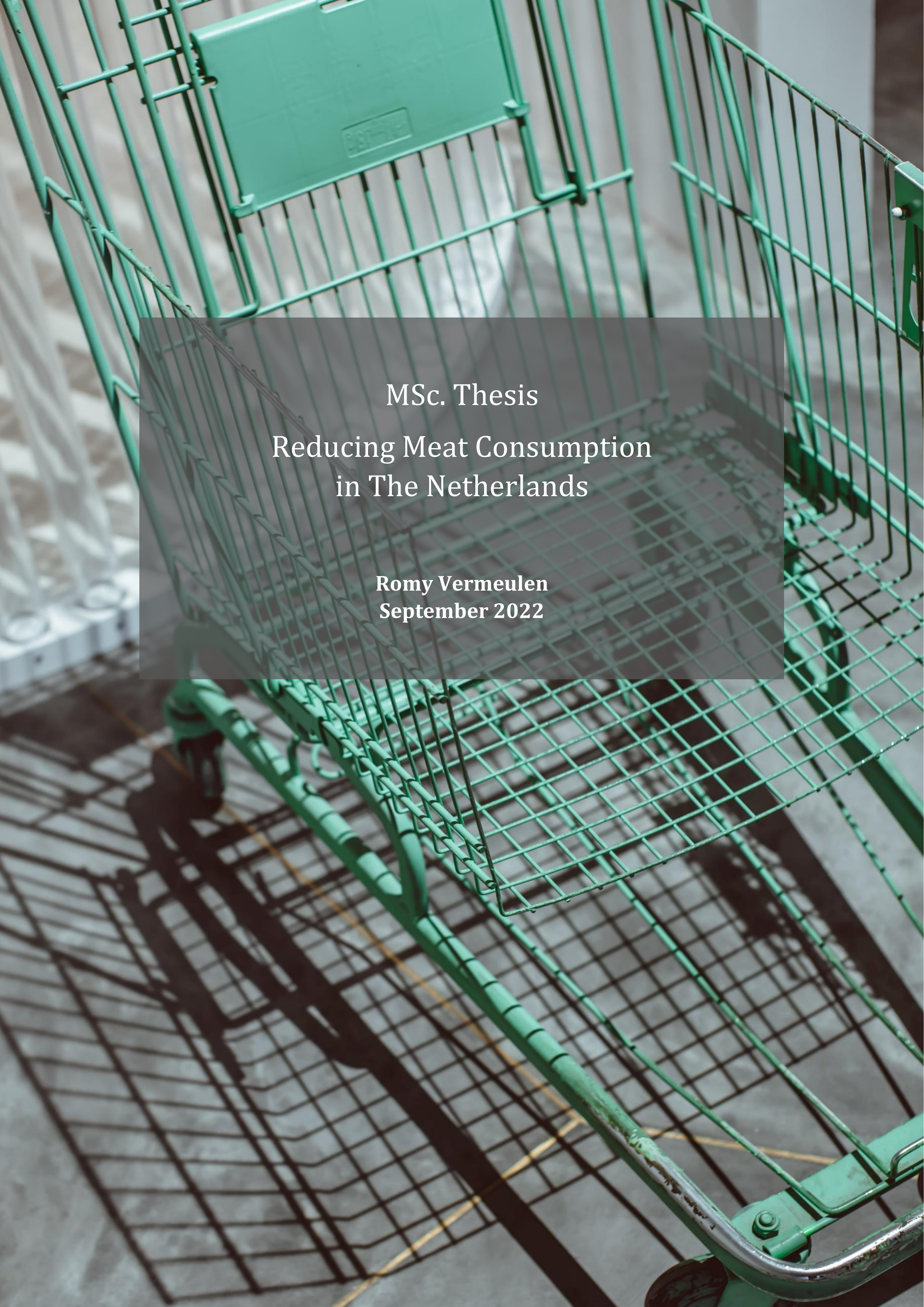

MSc. Thesis

Reducing Meat Consumption in The Netherlands

Romy Vermeulen

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THE EFFECTIVENESS OF POLICY PATHWAYS ON REDUCING MEAT CONSUMPTION IN THE NETHERLANDS

A PARTICIPATORY AGENT-BASED MODELLING APPROACH

Thesis submitted as final part to obtain the Master of Science in the field of Industrial Ecology

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Finally I am delivering my thesis to the public!!! It was a challenging process that taught me a lot, and during which I received an incredible amount of support. I always considered the acknowledgements section slightly exaggerating, but I definitely changed my mind on that. So here it comes…

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Enjoy reading my work!

Romy Vermeulen

EXECUTIVE SUMMARY

Reducing meat consumption is considered a crucial and urgent element in terms of reaching climate targets, public health and the protection of animal welfare. Especially in industrialised countries, it is considered the most important recommendation in the field of sustainable food consumption. The transition is difficult to realise, as meat consumption is a complex area involving numerous institutions and stakeholders with conflicting interests and consumers with very different opinions and behaviour. Meat consumption is the result of diverse individual factors, while being rooted in culture and social norms. It is thus considered challenging for policymakers to set this transition in motion, as intervening in the system comes with uncertainties, a lack of understanding, and possibly resistance on both the stakeholder and consumer side. Simulation models can be supportive in such a case, as they can support an increased understanding of the system, while being able to deal with the transition and all its complexity. Specifically agent-based models can be a suitable tool to support policymakers in making sense of this transition, as this type of modelling can deal with heterogeneity of consumers and is able to provide insight on how various policy interventions affect the individual and overall system behaviour.

The process of developing a simulation model for policy support using a technique that is not widely understood and accepted yet, can be challenging. Participatory modelling is a method in which stakeholders are involved throughout the modelling process to promote social learning and achieve model improvement. In this thesis, a participatory modelling process was designed to identify the potential use of agent-based modelling in reducing meat consumption in the Netherlands. The study focused on including elements of behaviour in the ex-ante evaluation of policy with the use of an agent-based model.

An agent-based model representing meat consumption behaviour of Dutch young adults was evaluated and improved together with a group of participants. Knowledge elicitation with the stakeholders working in the field of policymaking, research, and academia occurred through interviews, workshops, and mind mapping. The key findings of these sessions were that the participants desire to gain understanding on the socio-cultural factors influencing meat consumption and how these can be targeted with interventions. To respond to this lack of knowledge, the agent-based model was adjusted to capture meat consumption behaviour according to the COM-B wheel. This is a theoretical framework in which behaviour is categorised into physical and psychological capability, reflective and automatic motivation, and physical and social opportunity. In the agent-based model, consumers select and consume meals from a supermarket, take-away, or restaurant. Dietary preferences are based on knowledge and skills, environmental and animal welfare concerns, income, desired meat consumption, and social norms. The consumers are able to adapt their dietary preferences through reflection processes. The individual profiles were empirically grounded with input data from a cross-sectional questionnaire.

The agent-based model was used to study the effectiveness of various policy pathways that were formulated in consultation with involved participants. The policy pathways included in this study were various meat price increases, an increase of the vegetarian representation in the food environment, a social marketing campaign targeted at social norms, and combinations of the three. Of these interventions, meat price increases showed to be most effective in reducing the overall meat consumption. Increasing the vegetarian representation in the choice was effective, but to a lesser extent. The social marketing campaign on social norms showed no direct effect on the amount of meat consumed. When interventions were combined, even higher reductions were observed.

This study sheds a light on how the field of policy and science can together work on a gained understanding of this complex transition, with the use of agent-based modelling.

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1. INTRODUCTION

1.1 PROBLEM STATEMENT

The composition of diets influences the impact that the food system has on the environment as well as human health. In various nations, an increase in the consumption of fats, oils, meat, refined carbohydrates, and processed foods can be observed (Watts et al., 2015). These dietary shifts are considered a major contributor to human health issues and increasing greenhouse gas (GHG) emissions (Whitmee et al., 2015). Especially the production and consumption of meat are considered significant contributing factors to global GHG emissions (Tilman & Clark, 2014). Agricultural GHG emissions are a result of the agricultural production process, where ruminant animals release methane gases and inefficient conversion of plant to animal energy takes place (Hedenus et al., 2014). Besides high meat consumption being a major driver of GHG emissions, it causes land-use change, biodiversity loss, depletion of freshwater sources and pollution of aquatic and terrestrial ecosystems (Aleksandrowicz et al., 2016; Marinova & Bogueva, 2019; Springmann et al., 2018).

Reducing meat consumption is starting to play a large role in climate mitigation strategies. Shifting consumer diets from animal based to plant-based products or other alternatives could be a way to achieve this (IPCC, 2019). Meat consumption reduction is even of the most important recommendations in the field of sustainable food consumption (Verain et al., 2015). However, eating less meat is a complex transition that can unfold as multiple possible scenarios in which human behaviour, governance, resources and economics are important factors defining the outcome. The transition involves numerous different actors and comes with conflicting interests (de Bakker & Dagevos, 2012). Due to the complexity, it is desired to gain understanding on the impact of intervening in this system, before the actual implementation of policies. However, studies on topics that come with resistance, such as meat consumption, make it more difficult to realise policy engagement (Dagevos & Voordouw, 2013).

The Dutch National Institute for Public Health and the Environment (RIVM) focuses on both public health and environmental issues. The question is how they can give independent scientific advise to policy makers on a complex transition. As part of the Strategic Program RIVM, they initiated a research programme called "Integrated food policy", in which is studied what measures can possibly stimulate a different dietary composition of Dutch inhabitants (RIVM, 2021). RIVM aspires to create an assessment framework to test the effectiveness of various potential policies. Their subprogramme called SHIFT-DIETS focuses on reducing the consumption of meat of young adults in the Netherlands. The research involves literature studies, collecting data on meat consumption via a consumer panel, workshops with young adults and experts, and trial measures to see the effects on dietary choices (RIVM, 2020). It also includes using methods from complex systems science, community-based system dynamics and agent-based modelling (ABM) to advise policy in the face of a complex transition.

To identify how to shift diets of societal groups, it is crucial to understand what behavioural elements play a role and how these can be influenced for people with varying preferences and dietary compositions. With the use of ABM techniques, the overall behavioural responses of a population under various policies can be simulated. One advantage of ABM is that it can help to make sense of the complexity of socio-technical systems. ABM is potentially a tool to dynamically connect the individual micro level with the macro societal level. With topics such as dietary shifting, it is not solely about the social system or the physical system, but also about the interactions between the two. ABM allows to simulate these interactions (van Dam et al., 2013).

ABM is thus expected to be a suitable tool on the road to developing and evaluating policy pathways for transitions in complex socio-technological systems (van Bruggen et al., 2019). However, one must be cautious when using scientific models and its generated knowledge to build its policies upon (Houtcamp & Rip, 2021). In The Netherlands in 2019, commotion arose due to the use of scientific models and data as support for development of governmental strategies around regulating nitrogen issues. The validity of used data and scientific models was questioned by experts and the public (Houtcamp & Rip, 2021). This policy-science gap often is the result from a lack of communication between governmental institutions and field of research (Houtcamp & Rip, 2021). Participatory modelling (PM) is a method that can be used to bridge the gap between policymakers and scientists, as it generally increases transparency and results in a higher understanding of the implications that come with a model (Smajgl & Ward, 2013; Voinov et al., 2016). Due to the heavy focus on collaborative learning during PM, the process is expected to promote the stakeholders system understanding and awareness (Voinov et al., 2018). Challenges lie in the creation of an ABM that is to be used in policy making evaluation. The model should represent reality as accurately as possible, by making correct assumptions on the target population behaviour (Jager, 2021). In addition, the policies that are to be simulated should be realistic in terms of available governmental budget and resources.

1.2 RESEARCH GAP, QUESTIONS AND OBJECTIVES

This thesis focused on including elements of behaviour in the ex-ante evaluation of policy to shift diets of consumers to reduce meat consumption through the use of participatory ABM. Multiple studies have focused on identifying the behavioural elements involved in shifting diets, and more specifically determinants of meat consumption (Kwasny et al., 2022; Stoll-Kleemann & Schmidt, 2017; Van der Vliet et al., 2020). Few studies have used ABM techniques to study the effects from interventions on meat consumption behaviour (Scalco et al., 2019; Thomopoulos et al., 2021; Timmers, 2021). Previous ABM studies on meat consumption study the effectiveness of various policies, but they do not take factors such as knowledge, skills, and social norms around meat consumption into consideration. The Theory of Planned Behaviour is often taken as a guiding framework, however this theory does not address these factors (Michie et al., 2011). Also, it is not documented or tested whether these models and generated insights are considered relevant or useful for the potential users of the model that will have to set in motion the transition towards a reduced meat consumption.

This study is performed under supervision of RIVM, where a preliminary ABM on meat consumption behaviour has been developed (Groot et al., 2021). In the model, meat consumption behaviour of Dutch young adults in the age range of 18-35 years is simulated. In this study, the objective is to: (1) evaluate and improve the preliminary model together with stakeholders in a PM process, and (2) use the adjusted ABM to test the effectiveness of different policies targeting meat consumption reduction. This study builds forth on the ABM provided by RIVM, making adjustments based upon the lack of knowledge and interests of stakeholders identified during the PM process.

The research question of this study is formulated as follows:

" How can a preliminary ABM on meat consumption behaviour be improved based upon insights obtained through a participatory modelling process, and what is the effectiveness of various policy pathways on meat consumption in The Netherlands as simulated with this improved ABM? "

The study is composed of mainly three components, namely (1) participatory modelling (PM), (2) agent-based modelling as policy evaluation instrument in a complex transition, and (3) modelling meat consumption behaviour in the Netherlands. There is continuous interaction between these three components. A PM process is designed to identify the lack of knowledge of policymakers. The process of knowledge elicitation with stakeholders working in the field of policy-making, policy advisory institutes, and academia defines what becomes the focus of increasing the policy relevance and explanatory power of the ABM. The main objective of this study is to test, and where possible increase, the policy relevance of the ABM. Eventually, various policy pathways aimed at meat consumption reduction in The Netherlands are simulated with the ABM.

To explore the use of ABM in the policy evaluation, various stakeholders from Dutch governmental institutions and academic institutes are participated in this study. This participatory process is multi-purpose as it both supports ABM development, promotes communication between policy and science, and increases acceptance and understanding of the technique.

