. *ACM Transactions on Computer-Human Interaction (TOCHI)*, *20*(2), 1–25. http://doi.org/10.1145/2463579.2463582

Graham-Rowe, E., Jessop, D. C., & Sparks, P. (2014). Identifying motivations and barriers to minimising household food waste. *Resources, Conservation and Recycling*, *84*, 15–23. http://doi.org/10.1016/j.resconrec.2013.12.005

Griffin, M., Sobal, J., & Lyson, T. A. (2009). An analysis of a community food waste stream United States Department of Agriculture. *Agriculture and Human Values*, *26*, 67–81. http://doi.org/10.1007/s10460-008-9178-1

Halloran, A., Clement, J., Kornum, N., Bucatariu, C., & Magid, J. (2014). Addressing food waste reduction in Denmark. *Food Policy*, *49*, 294–301. http://doi.org/10.1016/j.foodpol.2014.09.005

Jörissen, J., Priefer, C., & Bräutigam, K. R. (2015). Food waste generation at household level: Results of a survey among employees of two European research centers in Italy and Germany. *Sustainability (Switzerland)*, *7*(3), 2695–2715. http://doi.org/10.3390/su7032695

Koivupuro, H., Hartikainen, H., Silvennoinen, K., Katajajuuri, J., Heikintalo, N., Reinikainen, A., & Jalkanen, L. (2012). Influence of socio-demographical , behavioural and attitudinal factors on the amount of avoidable food. *International Journal of Consumer Studies*, *36*(2), 183–191. http://doi.org/10.1111/j.1470-6431.2011.01080.x

Muir, J. F., Pretty, J., Robinson, S., Thomas, S. M., & Toulmin, C. (2010). Food security: the challenge of feeding 9 billion people. *Science*, *327*(5967), 812–818.

Parfitt, J., Barthel, M., & Macnaughton, S. (2010). Food waste within food supply chains: quantification and potential for change to 2050. *Philosophical Transactions of the Royal Society of London*, *365*((1554)), 3065–3081. http://doi.org/10.1098/rstb.2010.0126

Parizeau, K., Massow, M. Von, & Martin, R. (2015). Household-level dynamics of food waste production and related beliefs , attitudes , and behaviours in Guelph , Ontario. *Waste Management*, *35*, 207–217. http://doi.org/10.1016/j.wasman.2014.09.019

Principato, L., Secondi, L., Alberto, C., Secondi, L., & Pratesi, C. A. (2015). Reducing food waste : an investigation on the behaviour of Italian youths. *British Food Journal*, *117*(2), 731–748. http://doi.org/10.1108/BFJ-10-2013-0314

Quested, T. E., Marsh, E., Stunell, D., & Parry, A. D. (2013). Spaghetti soup : The complex world of food waste behaviours. *Resources, Conservation & Recycling*, *79*, 43–51. http://doi.org/10.1016/j.resconrec.2013.04.011

Quested, T. E., Parry, A. D., Easteal, S., & Swannell, R. (2011). Food and drink waste from households in the UK. *Nutrition Bulletin*, *36*(4), 460–467. http://doi.org/10.1111/j.1467-3010.2011.01924.x

Reisinger, H., van Acoleyen, M., O'Connor, C., Hestin, M., Laureysens, I., Morton, G., Dolley, P., Nelen, D., and Vanderreydt, I. (2011). (2011). *Evolution of (bio-) waste generation/prevention and (bio-) waste prevention indicators*.

Roodhuyzen, D. M. A., Luning, P. A., Fogliano, V., & Steenbekkers, L. P. A. (2017). Putting together the puzzle of consumer food waste: Towards an integral perspective. *Trends in Food Science & Technology*, *68*, 37–50. http://doi.org/10.1016/j.tifs.2017.07.009

Schader, C., Schmidt, U., & Brei, J. (2013). *Food Wastage Footprint: Full-cost accounting*.

Sharp, V., & Wilson, D. C. (2010). Delivery and impact of household waste prevention intervention campaigns (at the local level). *Waste Management & Research*, *28*(3), 256–268. http://doi.org/10.1177/0734242X10361507

Silvennoinen, K., Katajajuuri, J., & Hartikainen, H. (2014). Food waste volume and composition in Finnish households. *British Food Journal*, *116*(6), 1058–1068. http://doi.org/10.1108/BFJ-12-2012-0311

Stefan, V., Herpen, E. Van, Alina, A., & Lähteenmäki, L. (2013). Avoiding food waste by Romanian consumers : The importance of planning and shopping routines. *Food Quality and Preference*, *28*(1), 375–381. http://doi.org/10.1016/j.foodqual.2012.11.001

Sterman, J. D. (2001). *Business dynamics: systems thinking and modeling for a complex world*. McGraw-Hill Higher Education.

Vittuari, M., Politano, A., Gaiani, S., Canali, M., Azzurro, P., Elander, M., … Easteal, S. (2015). *Review of EU legislation and policies with implications on food waste* (FInal Repo). Retrieved from http://www.eu-fusions.org/index.php/download?download=161:review-of-eu-legislation-and-policies-with-implications-on-food-waste.

De Waal, J. (2017) *Wasting food on the level of a household. System Dynamics based study towards the potential effects of interventions (master's thesis).*

Williams, H., Wikström, F., Otterbring, T., Löfgren, M., & Gustafsson, A. (2012). Reasons for household food waste with special attention to packaging. *Journal of Cleaner Production*, *24*, 141–148. http://doi.org/10.1016/j.jclepr