The starting point of this research is the design of a process that allows communication between stakeholders and the scientific modeller. The goal of adjusting the ABM is to make it able to generate specific insights in which the participants state to be interested, thus aiming to increase the policy relevance and explanatory power of the model. The identified lack of insight and the interests from participants define in what ways the model is adjusted. After integration of the newly formalised concepts based on stakeholder interests with the preliminary model, the model is used to test the effectiveness of various interventions on the consumer and system behaviour. The ABM will help improve understanding the complexity of the transition towards reduced meat consumption in The Netherlands.

This is a study in line with the discipline Industrial Ecology (IE). IE is an emerging scientific field that focuses on the development strategies for societal issues with a high complexity. By taking a systems perspective, it incorporates aspects from social, environmental and engineering sciences (Kapur & Graedel, 2004). Elements from IE that will be applied in this research are systems modelling and transdisciplinary research and analysis, with the aim to increase insight in a complex transition towards reduced meat consumption, to eventually contribute to decreased environmental impact related to diets in the Netherlands.

2. THEORETICAL FRAMEWORK

The theoretical framework follows the structure of the three main research components of this study. First, relevant literature on PM processes and methods is collected. Second, information is given on the role of ABM as a policy supporting instrument in complex transitions. Lastly, a part is written on what factors influence meat consumption behaviour and what behavioural theories can be used to study this behaviour. Elements from existing theories and state-of-the-art research will be distilled later on for design of this study's methodology.

2.1 PARTICIPATORY MODELLING

Stakeholders without a background in modelling can have difficulty understanding and interpreting a computer model (van Dam et al., 2013). This can be problematic as policy advisors or decision-makers will be the people that might use or need the model product for supporting the formulation of advice or policy pathways. For both the modeller and the stakeholders it can be beneficial to have a certain relationship during the modelling process, where regular communication takes place (van Dam et al., 2013). This allows the modeller to aid stakeholders in the interpretation of the model and its results, while the knowledge elicitation with stakeholders can provide the modeller with a better understanding of the real issue and problem (van Dam et al., 2013).

Modelling interacting and autonomous agents, with their own set of behavioural rules, allows to generate new insights on the overall system behaviour, which can be very uncertain and unpredictable (van Dam et al., 2013). Taking a bottom-up approach for setting up individual agents in the model, allows to study the collective behaviour and eventually also the effect of interventions on the system. Therefore, social simulation instruments such as ABM can be helpful supporting instruments for the development and evaluation of policy pathways for complex systems (Barreteau et al., 2013; van Bruggen et al., 2019). However, challenges arise when involving stakeholders in the modelling process. Due to a model's complexity, a lack of transparency and understanding might result in lower acceptance on the policymaker's side (Macal, 2016). That is where PM might be of added value. Through actively involving decision-makers and other stakeholders in the modelling cycle, the chances of creating a correctly grounded simulation model to be implemented in decision-making processes, are increased (Voinov et al., 2016). Agent-based models can be intuitive and relatively easy to understand as they are based on a model narrative that describes the actions of agents and interactions between agents and with the environment over time. Even when simple behavioural rules are modelled, the mechanisms in the model can give rise to overall surprising patterns (van Dam et al., 2013).

Different methods and instruments can be used for building a model with stakeholders. The methodology is dependent on factors as the topic being studied, the modelling paradigm and the availability of time, resources and stakeholders (van Bruggen et al., 2019). Four general approaches to modelling with stakeholders are defined by (van Bruggen et al., 2019), namely nominal, instrumental, representative, and transformative. These approaches differ in the level of cooperation between the researcher and the participants, the degree of control that participants have over the research outcomes and model use, and the instruments used for communication throughout the process.

Combining ABM with PM seems particularly promising as ABM is one of the most suitable methods that is able to capture the core characteristics of transition dynamics (Halbe et al., 2020; Hansen et al., 2019). There is still limited documentation on the involvement of stakeholders in the development in agent-based models for complex transitions, but established participatory methodologies of companion modelling or Group Model Building could be applied on ABM development to expand knowledge in this area (Halbe et al., 2020).

2.2 ABM AS POLICY INSTRUMENT

AMBs require both human brain capacity and computer power to get to interesting insights. Humans are good at defining relations between system elements and recognizing patterns, whereas computers are excellent at systemically exercising these assumed relations (van Dam et al., 2013). ABM is considered a detailed quantitative modelling method, which can be of added value when compared to qualitative, semi-quantitative, or aggregated quantitative modelling methods (Voinov et al., 2018). When looking at consumption behaviour, an ABM distinguishes itself from these other methods as it is able to generate insights on the dynamic characteristics of individuals, but also the total simulated population (Voinov et al., 2018).

2.2.1 AGENT-BASED MODELS FOR TRANSITION GOVERNANCE

There are both advantages and disadvantages to using ABM in a policy context (Hansen et al., 2019). The main advantageous element is that the technique allows to study complex system dynamics with heterogeneous actors performing behaviour and interacting with each other (Deissenroth et al., 2017). It can do this on both an individual and a system level. Also, it allows to study the effects and side effects of policies, where can be ranged under various scenarios with different agent characteristics (Chappin et al., 2017). ABMs can be used for model-based decision support under deep uncertainty (Kwakkel, 2017). The idea is that when there are irresolvable uncertainties, the model can perform exploratory studies rather than predictive ones. Computational experiments with set ranges of uncertainties allow to study the system's behaviour under these variations (Kwakkel, 2017). Studying the uncertainties can provide interesting insights, but can also decrease the studies' relevance in policy context, due to the results being considered less tangible (Chappin et al., 2017).

The disadvantages, or say challenges with ABM, are the difficulties that can arise when validating the model, due to a lack of relevant data or the more general struggle with theoretical and empirical grounding (Ringler et al., 2016). Also, when using ABM for the study of consumption behaviour, it becomes difficult to quantify human agents psychological and behavioural values (Anatolitis & Welisch, 2017). In addition, behavioural rules are often defined ad hoc and not based on systemic theories of behaviour (Ringler et al., 2016). When social aspects are integrated, it is considered very challenging to model this (Hinker et al., 2017).

2.2.2 AGENT-BASED MODELS ON FOOD CONSUMPTION BEHAVIOUR

There have been a few studies that have used ABM techniques to analyse food consumption behaviour (Scalco et al., 2019; Thomopoulos et al., 2021; D. Zhang et al., 2014).

One study simulated meat consumption in Britain with the use of ABM (Scalco et al., 2019). Data from a representative sample of British consumers was used to empirically ground the model. Factors such as income, age, and concerns were used to compute a logistic regression model estimating the mean weekly meat consumption and the mean likelihood to consume a meat-base meal. The interventions simulated were various price increases of meat and social marketing campaigns targeted at individual's concerns on animal welfare, the environment, and health. Simulation studies showed that price interventions were effective in reducing meat consumption. However, the social marketing campaigns on environment and animal welfare showed modest to no effect.

Zhang et al. (2014) developed an ABM to study the potential effect of various policy interventions on food choice behaviour in a synthetic population. Individual decision-making was based on and demographic factors such as age, gender and education, taste preferences, health beliefs, food-price index, price sensitivity, and food accessibility. In addition, friend networks where social ties can have influence on other individual's decisions, were formed. Four policy interventions were simulated (1) tax on unhealthy food, (2) subsidies for healthy food, (3) promotion of healthy norms, and (4) regulation of local food environment. Results indicated that the promotion of healthy norms induced more desired model outcomes, i.e., increase of vegetable and fruit consumption, than tax-based or zoning policies.

The model by Thomopoulus et al. (2019) combines multicriteria argument networks around vegetarian diets with ABM to study the impact of messaging types on meat consumption behaviour at the individual level. The study aims to simulate the social diffusion of opinions and practices concerning meat consumption, to increase understanding of the balance between individual values and external influencing factors. Various arguments in favour of and against vegetarian options were defined and subsequently processed into an argument network. Example arguments include 'vegan diet safety is not proven' and 'no study is favourable to the vegan diet'. The argument network was translated into an ABM with a population of N citizens. Citizens were assigned (1) a constant level of need for food quality based on ethics, health, taste etc., (2) a variable level of perception of meat products, and (3) resistance to change. Citizens communicated with direct neighbours, with the possibility to alter their perception of meat consumption and thus dietary choices (Thomopoulos et al., 2021).

2.3 DRIVERS OF MEAT CONSUMPTION

2.3.1 DETERMINANTS OF MEAT CONSUMPTION

Food consumption behaviour is a result of numerous individual, social, and external factors. Different behavioural theories have been used to capture and identify the determinants that have an influence on food behaviour and more specifically meat consumption (Kwasny et al., 2022). These frameworks all have their strengths and weaknesses, and can be selected in studies based on their strengths required for a specific purpose. The conceptual framework on meat-eating behaviour by Stoll-Kleeman and Schmidt (2017), makes a clear distinction between personal factors, socio-cultural factors, and external factors. Personal factors are defined by sociodemographic factors and individual factors. The most influential sociodemographic factors are gender, age, and socioeconomic status (Stoll-Kleemann & Schmidt, 2017). The individual factors and personality traits can be grouped as follows: knowledge and skills, emotions and cognitive dissonance, values and attitudes, perceived behavioural control, and Habits and taste. The socio-cultural factors are a result from social norms, cultural, and religious elements. Meat consumption can be influenced by one's cultural or religious traditions. Besides culture, social norms have indicated to be able to strongly influence one's eating behaviour. The individual's environment is the third category that influences meat consumption. With this is meant the physical food environment, where infrastructure, and the availability and price of products play a role. Different studies point out that habitual factors seem to have higher influence on food choices than rational decision-making processes (Graça et al., 2019; Van der Vliet et al., 2020; Verain et al., 2015).

Studies have shown that only a minority of participants are ready to reduce meat consumption due to for example environmental reasons (Hartmann & Siegrist, 2017). Instead, the potential role of social influence is stressed. Interventions targeted at the activation of social norms can possibly steer consumers towards an increased plant-based diet. However, effects of these type interventions are not very well understood and quantified yet (Kwasny et al., 2022).

Social norms are implicit codes of conduct on how to behave (Cialdini & Goldstein, 2004). Studies have indicated that social norms play a role in food choices and amounts consumed (Higgs, 2015). Consumers perceive what other consumers are thinking, feeling, and doing regards a specific behaviour, such as eating meat. Individual attitudes and behaviours can be adapted to meet normative expectations (Kwasny et al., 2022). When considering social norms and influence, generally the distinction is made between injunctive and descriptive norms (Cialdini et al., 1990). Perceived injunctive norms around meat consumption are related to whether eating a meat or plant-based meal is approved by others, whereas descriptive norms are related to the observation of how frequent others consume meat or plant-based products (Sharps et al., 2021).

2.3.2 BEHAVIOURAL THEORIES

Various behavioural theoretical frameworks are used in food consumption studies (Verain et al., 2015). Examples of these theories are the Theory of Planned Behaviour (TPB) (Ajzen, 1991), the Theory of Reasoned Action (Ajzen & Fishbein, 2005), the Norm Activation Model (Schwartz, 1977), and the Value-Belief-Norm model (Stern, 2000). The TPB (Figure 1) is an extended version of the original Theory of Reasoned Action, with the addition of the concept perceived behavioural control, i.e., the perception of the difficulty of enacting a behaviour. This theory is widely used as a guiding framework for studies on consumption behaviour.

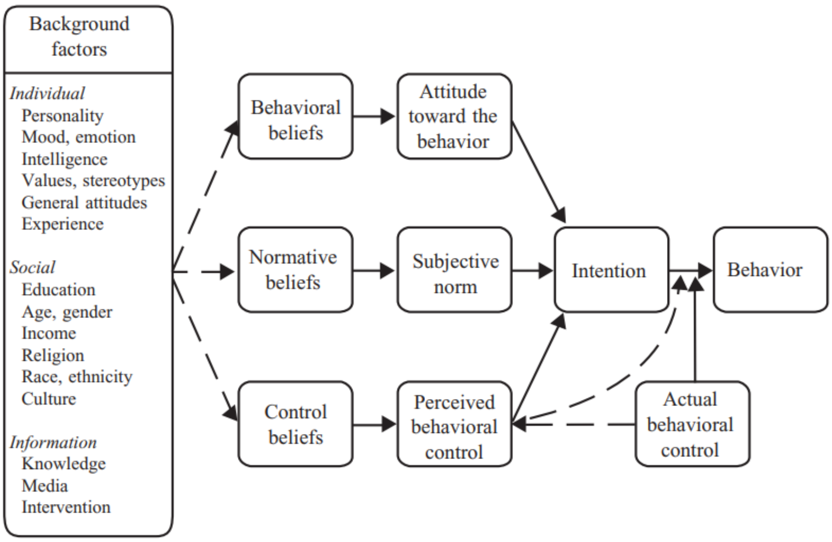

Figure 1. The Theory of Planned Behaviour (Azjen and Fishben, 1991)

There are a few limitations on frameworks such as the TPB. For example, it is assumed that the person with a certain behaviour has acquired the opportunities and resources, and that the behaviour is a result from a linear decision-making process, without considering the fact that behaviour can be dynamic and adaptive over time (Michie et al., 2011).

A more recently developed theory is the COM-B model by Michie et al. (2011) behavioural framework designed to use for the design of interventions (Figure 2). The theory is developed based upon the limitations of previously developed behavioural frameworks. The theory states that behaviour is generated as a result of the interaction between three components, namely capability, opportunity, and motivation. The capability component is defined as the individual physical and psychological capacity to engage in the concerned activity. This mainly involves having all the necessary skills and knowledge to engage in the activity. Opportunity is formed by social and physical external factors, that lie outside the individual's own actions and thinking. Examples are perceived behaviour by peers and the products that are available to the individual. The motivation component involves brain processes, both automatic and reflective, that energize and direct behaviour (Michie et al., 2011).

A strong characteristic of the COM-B wheel is that it also provides information on what interventions can target different behavioural aspects. The intervention functions (red) are linked to the components of behaviour (green), to allow a more efficient method of choosing the kinds of intervention likely to be appropriate for a certain behavioural target (Michie et al., 2011).

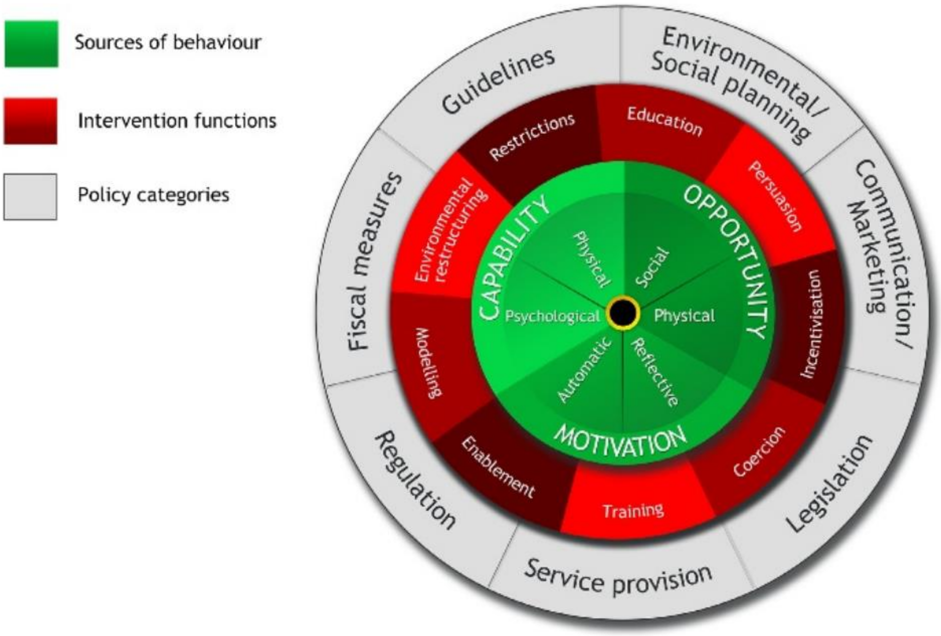

Figure 2. The behaviour change wheel COM-B Model (Michie et al., 2011)

EFFECT OF POLICY INSTRUMENTS ON BEHAVIOUR AND SHIFTING DIETS Multiple studies have linked human food consumption behaviour to economic models, to investigate the effect of different policies on diet shifting. One study investigated the factors that steer diet changes towards a lower meat consumption by linking a model of human behaviour to an integrated assessment model (Eker et al., 2019). Results showed that the social norm effect and self-efficacy are the main drivers of widespread dietary change. One study estimated the effects on human health and climate of applying a tax on red and processed meats (Springmann et al., 2018). Another study identified the main drivers of the consumption of meat, making distinctions based on location and various types of meat. This was done to anticipate future trends and to support in developing future policy interventions (Milford et al., 2019).

One study merged the Self-Regulation Model and Theory of Planned Behaviour to identify relevant socio-psychological factors influencing people's willingness to reduce their meat consumption (Weibel et al., 2019). The identified most influential factors were attitude, perceived behavioural control, personal norm, and awareness. A case study in Sweden investigated the effectiveness of different policy instruments and interventions on meat consumption (Carlsson et al., 2022). The results of this study indicated that gender, age, level of education and the taste of meat alternatives were the main influential factors. The study also indicated that a number of instruments, including economic, informational, and regulatory would be needed to reach the desired behavioural change and acceptance among consumers. Social norms, traditions, roles and relationships and the construction of identities and lifestyles are all factors that possibly shape people's behaviour towards meat consumption (Stoll-Kleemann & Schmidt, 2017). Information provision alone, has also shown to be effective at increasing willingness to reduce meat consumption (Harguess et al., 2020).

3. METHODOLOGY

3.1 PARTICIPATORY PROCESS

Prior to starting with the development or extension of a model, it is important to have a thorough understanding of the exact problem statement and lack of insight the model should answer to. Questions to be asked during this phase are 'What is the exact lack of insight we are addressing?', 'What is the observed emergent pattern of interest to us?', and 'What actors are involved?' (van Dam et al., 2013). The exact lack of knowledge is inventoried together with the stakeholders during early stages of the PM process.

The purpose of a simulation model can range from educating the general public to the prediction of system behaviour (Epstein, 2008). Clearly defining the purpose of a model in advance, benefits effective development, understanding and interpretation later. Different purposes imply different ways of building, judging and justifying the model (Edmonds et al., 2019). At this stage, where the potential of ABM is being explored, the modelling purpose of this study is to develop a model that supports social learning. The development of this model in a collaborative way is mostly about creating common knowledge and exploring common goals about the target system (Edmonds et al., 2019). This purpose involves reaching a common understanding on the technique and its strengths and weaknesses.

There can be various expectations when using a participatory approach for simulation of social complexity. Barreteau et al. (2013) defined the following three: (1) Increasing quality of the simulation model per se, (2) Increasing the suitability of the simulation model for a given use, and (3) Participation support (Barreteau et al., 2013). Prior to setting up a PM process, it helps to select one of these approaches. In this study, all three expectations play a certain role, but the main expectation of going through the PM process is increasing the suitability of the simulation model for the use in decision-making processes.

3.1.1 PARTICIPATORY MODELLING

The type of modelling with stakeholders of this study can be categorised under representative modelling. This is the type of PM where there is dialogue between researchers and stakeholders and, there is co-building of a model (van Bruggen et al., 2019). Due to the relatively short time frame and the limited time of six months and of stakeholders to participate in the research, the stakeholders do not really receive control over the model use yet. In similar studies where a more extensive form PM is performed, the process spans a timeframe of more than a year (Koh et al., 2018).

The theoretical framework from Voinov et al. (2016) is used as inspiration for design of the PM process. The framework consists of seven stages that together make up the PM process: (1) scoping and abstraction, (2) envisioning and goal setting, (3) model formulation, (4) data, facts, logic, cross-checking, (5) model application to decision making, (6) evaluation of outputs and outcomes, and (7) facilitation of transparency. The degree of stakeholder involvement, and what methods are used, differ throughout the modelling process and for each of the steps (Voinov et al., 2016). In addition, inspiration is taken from the study from (Koh et al., 2018), in which a group model building (GMB) approach is used for development of an ABM.

In this study, the PM aims to increase the policy relevance of a preliminary ABM. When conducting an ABM study, one generally follows ten practical steps (van Dam et al., 2013). The steps are: (1) problem formulation and actor identification, (2) system identification and decomposition, (3) concept formalisation, (4) model formalisation, (5) software implementation, (6) model verification, (7) experimentation, (8) data analysis, (9) model validation and (10) model use. The ABM protocol is aligned with the components of the PM process, to create a methodology suitable for this specific study.

Table 1 lists the seven components of the PM process, an indication of degree of involvement, corresponding steps of the ABM protocol, selected tools, methods and intended results per component. The table forms the overall methodology of this study. The approach is summarised below in Table 1 and the different steps are further elaborated on in the following sections.

Table 1. Overview of participatory ABM process together with used method(s), tool(s) and intended results per stage. The research activities involving stakeholder participation are indicated with italic font

SPM component (Voinov et al. 2016)	**ABM protocol Steps (van Dam et al. 2013)**	**Research activity: Method(s) and Tool(s)**	**Intended result**
Scoping; Abstraction; Envisioning; Goal setting *(High stakeholder involvement)*	Problem formulation & Actor identification; System identification & decomposition	Literature study; Use of existing stakeholder network and snowball method to recruit stakeholders for participation	Overview of Dutch food system and relevant stakeholders
		Interviews and meetings with policy advisors	Increased insights on current practices, desired transition, involved actors, problem owner
		Workshop 1, Brainstorming and collective mind mapping with policy advisors and experts	Lack of insights, Research priorities, Experimental scenarios for ABM simulation
Model formulation *(Medium stakeholder involvement)*	Concept formalisation; Model formalisation;	Revise the preliminary ABM, *conceptualise and formalise additional concepts based on stakeholder interests*	Conceptualised and formalised model processes, model narrative,
		Collection of empirical data (survey data)	Validated ABM input data
		Mail contact with stakeholders	Feedback on conceptualisation/ formalisation (iterative process)
Data, facts, logic, cross-checking *(No stakeholder involvement)*	Software implementation Model verification;	Implementation of formal model into NetLogo; Verification by single- and multi-agent tracking;	ABM in NetLogo; Verified ABM
Model application to decision making; Evaluation of outputs and outcomes; Facilitation of transparency *(Medium stakeholder involvement)*	Experimentation; Data analysis; Model validation; Model use	Simulation experiments	Experimental data
		Model validation by literature comparison and sensitivity analysis	Validated ABM
		Workshop 2, Presentation of model and simulation results	Final version of ABM communicated to stakeholders; final feedback on project and ABM

PRE-ASSESSMENT

Prior to the design of the PM process, there is a pre-assessment phase to become familiar with the context and topical aspects of meat consumption in the Netherlands. The phase consists of a literature study, various meetings with research experts, and semi-structured interviews with two policy advisors working for the Dutch government. The interviews are held to get a clear picture of what are the current objectives of policymakers related to meat consumption, and what are their challenges in this transition. The first interviewee is a senior policy advisor on nutrition, with a main focus on health. The second interviewee is a senior policy officer on agro-economy and sustainability. Both interviews took approximately 90 minutes.

STAKEHOLDER SELECTION

The participatory modelling process starts with recruiting potential stakeholders that are willing to participate in the study. For the mapping of stakeholders, an existing Dutch stakeholder network on sustainable food consumption provided by RIVM was revised and updated. The choice was made to involve experts in the field of policy and research, as the focus of this study is on the potential role of ABM in decision-making processes of governmental institutions. A variety of policy advisors, experts, and academic researchers were contacted via e-mail, with the invitation to participate in the first workshop session.

3.1.2 WORKSHOP SESSION 1

The first two steps of the ABM protocol - the problem formulation and actor identification, and system identification and decomposition - are performed together with stakeholders in workshop 1 (Table 2). Prior to the workshop, a 4 hour programme was created, a script was written for the two facilitators. The workshop session together with policy advisors and experts was organised to (1) create an inventory of elements that relate to meat consumption in the Netherlands, (2) formulate the problem statement, i.e. identify what are participants' concerns, (3) create an inventory of potential interventions aimed at reducing meat consumption, (4) identify what interventions are of interest but are difficult to implement due to lack of insight, and (5) identify to what interventions participants assign priority.

Table 2. Participants workshop session 1. Of the participants (age range 25 – 60 years), 2 were female and 5 were male attendees.

Role	Sector	Profile
Participants	Government	Policy advisor
	Government	Policy officer
	Research advisory institution	Behavioural expert
	Academic	ABM and complex systems expert
	Academic	Consumption expert
	National research institute	Nutrition expert
	National research institute	Behavioural expert
Facilitator	National research institute	ABM and complex systems expert
	Academic	ABM researcher

ICEBREAKER

The workshop starts with a short introduction game, where participants write on post-its their hopes and fears for this session and the research as a whole. The outcomes are collected by the facilitator and briefly discussed.

COLLECTIVE MIND MAPPING

The brainstorm session consisting of multiple rounds is designed to gather the first input required for ABM creation:

1. **Round 1:** What do we observe related to meat consumption, considering the following elements?
    a. Humans, e.g., behaviour, values, culture
    b. Things, e.g., materials, infrastructure
    c. Rules, e.g., laws, habits, agreements
    d. World, e.g., climate, geopolitics, trends
2. **Round 2:** What do we worry about? *(Based on output round 1)*
3. **Round 3:** In what ways can we intervene & What interventions do we want but can we not do due to lack of knowledge? *(Based on output round 2)*
4. **Round 4:** What questions do we want to give priority to? *(Based on output round 3)*

For the structured brainstorm session, 2 hours were scheduled. Facilitator 1 explained the question per round, after which participants wrote answers on post-its. Facilitator 1 collected the post-its and read and interpreted the answers out loud, one by one. Participants were allowed to reflect or comment. This was done to ensure correct interpretation. Facilitator 2 then processed the post-its in the digital mind-map software programme Freeplane (Appendix A.4).

SCIENTIFIC REFLECTION

The session with participants helped formulating the lack of insights that stakeholders have. To link the outcomes of the workshop session to the ABM, a scientific reflection was written. The reflection illustrates for the priorities identified in section 5.1.2, whether ABM is expected to be a suitable instrument for obtaining desired insights. At the end of the workshop session, no time was left to scientifically reflect together with the group participants, i.e., formulate what elements from the workshop results are selected as area of focus for ABM adjustments in this study. The scientific reflection was written by the facilitator afterwards. At the end of the session, participants were asked to fill in a reflection form that helped identifying whether the session was organised successfully and contributed to an increased understanding of ABM of participants.

3.1.3 WORKSHOP SESSION 2

The last stage of the PM process is the facilitation of transparency, which overlaps with the model use phase of the ABM protocol. The model use is about the communication of the model and its experimental results. A second workshop session was organised to present and discuss the model adjustments and the indicative outcomes of interventions. The same group of participants that attended workshop session 1 was invited to attend the session. After presentation of ABM adjustments and the methods that were used to empirically and theoretically ground the model, there was room for discussion, questions, and feedback.

The involvement of stakeholders was thus performed by qualitative interviews and workshop sessions. These events were documented and processed as anonymised summaries and mind maps.

3.2 AGENT-BASED MODEL

3.2.1 ABM ADJUSTMENTS

The starting point for the modelling process is the preliminary ABM that is provided by the RIVM institute, built by a group of students (Groot et al., 2021). The ABM used in this study is thus not built from scratch, but the model is reviewed and extended, through involvement of stakeholders in the PM process. The decisions on the ABM adjustments are made based on the outcomes of the participatory sessions with stakeholders. The outcomes of these sessions and how these are translated to ABM adjustments is described in results section 4.1. Here, the system is identified and the model is decomposed.

3.2.2 SYSTEM IDENTIFICATION AND DECOMPOSITION

The ABM study starts with a description of entities and model characteristics, for which the preliminary model provides the basis. The model developed that was provided by the RIVM institute showed to be in line with the scope and questions identified in the PM process, and was thus taken for further improvement. The agent's action and interaction mechanisms are adopted from the preliminary model (Groot et al., 2021). A high-level overview of the model's components is illustrated in Figure 3. The model outcomes are the average daily amount of meat consumed (grams), the average daily amount of meat consumed during dinner, the average frequency of meat consumption, and the average level of willingness to change. The list of all model assumptions is given in appendix C.2.

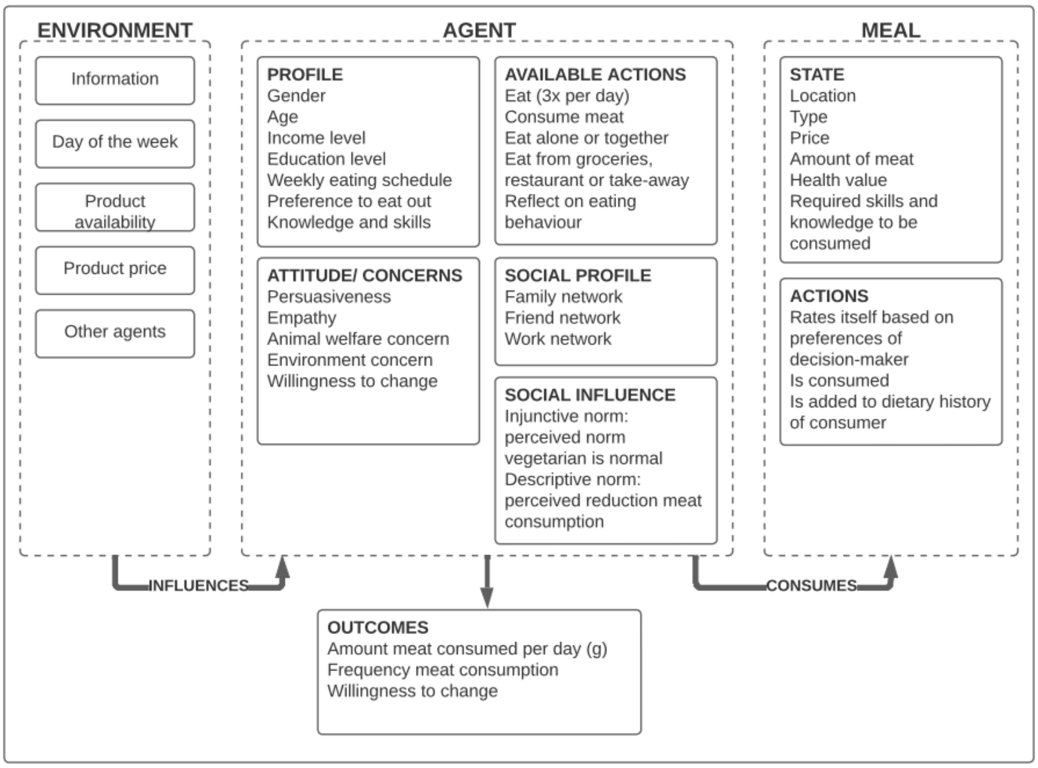

Figure 3. ABM high-level overview of entities and interactions between entities and environment

3.2.3 CONCEPTUALISATION & FORMALISATION: MODEL NARRATIVE

With the concept and model formalisation, the system, agents, states, relationships, behaviours, interactions, and series of events are conceptualised and formalised to sequential computer-understandable language (van Dam et al., 2013). In this sub-chapter, flow diagrams are created per model sub-process to illustrate what events and mechanisms are implemented in the model, together with a model narrative to explain how agents act and interact over time. In Figure 4, an overview of the model sub-processes is conceptualised. These five sub-processes are further explained in the following chapters. The model narrative is in its conceptualisation and formalisation are adopted from de Groot et al. (2021), but adjusted to increase clarity of the different steps taken. Participatory sessions formed the input for finalizing the conceptualization (see section 4.1.2).

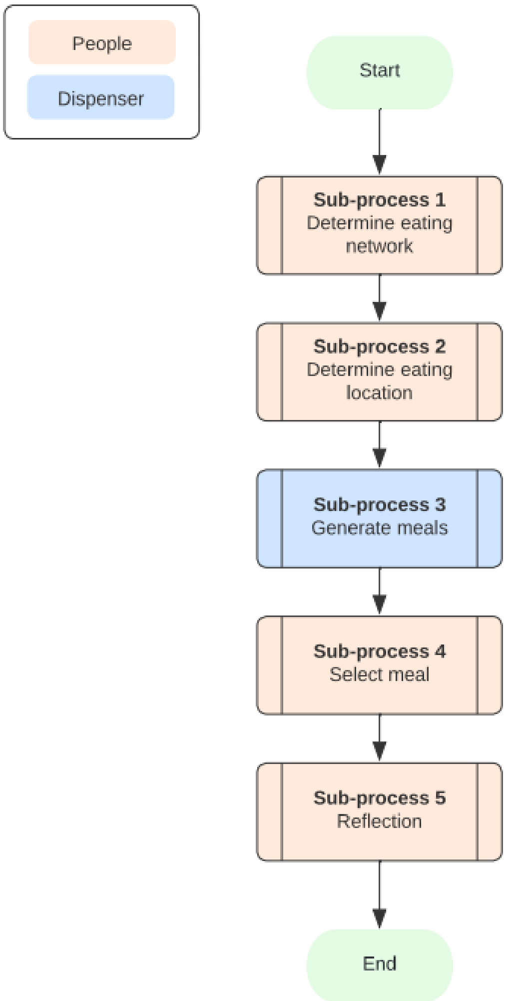

Figure 4. High-level overview of model processes

SUB-PROCESS 0: AGENT INITIALISATION

When setting up the model, the people, meal dispensers, weekly eating schedules, and tables on meal data are created. First, the selected number of people is initialised. The input data is read to set up the individual people profiles. The following meal dispensers or places people eat are set up: supermarket, take-away, and restaurant. The three dispensers read in the meal data information to be able to generate dispenser-specific meals for the people (Appendix C.1).

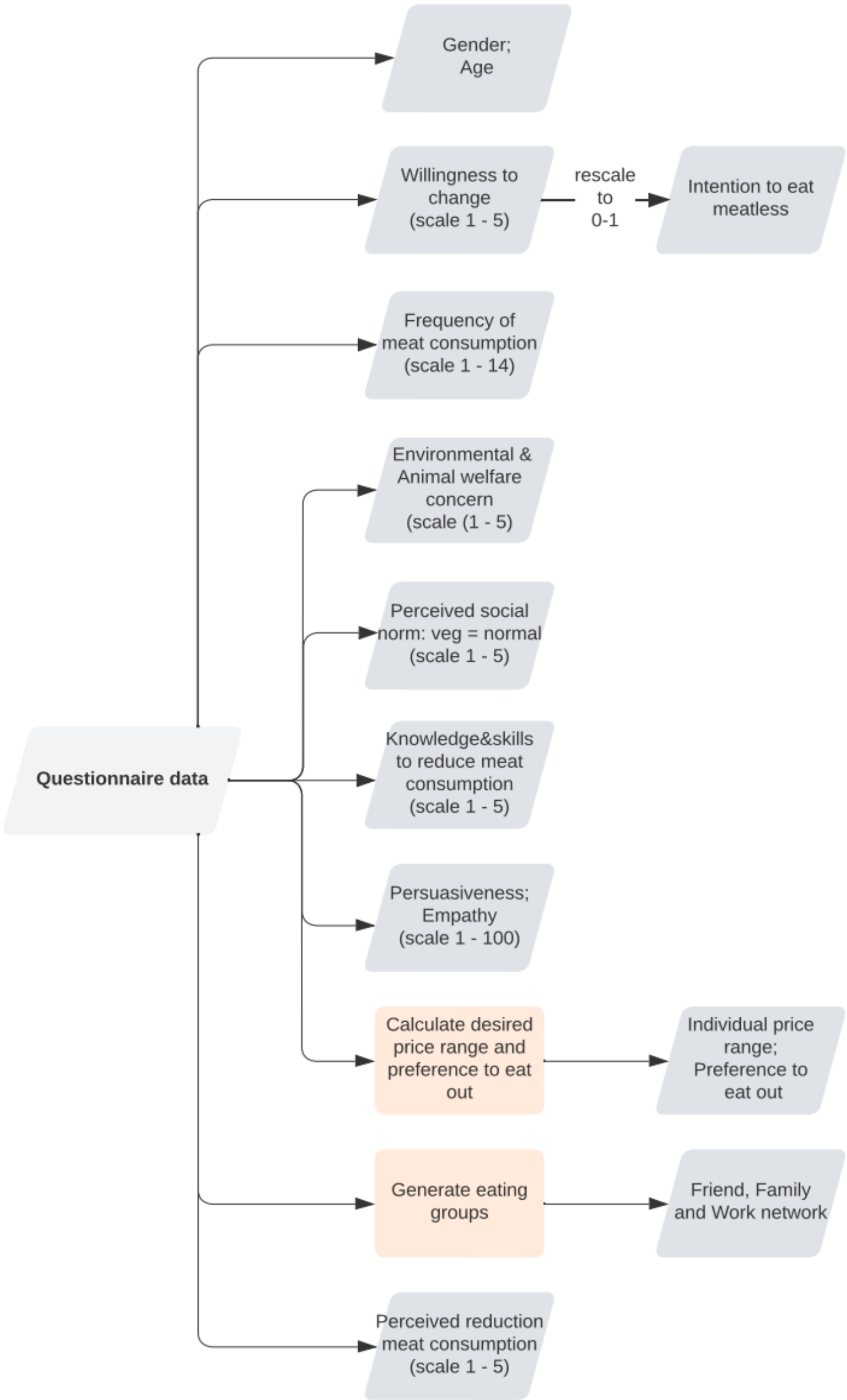

Figure 5. Conceptualisation of setting up the individual profiles of people

SUB-PROCESS 1: GENERATING EATING NETWORKS

People have social networks, which are represented as eating networks in the model. The model generates eating networks for every person in the model. The network generation process considers one's education level for the work networks. Based on the person's centrality in a social network, for every network a decision-maker is selected.

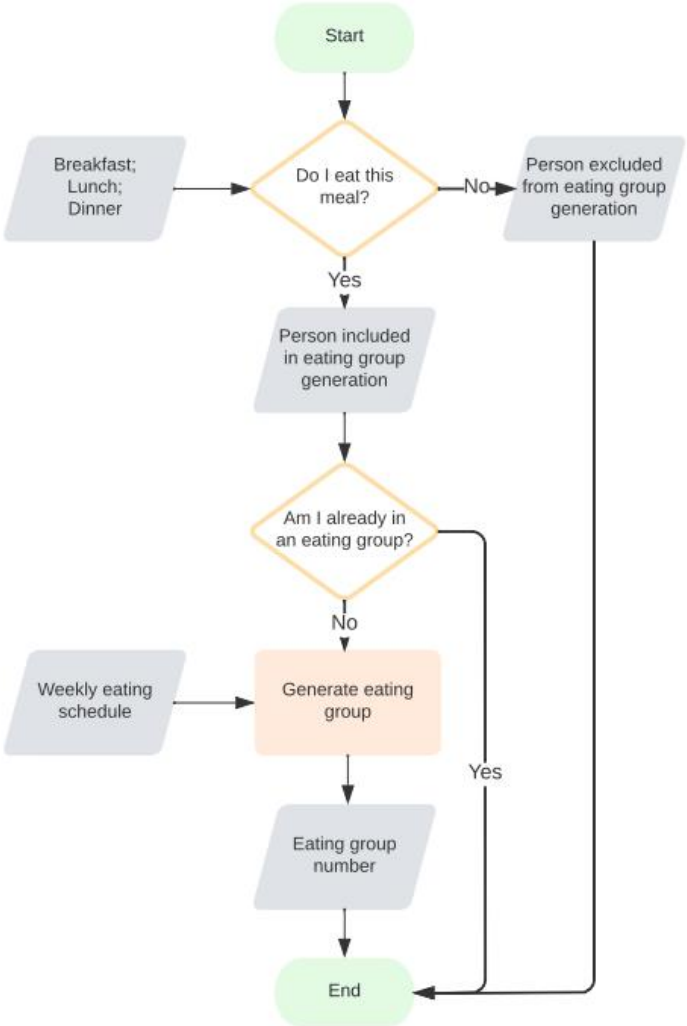

Figure 6. Conceptualisation of sub-process 1

SUB-PROCESS 2: SELECTING EATING LOCATION

Depending on the person's eating schedule that day of the week, he or she eats alone or together with people in his or her eating network. The person with the highest network centrality becomes the decision-maker of that eating group. The decision-maker considers his own income level and the income level of the people in the eating group to a certain extent, depending on the person's empathy level. The person decides to either go to the supermarket for groceries or go to a take-away or restaurant. The eating location process is repeated three times a day, to provide the person with a breakfast, lunch, and dinner.

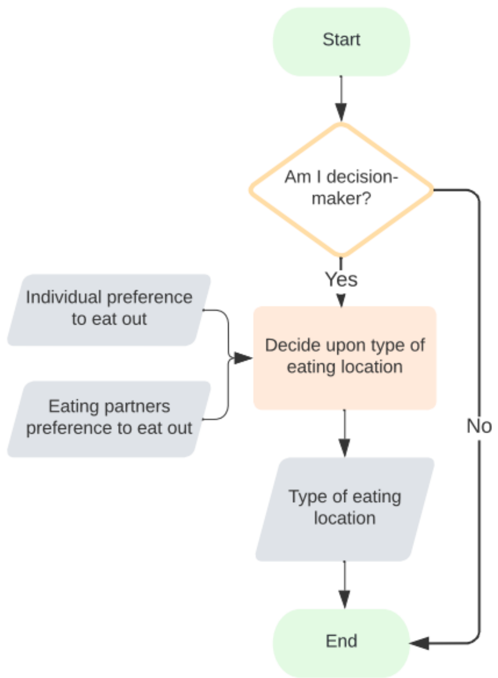

Figure 7. Conceptualisation of sub-process 2

SUB-PROCESS 3: GENERATING MEAL OPTIONS

Once the person or eating group has decided to eat a specific location, the designated dispenser creates a set of meals for the person or group. The share of meat meals offered and the price of meat and thus the meals containing meat, is dependent on environmental variables (i.e., the policy intervention space). Decision-makers can make decisions in the model interface to increase or decrease the price of meat and the availability of meat offered to the consumers in the model. The meals generated by the dispensers contain the following characteristics: meal type (containing meat or vegetarian), price, quantity meat, a required level of knowledge and skills to reduce meat, and a health value (based on the quantity of fresh fruit/ vegetables). The meal generation process is repeated for the three mealtimes, to provide the person with breakfast, lunch, and dinner. The meals containing meat, and the meals from the take-away and restaurant dispenser do not require a level of knowledge and skills to reduce meat consumption.

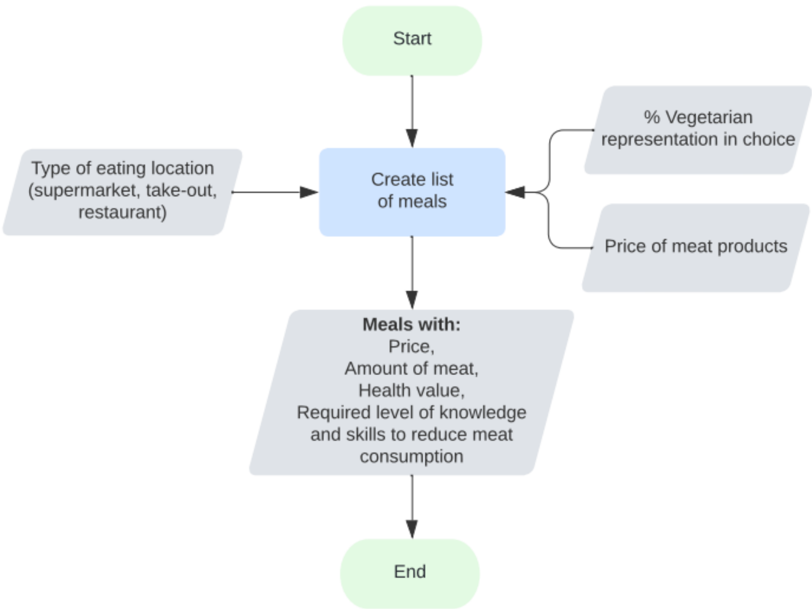

Figure 8. Conceptualisation of sub-process 3

SUB-PROCESS 4: SELECTING MEAL

Once arrived at the chosen meal dispenser, the decision-maker perceives the set of meal options available. The decision-maker sets boundaries to create a list of potential meals, based on its individual level of knowledge and skills, and the desired price range. The price range is based on its individual income level and when eating together with a group, the price range of the others is considered. The meals perceive the preferences of the decision-maker and go through a rating process. The most influential factor considered in the rating process is the weighted desire to eat meat, which is calculated based upon the person's frequency of meat consumption and the person's intention to eat meatless. The person also considers the desire to eat meat of others in the eating group to a certain extent, depending on his or her individual empathy towards others. Other factors that the person considers in the meal rating process are the price of the meal, the norms around meat consumption that the person perceives, and the individual level of concerns for animal welfare and the environment. When the dispenser is a supermarket, the decision-maker is the one who does the groceries, selects the meal, and passes on the meal towards the other members of the eating group. When the meal dispenser is a take-away or restaurant, all people in the eating group go through the meal rating process to select a meal that fits best their individual preferences. The meal selection process is repeated for breakfast, lunch, and dinner.

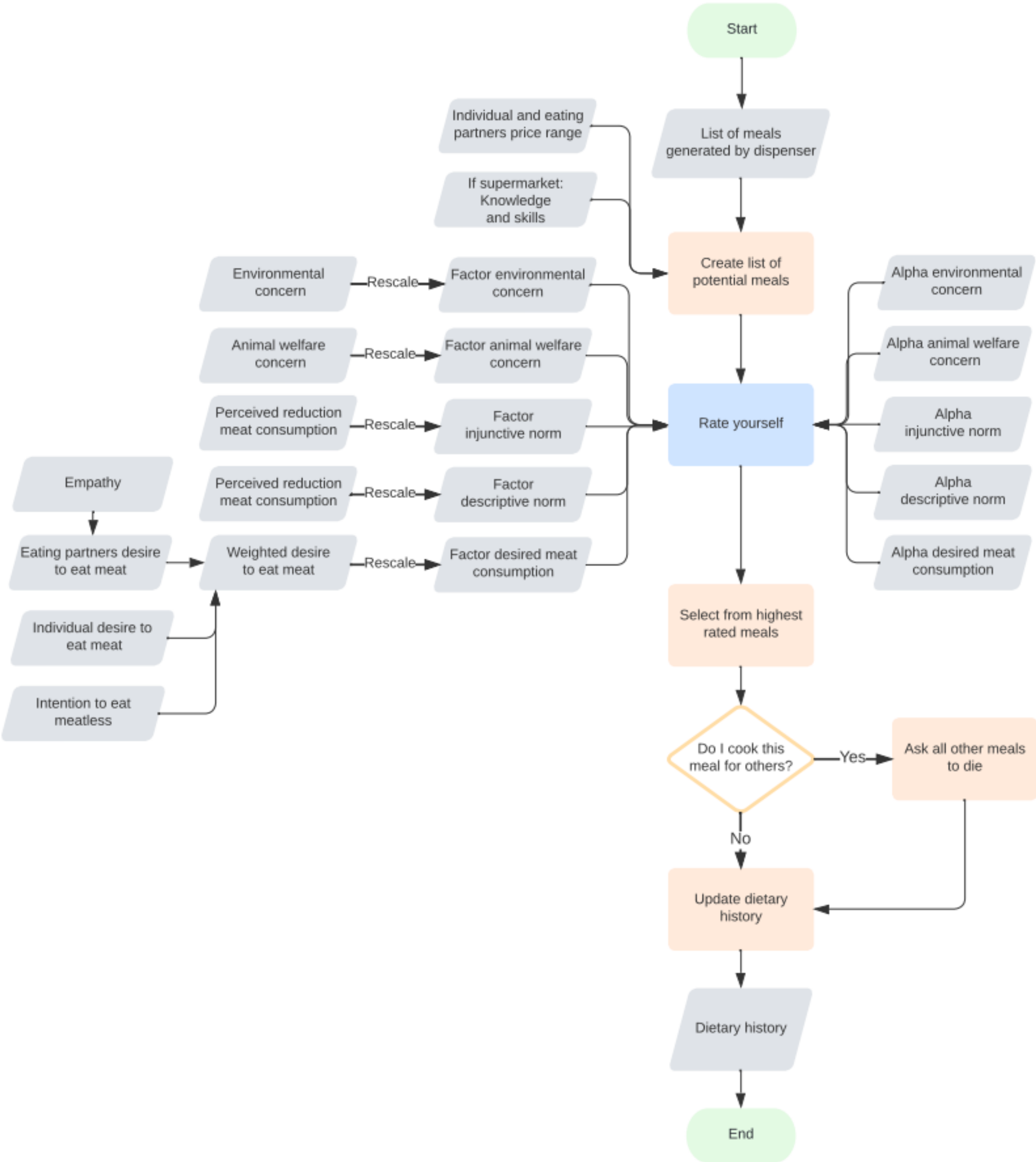

Figure 9. Conceptualisation of sub-process 4

SUB-CONCEPT 5: REFLECTION

Over time, the consumers in the population take time to briefly reflect on their individual food choices. Every three months, a reflection moment is scheduled where the person reconsiders his or her willingness to change (WTC), and thus intention to eat meatless, and his or her frequency of meat consumption. To reflect on the intention to eat meatless, the person perceives the concerns on the environment and animal welfare of people in the social networks. The degree to which the person considers the concerns of others, is dependent on the other's level of persuasiveness. To reflect on the frequency of meat consumption, the person looks at his or her dietary history, which is a list that stores the ratings of vegetarian and meat meals. The person then evaluates the ratings of vegetarian meals and meat meals that have been consumed, together with his or her level of WTC, in order to update the frequency of meat consumption. A person can be confronted with eating vegetarian more often, due to not always being the decision-maker of the eating group. The experience with vegetarian meals must be greater than the reverse WTC, to let the person's frequency of meat consumption decrease slowly.

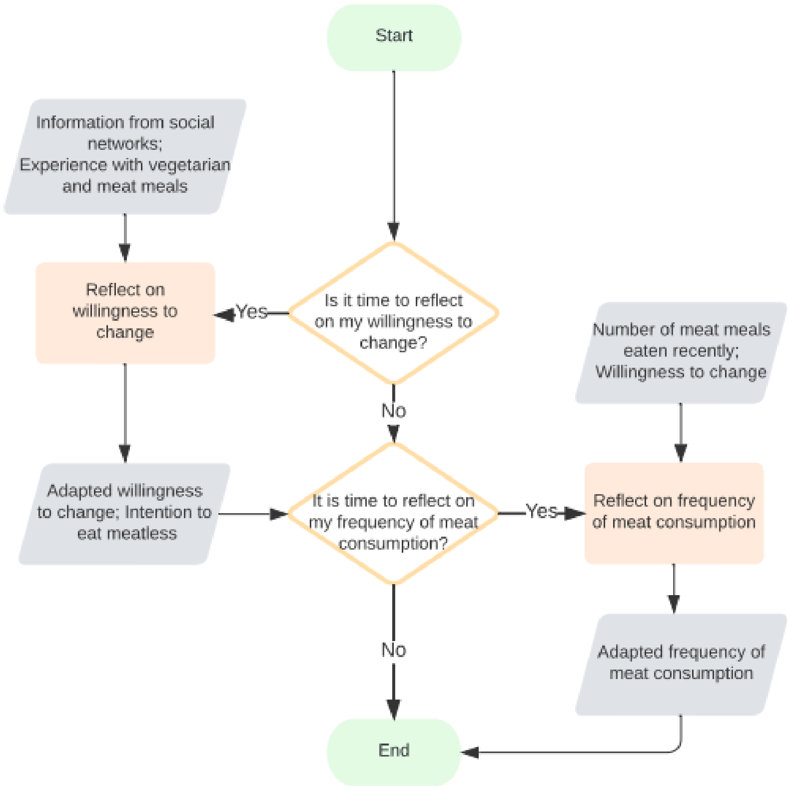

Figure 10. Conceptualisation of sub-process 5

3.2.4 MODEL DESCRIPTION

The model has been developed in the language and software programme NetLogo. NetLogo is a common and popular tool in the academic world of agent-based modelling, due to its low barrier to entry and fairly simple programming syntax (van Dam et al., 2013).

MODEL INTERFACE

An overview of the NetLogo interface of the model is shown below. The control buttons are used for starting and stopping the simulation experiments. The policy options are represented by the sliders that can be adjusted. The required number of agents can be entered in the input variables. The input parameters with an influence on the meal rating process can be altered with the sliders. On the right are various graphs that allow real-time monitoring of results.

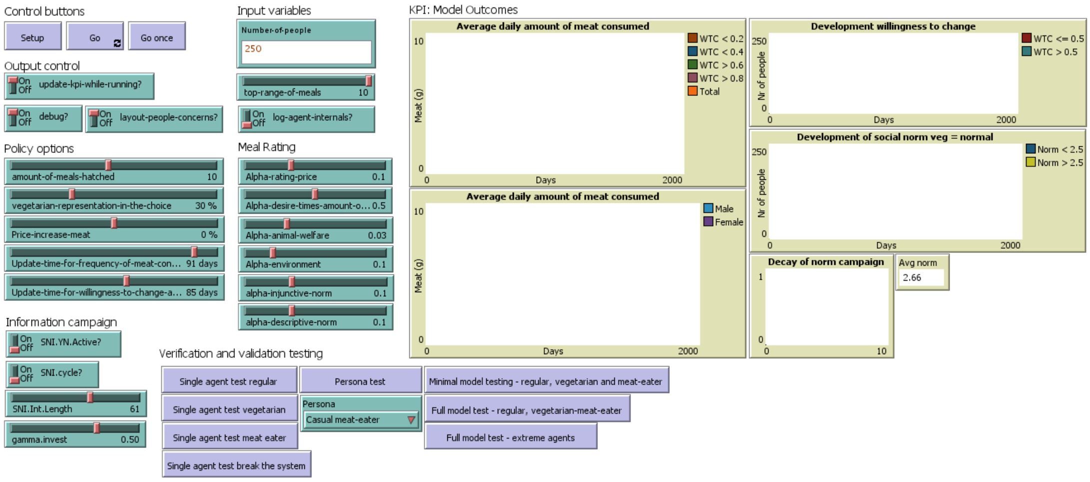

Figure 11. Agent-based model interface in NetLogo

MODEL PARAMETERS

Table 3 provides a complete overview of the model parameters, subdivided per agent type. While the agent performing the behaviour of interest is the consumer, three additional agents are initialised, namely meals, dispensers, and links. Model parameters are largely adopted from de Groot et al. (2021).

Table 3. Model parameterisation

Overview of entities, parameters, (default) values				
State variable	**Dynamic**	**Type**	**Range**	**Source**
Consumer				
Status	No	String	[Start, Idle]	Endogenous
Decision-maker?	Yes	Boolean	[True, False]	Endogenous
Gender	No	String	[Male, Female]	Questionnaire
Age	No	Int	[18, 35]	Questionnaire
Income-bracket	No	Int	[1, 7]	Questionnaire
Education-level	No	Int	[1, 3]	Questionnaire
Empathy-index	No	Float	[1, 100]	Endogenous
Persuasiveness	No	Float	[1, 100]	Endogenous
Weekly-eating-schedule	No	List, Sub-list, String	List per meal, with list per weekday, with string: Alone, Family, Work, Friend, NA	Endogenous
Preference-to-eat-out	No	Float	[1, 7]	Based on income
Knowledge-and-skills-to-reduce-meat	No	Float	[1, 5]	Questionnaire
Type-of-eating-location	Yes	String	[Supermarket, Take-out, Restaurant]	Endogenous
Eating-group-ID	No	Int	[1, ∞]	Endogenous
Dietary-history	Yes	List, Sub-list, String	Sub-list per meal, contains price, needed-knowledge-and-skills, health-value, rating, rating-for-veggies, rating-for-meat	Endogenous
Frequency-of-meat-consumption	Yes	Float	[1, 14]	Questionnaire
Concern-animal-welfare	No	Int	[1, 5]	Questionnaire
Concern-environment	No	Int	[1, 5]	Questionnaire
Perceived-norm-veg-normal	Yes	Float	[1, 5]	Questionnaire
Perceived-behavioural-control	No	Int	[1, 5]	Questionnaire
Perceived-reduction-meat-consumption	No	Int	[1, 5]	Questionnaire
Willingness-to-change	Yes	Float	[1, 5]	Questionnaire
Intention-to-eat-meatless	Yes	Float	[0, 1]	Based on WTC
Eating-partner?	Yes	Boolean	[True, False]	Endogenous
Grams-eaten	Yes	Float	[0, ∞]	Endogenous
Grams-eaten-last-meal	Yes	Float	[0, ∞]	Endogenous
Family-member?	No	Boolean	[True, False]	Endogenous
Agent-family-ID	No	Int	[1, ∞]	Endogenous
Family-centrality	No	Float	[0, ∞]	Endogenous
Family-decider?	No	Boolean	[True, False]	Endogenous
Work-member?	No	Boolean	[True, False]	Endogenous
Agent-work-ID	No	Int	[1, ∞]	Endogenous
Work-centrality	No	Float	[0, ∞]	Endogenous
Work-decider?	No	Boolean	[True, False]	Endogenous

State variable	Dynamic	Type	Range	Source
Meals				
Type-of-meal	Yes	String	[Breakfast, Lunch, Dinner]	Meal data
Price	Yes	Float	[0.1, ∞]	Meal data
Amount-of-meat	Yes	Float	[0, ∞]	Meal data
Needed-knowledge-and-skills-to-reduce-meat	Yes	Float	[0, 100]	Meal data
Rating	Yes	Float	[0, ∞]	Meal data
Dispenser				
Type-of-dispenser	No	String	[Supermarket, Take-out, Restaurant]	Endogenous
Network links				
Type-of-link	No	Breed	[Family, Work, Friend]	Endogenous
Link-weight	No	Float	[0, 1]	Endogenous
Link-<breed>-ID	No	Int	[1, ∞]	Endogenous
Friend-member?	No	Boolean	[True, False]	Endogenous
Agent-friend-ID	No	Int	[1, ∞]	Endogenous
Friend-centrality	No	Float	[0, ∞]	Endogenous
Friend-decider?	No	Boolean	[True, False]	Endogenous
Network-table	No	Table	Keys: Family, Work, Friend Reports: Agent-<breed>-ID	Endogenous

3.2.5 EMPIRICAL GROUNDING

The ABM is empirically grounded with data from a quantitative cross-sectional study on identifying barriers and transitions to reduce meat consumption (van den Berg et al., 2022). This study has been recently published by RIVM, allowing accessibility to the data. The questionnaire was designed based on the COM-B behavioural framework (Michie et al., 2011). In this study, it is decided to extensively make use of the COM-B framework for the empirical and theoretical grounding.

EXPLORATION OF QUESTIONNAIRE DATA

The study is composed of various statements which 1806 respondents answered based on a Likert scales (van den Berg et al., 2022). The statements are related to meat consumption and are subdivided into the six components of the COM-B behavioural framework. The complete overview of questionnaire statements can be found in appendix B.2. The empirical grounding is done by performing a correlation analysis and a multivariate regression analysis. Both methods are performed to gain understanding of the relationship between questionnaire statements and the self-reported meat consumption.

CORRELATION ANALYSIS

To observe whether there is correlation between the questionnaire statements and the respondent's self-reported meat consumption, a correlation analysis is performed. The Spearman coefficients are calculated in Python.

MULTIVARIATE REGRESSION ANALYSIS

To empirically validate the agent-based model input, the relationship between the questionnaire statements and the frequency of meat consumption is studied by conducting a regression analysis. Multivariate regression analysis enables the description of how the changes in the independent variables relate to changes of the dependent variable. The relationships in the questionnaire data are studied by performing an ordinary least squares (OLS) analysis is in Python. The analysis is executed per COM-B category, which is based on the categorisation of the questionnaire study (van den Berg et al., 2022). Physical and psychological capability are considered one category, to allow combination of its statements into one ABM variable. Per category, the independent variables are the questionnaire statements, where the dependent variable is the self-reported frequency of meat consumption. To perform the test, respondents with missing values had to be removed from the dataset, leaving 531 respondents. Per category, the statements with highest regression coefficients and a P value < 0.05 are selected. From the statements that were found to have a statistically significant relationship with the self-reported frequency of meat consumption, a selection was made to empirically validate the formulated ABM agent variables. When multiple statements were combined to form one agent variable, Cronbach's Alpha was calculated. To ensure a certain level of reliability, Cronbach's alpha > 0.6 was considered acceptable.

3.2.6 THEORETICAL GROUNDING

The COM-B behavioural wheel is selected as a guiding theoretical framework for development and structuring of the ABM Michie et al. (2011). This framework is expected to be suitable for this type of study, as it covers behavioural components, intervention functions that can address these behavioural elements, and policy categories that can enable those interventions. This way, interventions and policies targeted at specific behavioural components can be formulated.

MODEL INPUT DATA

There are four different types of model input data:

- Questionnaire for agent profiles
- Meal data for meal generation
- Weekly eating schedule
- Network generation

The meal data, weekly eating schedule data, and network generation data are adopted from the preliminary ABM (Groot et al., 2021) and can be found in appendix C.1.

3.2.7 MODEL VERIFICATION

To ensure that all entities and variables from the conceptualisation phase are correctly translated into the NetLogo software, various verification tests are performed. There are various methods that can be used for agent-based model verification. In this study, the following tests are performed, as proposed by (van Dam et al., 2013):

- Code walk-through
- Recording and tracking agent behaviour
- Single-agent testing

More detail on the execution of the verification steps and outcomes can be found in appendix C.4, C.5, and C.6. These steps were done for the preliminary model and repeated again after the model was adjusted.

3.2.8 EXPERIMENTAL DESIGN

Once the model is all set-up and verified, insights on model behaviour can be generated by performing simulation studies. First, the overall model behaviour will be observed over time. After, the model's behaviour under various policy pathways is studied. When performing experiments with agent-based models, results cannot be based on a single run. In the model, variation mostly occurs due to randomisation in the selection of questionnaire data for setting up the people and individual profiles, and randomisation in the generation of social eating networks.

For the scenario studies, various policy pathways are formulated, together with the stakeholders. What intervention studies are executed is thus dependent on the outcomes of the participatory sessions, mainly on the workshop session 1. Another crucial part of the experimental runs is to validate the ABM. The results will be validated based upon literature, and a sensitivity analysis is performed to explore to what extent the model outcomes are related to the uncertainty of input parameters. The data analysis and the Sobol sensitivity analysis are performed in Python. The open-source Python library EMA workbench (Kwakkel, 2017) is used for setting up the NetLogo model in python and for executing the simulation experiments. The sensitivity analysis studies the behaviour of the ABM without any intervention, while ranging the input parameters. The sensitivity analysis is performed with the use of the EMA-workbench and SALib libraries. To improve runtime of simulation studies from the original model, parallel computing was set up in Python. The visualisation of model outcomes is done with the use of Seaborn pairplots, as this type of plot allows to observe both the distribution of single KPIs, but also the relationship between different KPIs. As the simulations in this study are exploratory and come with a level of uncertainty, the relationship between the various KPIs can provide additional insights that are relevant for policymakers.

BASE CASE

The selected temporal boundary of observing the model behaviour, is a time-frame of 2000 ticks, which are in this model seen as equal to days, which can be considered a foresight until the year 2028.

As the general goal is to reduce meat consumption, the main key performance indicator (KPI) of interest is the average daily amount of meat consumption. This is monitored for the total population, the male population, and the female population. To visualise the model behaviour over time without any intervention, the following KPIs are used:

- Average daily amount of meat consumed (grams)
- Average daily amount of meat consumed by male individuals (grams)
- Average daily amount of meat consumed by female individuals (grams)

To run the model simulations, various input parameters are set at a fixed value The number of people is set at 250, to ensure heterogeneity between individual agent profiles and social networks. The vegetarian representation in the choice is estimated at 30%. The update time for the reflection processes on the individual WTC and frequency of meat consumption, are fixed at around 90 days, i.e. four times a year. The alpha parameters are the factors that directly play a role in the meal selection process. Setting the alpha values at a certain value is a quantification of human behavioural and psychological values. It must be noted that these are estimations. The alpha desired meat consumption is fixed at 0.5 as the individual's desired meat consumption can be argued to be the most significant decision factor of one's choice to eat either vegetarian or not. The other alpha values are all set at 0.1, except for the animal welfare concern set at 0.03, as this variable showed a relatively weak relationship with the frequency of meat consumption in the multi-linear regression analysis when compared to the other factors.

Table 4. Input parameters model behaviour over time (100 runs)

ABM variable	Value
Number of people	250
Vegetarian in choice (%)	30
Alpha desired meat consumption	0.5
Alpha price	0.1
Alpha environmental concern	0.1
Alpha animal welfare concern	0.03
Alpha injunctive norm	0.1
Alpha descriptive norm	0.1
Update time WTC	85 days
Update time frequency of meat consumption	91 days

POLICY PATHWAYS

The COM-B wheel is a framework that combines behavioural theory with the design of interventions aimed at altering the behaviour (Michie et al., 2011). Table 5 displays how the framework links nine different interventions functions to their target behavioural component(s). The overview of the definitions of interventions and policies as formulated in the COM-B wheel are given in appendix B.1.

Table 5. Links between components of the COM-B model of behaviour and the intervention functions (Michie et al., 2011)

Model of behaviour: sources	Education	Persuasion	Incentivisation	Coercion	Training	Restriction	Environmental restructuring	Modelling	Enablement
C-Ph					√				√
C-Ps	√				√				√
M-Re	√	√	√	√					
M-Au		√	√	√			√	√	√
O-Ph						√	√		√
O-So						√	√		√

1. Physical capability can be achieved through physical skill development which is the focus of training or potentially through enabling interventions such as medication, surgery or prostheses.
2. Psychological capability can be achieved through imparting knowledge or understanding, training emotional, cognitive and/or behavioural skills or through enabling interventions such as medication.
3. Reflective motivation can be achieved through increasing knowledge and understanding, eliciting positive (or negative) feelings about behavioural target.
4. Automatic motivation can be achieved through associative learning that elicit positive (or negative) feelings and impulses and counter-impulses relating to the behavioural target, imitative learning, habit formation or direct influences on automatic motivational processes (*e.g.*, via medication).
5. Physical and social opportunity can be achieved through environmental change.

The main KPI of interest is again the average daily amount of meat consumption. However, when simulating interventions it can be interesting to also gain insights on the development of individual behavioural characteristics, by keeping track of other variables. The following KPIs are used for the scenario studies:

- Average daily amount of meat consumed (grams)
- Average daily amount of meat consumed at dinner (grams)
- Average frequency of meat consumption (level 0 – 14)
- Average WTC (level 0 – 1)

3.2.9 MODEL VALIDATION

The validation of a model involves checking whether the created model serves its original purpose and is built correctly (van Dam et al., 2013). In this study, model validation is performed by literature consultation. In addition, a sensitivity analysis is performed to test the model's sensitivity to ranging values of input parameters.

SENSITIVITY ANALYSIS

The ABM development comes with various model uncertainties and model levers. Any parameterization over the model levers is known as a policy, while any parameterization over the model uncertainties is considered a scenario (Kwakkel, 2017). The EMA workbench allows to sample both over model levers, thus testing the effect of policies, and to simulate over the model uncertainties (Kwakkel, 2017). In this study, it was chosen to study the effects of interventions with static model input parameters. As these parameters are likely to differ in reality, it can be useful to conduct a sensitivity analysis. With the EMA workbench, various uncertainty sampling techniques can be used for testing the sensitivity of the model outcomes to the values of input parameters. As the simulation of meat consumption behaviour comes with several uncertainties due to made assumptions and subjectivities associated with human behaviour, a Sobol analysis is conducted on the following KPIs:

- Average daily amount of meat consumed (grams)
- Average daily amount of meat consumed at dinner (grams)

Table 6 lists the parameters and corresponding uncertainty ranges used for performing the Sobol sensitivity analysis.

Table 6. Model input parameter ranges for Sobol sensitivity analysis (300 scenarios)

ABM variable	Value range
Number of people	150 - 250
Alpha desired meat consumption	0.25 – 0.75
Alpha price	0 – 0.2
Alpha environmental concern	0 – 0.2
Alpha animal welfare concern	0 – 0.06
Alpha injunctive norm	0 – 0.2
Alpha descriptive norm	0 – 0.2
Update time WTC (days)	55 - 175
Update time frequency of meat consumption (days)	60 - 180

With the analysis, the first-order (S_1) and total (S_T) Sobol indices of the model inputs are calculated. The Sobol indices are the degree of contribution to the variance of the model output, in this case the average daily amount of meat consumed and the average daily frequency of meat consumption. The generated S_1 index refers to the individual contribution of a parameter to the output variance, and the S_T index refers to the contribution of a parameter to the output variance in interaction with all other parameters. The difference between S_1 and S_T indicates the importance of parameter interactions (X. Y. Zhang et al., 2015).

4. RESULTS

Here, the outcomes of the participatory sessions are described first, as they form the basis for the simulation experiments, of which the outcomes are visualised and described thereafter.

4.1 PARTICIPATORY SESSIONS

4.1.1 PRE-ASSESSMENT: INTERVIEWS

The key findings of the two interviews are described here. During both interviews there was discussion on ABM and its potential use, however this is excluded from the summary here, as only findings considered relevant for defining the scope and preparation of the workshop sessions are described.

The policy advisor on nutrition noted that in their work, the ‘Wheel of five’ guidelines are leading, of which the protein transition is a part. However, reducing meat consumption is not the main focus of dietary shifting from a health perspective. It is noted that the consumption of red and processed meat should be reduced. Difficulties with this transition are a lack of knowledge on what reducing meat consumption entails for various population groups such as the elderly, weak or sick. In addition, there are uncertainties on the effects on human health of replacing meat products with e.g. processed plant-based alternatives. The interviewee notes that it is difficult to promote alternative products while there is still a lack of knowledge on the nutritional value of these substitutes. Another great challenge in this transition is to receive both political and public support. Questions that arise are: “What is the role of both the social and the physical environment?” and “How to deal with cultural factors and food routines?”. The interviewee notes that in case simulation models will be developed for supporting such a transition, it is important that these do not turn into a black box, are transparent, and come with clear visual communication.

The second interviewee’s work focuses on the transition towards reduced meat consumption in The Netherlands, from a sustainability perspective. The interviewee is interested in how various system analysis techniques such as ABM and fuzzy cognitive mapping can possibly support policymakers in this transition. Questions that arise are: “What is the public and political support”, “How do we get the system to work on reducing its meat consumption”, “How to implement various flanking policy measures and what is the effectiveness of these measures?”, and “How can a meat tax be processed and recirculated effectively through the entire production and consumption chain, and what does this entail for parties such as supermarkets and restaurants?”. The interviewee is interested in what research has been performed already, what models have been built, and what knowledge ABM can generate with what level of validity.

Appendix A.3 provides anonymised summaries of both interviews.

4.1.2 WORKSHOP SESSION 1

The first workshop that is described in section 3.1.2, resulted in various outcomes: the hopes & fears of participants, an overview of the observed trends and the system’s components, desired policy pathways, and on what system elements or phenomena there is still lack of knowledge or insight. The results most relevant for the model conceptualisation are summarised here.

From round 3, following questions and areas with a lack of knowledge were identified and assigned priority to by participants (sorted from highest to lowest priority):

1. What interventions will be effective and why?
2. How to change culture-related behaviour and social norms?
3. How to set the market in motion?
4. How can eating meat be made the new smoking?
5. Gaining insight on the health effects of meat alternatives.
6. What are the right incentives for reducing meat consumption?

From round 4, the following desired interventions were assigned priority to by participants (sorted from highest to lowest priority):

1. A government actively aiming at a reduction of meat consumption
2. A government actively stimulating a food environment with reduced or no meat
3. No more subsidies on meat, subsidies on alternatives, meat tax
4. Extending the market of cultured meat
5. Acknowledging food consumption as a system; paying attention to all its actors

Stakeholders indicated that they are not only interested in interventions with a focus on fiscal measures, but also in reducing the amount of meat available to consumers and changing the culture and social norms around meat consumption. Intervening in such a complex system is expected to have a different effectiveness on people with varying behavioural profiles. Other points of discussion and interest were what can be effective combinations of various policy instruments, and what interventions are most suitable to use when a price increase of meat products is not executable due to societal or political constraints.

The focus of designing the intervention studies will thus be on fiscal measures, reducing meat availability and social norms around meat consumption. More information on the simulation of the policy pathways is given in section 4.2.3. The results of the mind mapping session can be found in appendix A.4.

4.1.3 SCIENTIFIC REFLECTION

The reflection on the two questions that were signed highest priority to is summarised here, as there two are selected to be the area of focus for ABM improvement. These two questions are selected for the focus of ABM adjustments that are well suited to answering with an ABM, scientifically relevant, of interest to the participants – especially the policy makers and advisors -, while keeping in mind the available time and resources and the capabilities of the preliminary model that was used as starting point.

1. What interventions will be effective and why?

ABM can generate interesting insights on this matter. When constructing an ABM on consumption behaviour, the behaviour of autonomous individuals is translated to rules and interactions between these individuals. By simulation of individual behaviour, effects both on the individual as system level can be observed. Patterns, structures and behaviour over time are not processed as model input, but develop throughout the simulation. The effects of various interventions such as price increase or reduced availability can thus be studied with ABM. Even when results can not necessarily be considered predictive, emergent or surprising results can occur, which are possibly not observable with traditional mathematical modelling methods.

2. How to change culture-related behaviour and social norms?

ABM can be a suitable tool to find (partial) answers on this complex question. ABM is able to simulate social interaction and thus can study the development of social norms over time. Social and cultural factors influencing meat consumption can be translated into agent characteristics and behavioural rules and interactions. Via simulation, the cultural or social developments of interest can be observed over time. However, this does not yet provide information on how the behaviour can be steered into another direction. To date, the knowledge and data on sociocultural processes is less extensive than on rational decision-making processes (Graça et al., 2019). By formulating assumptions on the factors that influence consumption behaviour it is possible to implement sociocultural factors in an ABM.

ABM ADJUSTMENTS

The decisions on how the model is modified, were based on the following criteria: the interests of the stakeholders, the structure and characteristics of the provided ABM, the time and resources available, and the scientific relevance of additional concepts.

The ABM was linked to the COM-B behavioural framework (Michie et al., 2011). The participants stated that they want to increase understanding on the social norms and cultural factors influencing meat consumption. A framework considered suitable for capturing behaviour in its entirety, is the COM-B wheel. The focus of the ABM adjustments were on capturing the social opportunity component of the COM-B wheel, as this was not implemented in the preliminary ABM.

To capture the influence of social context on the individual meat consumption, one injunctive and one descriptive social norm were defined. The injunctive norm was formulated as the 'perceived norm eating vegetarian is normal' and the descriptive norm as a 'perceived reduction in meat consumption' (Figure 12). To investigate what was the effect of changing these levels of social norms towards more acceptance of vegetarian eating, a social marketing campaign was implemented in the ABM.

To increase the policy relevance of the ABM, the model input data is empirically grounded instead of making assumption-based selections. The ABM is empirically grounded by performing correlation analyses and multi-linear regression analyses on the model input data, to be able to select input data that is used for setting up the behavioural characteristics in the ABM. All input data from the preliminary model is revised and adjusted according to the findings of these studies. The ABM input data is eventually categorised under the six behavioural components of the COM-B.

As participants stated to be interested in gaining understanding the behavioural mechanisms and differences between subpopulations, the ABM and its interface are modified in such a way that it allows to monitor behavioural differences between various population groups over time. These subpopulations can be distinguished based on e.g. their willingness to change, gender, or socio-economic status.

Other aspects that were changed were an extension of the time horizon of simulation studies to 2000 ticks/ days, which can be considered a foresight until the year 2027-2028. To ensure behavioural diversity in the virtual population, the number of agents was increased to 250.

4.1.4 WORKSHOP SESSION 2

The second workshop session resulted in a few key findings and feedback of involved participants that are concisely described here. Participants had several questions on the ABM mechanisms and made assumptions. Examples of those questions were: "What factors are taken into account during network generation of eating groups?" and "How does the mechanism behind the social marketing campaign work?". Also, there was discussion on to what degree the ABM is empirical and/ or explanatory. Participants mostly agreed that taking the COM-B wheel as guiding framework, promotes the communication and transparency of the model. In addition, it was recommended to share the model and its outcomes with a wider range of people working in the field of policy and research, as results are promising and considered useful for this transition. Participants noted that the acceptance of ABM should be increased prior to its use in any policy context, as currently there is still doubt on these relatively new techniques.

4.2 EXPERIMENTS

4.2.1 EMPIRICAL AND THEORETICAL GROUNDING OF THE ABM

CORRELATION ANALYSIS

The correlation analysis was performed on all questionnaire statements, but with a focus on the social opportunity category, as this is the category that participants have stated to have relatively little knowledge and understanding of. Table 7 lists the statements from the social opportunity component, together with the type of norm, being either cultural and social or dynamic. This categorisation is adopted from the questionnaire study (van den Berg et al., 2022).

Table 7. Overview of questionnaire statements from social opportunity category

Number	Question: To what extent do you agree with the following statement:	Social norm type
17 / Q5_1	My friends find it important to eat meat	Cultural/ social norm
18 / Q5_2	My household finds it important to eat meat	Cultural/ social norm
19 / Q5_3	My family finds it important to eat meat	Cultural/ social norm
20 / Q5_4	My colleagues/ fellow students find it important to eat meat	Cultural/ social norm
21 / Q5_5	Eating meat is part of my culture	Cultural/ social norm
22 / Q5_6	My friends accept people who want to eat less meat	Dynamic norm
23 / Q5_7	My household takes people who want to eat less meat into account	Dynamic norm
24 / Q5_8	My colleagues/ fellow students accept people who want to eat less meat	Dynamic norm
25 / Q5_9	My family takes people who want to eat less meat into account	Dynamic norm
26 / Q5_10	I can decide for myself whether I eat meat or not	Dynamic norm
27 / Q5_11	People in my environment eat less and less meat	Dynamic norm

Table 8 shows the results of those statements that fall under the social opportunity category. The highest correlation with the frequency of meat consumption was observed for Q5_1, Q5_3, Q5_5, and Q5_11. The results show that the respondents attach value to whether eating meat is considered important in their social environment, and whether it is considered a part of their culture. Also, a perceived reduction of meat consumption in the social environment shows correlation with the individual frequency of meat consumption. Stronger influential ties are observed for friends and household members, than for colleagues or peers. The correlation matrix performed on all questionnaire statements can be found in appendix B.2.

Table 8. Spearman correlation test results (n=1670): correlation tested between questions from the 'social opportunity' category and Q8 (frequency of meat consumption with hot meal) and Q9 frequency of meat consumption besides hot meal)

Question	Coefficient (Q8)	P	Coefficient (Q9)	P
Q5_1	0.339	<0.001	0.244	<0.001
Q5_2	0.355	<0.001	0.186	0.002
Q5_3	0.387	<0.001	0.245	<0.001
Q5_4	0.201	<0.001	0.144	<0.001
Q5_5	0.460	<0.001	0.351	<0.001
Q5_6	-0.212	0.002	-0.193	<0.001
Q5_7	-0.332	<0.001	-0.232	<0.001
Q5_8	0.100	0.481	-0.114	0.062
Q5_9	-0.278	<0.001	-0.208	<0.001
Q5_10	-0.119	<0.001	-0.072	<0.001
Q5_11	-0.367	<0.001	-0.248	<0.001

MULTIVARIATE REGRESSION

The OLS results of the social opportunity category resulted in an R-squared of 0.272. Of the 11 statements, 6 indicated to have a significant relationship ($P < 0.05$) with the self-reported frequency of meat consumption. The regression coefficients were in the range of 0.201 - 0.558. The analysis on the category capability (physical and psychological), resulted in R-squared of 0.263. Of the 9 statements, 4 were statistically significant, ranging from 0.188 – 0.549. The reflective motivation category resulted in an R-squared of 0.360, with 6 out of 9 statistically significant coefficients in the range of 0.190 – 0.500. For the automatic motivation, the R-squared was 0.457 and 6 out of 7 statistically significant coefficients in the range of 0.173 – 0.516 were obtained. The statements that are selected to empirically validate the ABM variables are listed in Table 9. Appendix B.4 gives an overview of all analysis outcomes.

Table 9. Overview of selected questionnaire statements based on highest regression coefficient and P < 0.05

Questionnaire statement	Agent state variable	Cronbach's Alpha
5_2 and 5_5	Perceived_norm_veg_normal	0.603
5_11	Perceived_reduction_meat_consumption	NA
2_2 and 3_1	Knowledge-and-skills-to-reduce-meat	0.703
6_1	Concern-environment	NA
6_2	Concern-animal-welfare	NA
7_1, 7_2, and 7_4	Willingness-to-change	0.740

THEORETICAL GROUNDING

The ABM captures meat consumption behaviour by linking the agent variables (Table 9) to the behavioural components of the COM-B framework (Figure 12).

This approach allows the following components of the COM-B wheel to be implemented in the model by setting up individual agent profiles: (1) physical capability, (2) psychological capability, (3) reflective motivation, (4) automatic motivation, (5) social opportunity. The agent's environment, i.e., the price and availability of meat products and alternatives, are considered the elements that make up the physical opportunity and are thus covered by the policy intervention space. As individuals are assigned a socio-economic status defined by income and education level, these environmental variables indirectly affect the individual's physical opportunity.

Social influence is captured by the definition of social norms, of which the level is calculated for every individual based on the questionnaire statements. Two norms were defined. The injunctive norm was formulated as the 'perceived norm eating vegetarian is normal' and the descriptive norm as a 'perceived reduction in meat consumption' (Figure 12). These formulations were made in consultation with a behavioural expert, to increase validity of made assumptions. These norms were assumed to play a role in the meal selection process, and to do this were treated similarly as the environmental and animal welfare concern. The assumption was thus made that a high level of the perceived norms results in a lower rating of meat-containing meals. The questionnaire statements were processed to ABM agent variables, as described in appendix C.3.

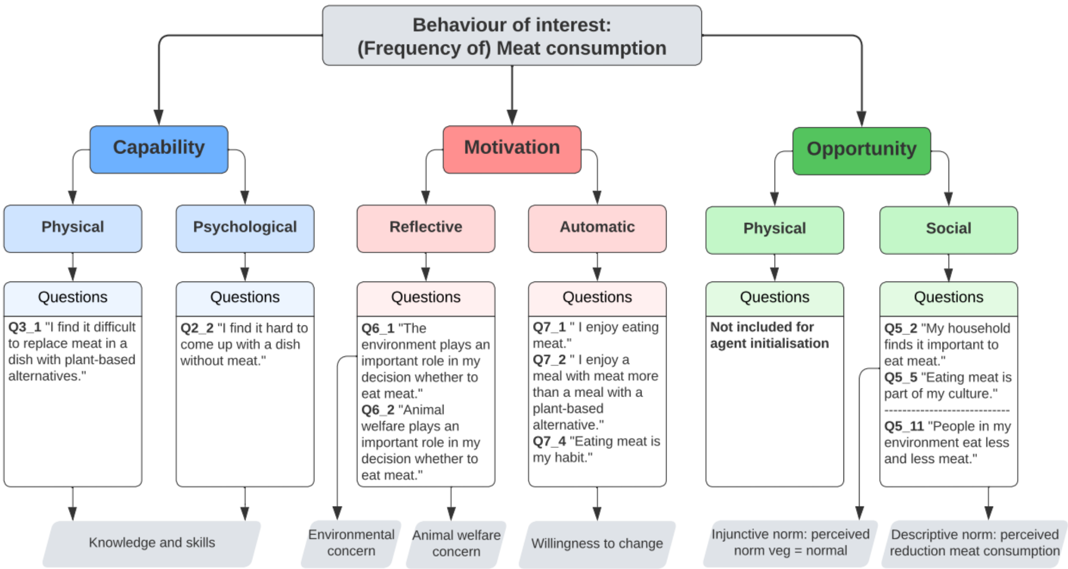

Figure 12. Empirical validation of the ABM by selection of input variables based on COM-B components

4.2.2 BASE CASE

In this section, the meat consumption behaviour in the ABM is studied without any external influence in the form of policy interventions. Figure 13 shows variance between the consumption behaviour of various subpopulations. It must be noted that these are indicative results based on a single simulation run, and variance occurs between runs due to stochastic model properties. The upper left real-time plot shows the variance in the amount of meat consumed for individuals with a different willingness to change. As the WTC is calculated based upon the following questionnaire statements: “I enjoy eating meat”, “I enjoy eating a meal with meat more than a meal with a plant-based alternative”, and “Eating meat is my habit”, these findings are in line with expectations. The plot indicates that agents with a low level of WTC (< 0.4) consume on average 120 grams of meat per day, whereas this is around 20 grams for agents with a high level of WTC (> 0.6). In the bottom left plot, the distinction is made based on gender. These results indicate that the male members in the population consume more meat than the female members. Distinctions made based on socio-economic factors such as income and education illustrate that agents with a higher income consume more meat than people with a lower income, and that those with a higher education seem to consume slightly more meat than the lower educated.

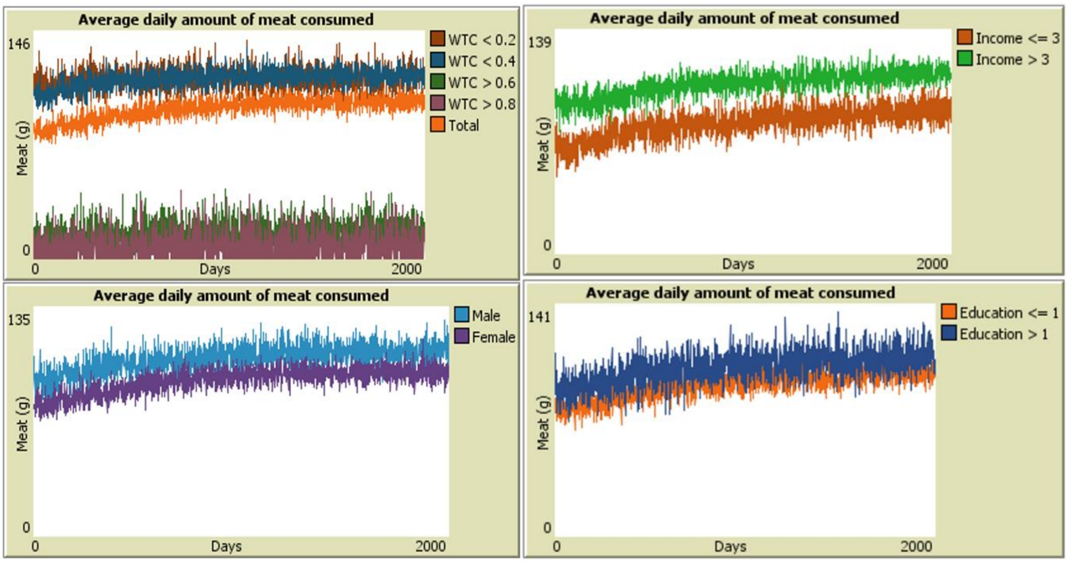

Figure 13. Average (250 agents) daily meat consumption monitored over time in NetLogo live plots (1 run). Upper left: distinction between level of willingness to change. Upper right: distinction between income level. Bottom left: distinction between gender. Bottom right: distinction between education level.

The average daily meat consumption lies fluctuates roughly between 80 – 110 grams a day (Figure 15). There is a slight increasing trend in meat consumption at the first phase of the model simulations. This trend might be due to the development of agent adaptation, as the reflection mechanisms allow the agents to alter their consumption pattern over time. Towards the end of simulation runs, the average daily amount of meat consumed lies around 100 grams when looking at the total population, 95 grams when considering the female population, and 110 grams for the male population.

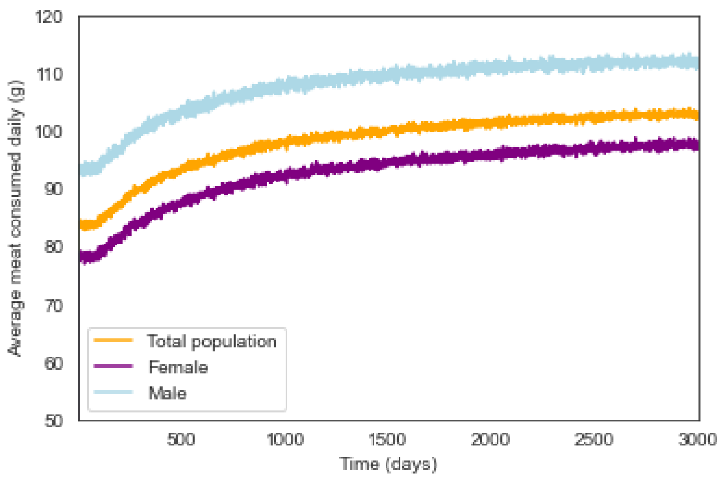

Figure 14. ABM results over time (100 runs)

4.2.3 POLICY PATHWAYS

For the simulation of various policy pathways, the outcomes of the participatory sessions with stakeholders were taken as a starting point. The prioritised interventions were: (1) a government actively aiming at a reduction of meat consumption, (2) a government actively stimulating a food environment with reduced or no meat, (3) no more subsidies on meat, subsidies on meat alternatives or a meat tax, (4) extending the market of cultured meat, (5) acknowledging food consumption as a system; paying attention to all its actors.

Based on the ABM capability and available time, it was decided to focus on the three interventions that were attributed highest priority to. The first and second intervention are formulated in a rather abstract way, making them multi-interpretable. It was chosen to combine and translate these two interventions to a reduction of meat product availability in the food environment, thus an increase of the vegetarian representation in the choice. The third intervention is translated to various meat price increase scenarios. As the influence of social and cultural factors was a returning point of discussion during the interviews and workshop session 1, it was chosen to create a social marketing campaign intervention to influence the social norms around meat consumption.

The scenario studies thus focus on a reduced meat availability, a price increase for meat products, and a campaign targeted at influencing the social norm dynamics around meat consumption and vegetarian consumption. In addition, combinations of these three intervention types are made (Table 10). The combination studies were formulated in consultation with the participants during the second workshop session.

Table 10. Experimental Design ABM intervention studies (50 runs per policy simulation)

Experiment	Policy/ Intervention	ABM Settings		
		Veg in choice (%)	Price increase meat (%)	Campaign social norm
1	Base case (no policy)	30	0	Off
2	Reduced meat availability	40	0	Off
3	Meat price increase 15%	30	15	Off
4	Meat price increase 20%	30	20	Off
5	Meat price increase 30%	30	30	Off
6	Combined policy 1	40	20	Off
7	Social norm campaign	30	0	On
8	Combined policy 2	30	20	On
9	Combined policy 3	40	20	On

REDUCED MEAT AVAILABILITY

The first intervention is an alteration in the physical environment of the consumer. The model increases the availability of vegetarian products offered in supermarkets, restaurants and take-aways, while reducing the availability of meat products. The vegetarian representation in the choice will be increased from 30% to 40%, thus reducing the meat representation from 70% to 60%.

When looking at the COM-B wheel's definitions of interventions and policies, reducing meat availability can be categorised under 'Environmental restructuring'. This intervention is defined as "designing and/ or controlling the physical or social environment" (Michie et al., 2011). This intervention category is targeted at automatic motivation, physical opportunity, and social opportunity. This type of intervention thus places more focused on external influences, and less on personal agency (Michie et al., 2011).

PRICE INCREASE MEAT PRODUCTS

The second type of intervention is the price increase of meat products. The effects of the following price increases are studied: 15%, 20%, and 30%.

According to the COM-B wheel, increasing the price of meat could also be considered a form of environmental restructuring, and more specifically changing the physical context. This intervention category is thus targeted at automatic motivation, physical opportunity, and social opportunity (Michie et al., 2011).

SOCIAL MARKETING CAMPAIGN

The third intervention is less straightforward and should be considered more exploratory than the other policy interventions. This intervention is aimed at changing the social norms around meat consumption and vegetarian consumption, as perceived by the individual. To study the social norm effect, i.e. the extent to which eating meat or eating vegetarian is considered normal, this intervention is included.

For simulating the influence of a social marketing campaign, the approach for from Zhang et al. (2014) is adopted, and applied on the social norm vegetarian is normal, instead of on environmental or animal welfare concerns, as was done in other studies (Scalco et al., 2019; Timmers, 2021; D. Zhang et al., 2014).

The influence of the social marketing campaign is modelled as a weighted average depending on the weight w and relative concerns of an agent i compared to its peers (D. Zhang et al., 2014). In this study, the peers are considered those people that are in the individual's family and friend eating groups. The members from work eating groups are excluded as these ties indicated to have a negligible effect on the self-reported frequency of meat consumption in the multi-linear regression analysis. The influence of the campaign is modelled by implementation of the equation below:

$$c_{i,t} = (1 - s_i)C_{1,t-1} + s_i \frac{\sum_{C_{j,t-1} > C_{i,t-1}}^{j \in peers(i)} (1+w)C_{j,t-1} + \sum_{C_{j,t-1} \leq C_{i,t-1}}^{j \in peers(i)} (1-w)C_{j,t-1}}{\sum_{C_{j,t-1} > C_{i,t-1}}^{j \in peers(i)} (1+w) + \sum_{C_{j,t-1} \leq C_{i,t-1}}^{j \in peers(i)} (1-w)}$$

The C represents the value of the agent's concern, in this case this is the perceived norm vegetarian is normal, at time t. Parameter w indicates the degree that the campaign affects the agents, which can be hypothesised at low, medium, or high. For this study, the simulation is performed with the success set at medium, however it can be ranged to either low or high in the model interface. Parameter s denotes the susceptibility of the agent towards its social members. For the sake of simplicity in this study, s is set at 0.01 for both family and friend members. Parameter w decays over time, to simulate lower attention to the marketing campaign after over time. The following formula is used for the decay of the marketing campaign:

$$w_t = w_t * e^{(-dt)}$$

In this formula, d represents the exponential decay constant, and t represents the current week in the simulation.

According to the COM-B framework, this type of intervention can be classified as 'Environmental restructuring', but directed on the social context instead of physical context. Similar as the previous two interventions, the three target behavioural components are automatic motivation, physical opportunity, and social opportunity (Michie et al., 2011).

COMBINED POLICIES

The stakeholders have stated to be interested in the effectiveness of combined interventions. For that reason, intervention studies are simulated where above-described policy pathways are combined. The selected temporal boundary of observing the model behaviour under these interventions, is 2000 ticks/ days, which is roughly considered to be a foresight until the year 2027-2028.

The three interventions can all be classified under environmental restructuring, and are thus targeted at three behavioural components. In the ABM, automatic motivation is represented by the willingness to change, physical opportunity is the category that represents the policy intervention space, and social opportunity is defined by the injunctive and descriptive norms.

To test whether the interventions are effective in targeting the corresponding behavioural component, the components can be monitored. At this stage, the WTC (automatic motivation) is the only variable suitable for monitoring, as the injunctive and descriptive norms (social opportunity) are static, except for when the social marketing campaign is activated.

4.2.4 EXPERIMENTAL RESULTS SIMULATION STUDIES

Figure 15 provides a static look at the outcomes of the simulation experiments with policy interventions focusing on a vegetarian choice increase, price increase of meat products, and a combination of the two. The density plots visualise the distribution of the numerical KPI values on the x-axis, being a smoothed version of the more standard histogram. The scatter plots allow to observe the relationships between various KPIs. As the ultimate aim of this study is to reduce the overall meat consumption, the amount of meat consumed is considered the most important criterion to measure the effectiveness of the interventions. The first two density plots (upper-left) are most suitable for the interpretation of the policy pathway effectiveness.

Similar outcomes are observed for the amount of meat consumed on a daily basis, and the average daily amount of meat consumed during dinner. The amount of meat consumed during dinner seems to be on the same level as the daily amount of meat consumed, indicating that no or a negligible amount of meat is consumed during breakfast and lunch. The base case outcomes show an average daily meat consumption of approximately 100 grams, which is in line with the findings in section 4.2.2. The efficacy of the interventions is listed from high to low below:

1. Combined policy 1, resulting in an average meat consumption of ≈ 50 grams per day.
2. 30% meat price increase, resulting in a consumption of ≈ 55 grams per day.
3. 20% meat price increase, resulting in a consumption of ≈ 60 grams per day.
4. 10% meat price increase, resulting in a consumption of ≈ 65 grams per day.
5. 10% vegetarian choice increase, resulting in a consumption of ≈ 90 grams per day.

These findings indicate that price interventions are more effective than changing the availability of meat products in the food environment. This result can be explained due to the fact that both interventions can reduce one's physical capability to buy and consume meat, but price changes can become a choice restriction instead of guidance for people with a lower income, which is not the case for a 10% change in product availability.

The third density plot shows the level of the average willingness to change in the population. The WTC seems to be insensitive to the applied interventions. During simulation, the reflection process can result in the individual adapting his or her WTC. The fact that the WTC is not reacting to the price and availability interventions, indicate that the reduction of meat consumption is not a result of automatic motivational processes. These findings confirm that the observed behavioural change is a result of a difference in physical opportunity. Unlike the WTC, the frequency of meat consumption is sensitive to the applied interventions (bottom right density plot). The applied interventions affect the frequency of meat consumption similarly as they affect the amount of meat consumed. This indicates that not just the amount of meat consumed is reduced, but also the number of meat-containing meals consumed.

The relationship between the four KPIs can be observed in the scatter plots. The amount of meat consumed during the day and dinner seem to have a perfect linear relationship. There seems to be no clear correlation between the WTC and the amount of meat consumed. Also between the frequency of meat consumption and the WTC, no correlation is observed. This result may be attributed to the fact that there is such minor changes in the level of WTC under these types of intervention. The frequency of meat consumption and the amount of meat consumed do show a certain level of correlation, albeit less obvious.

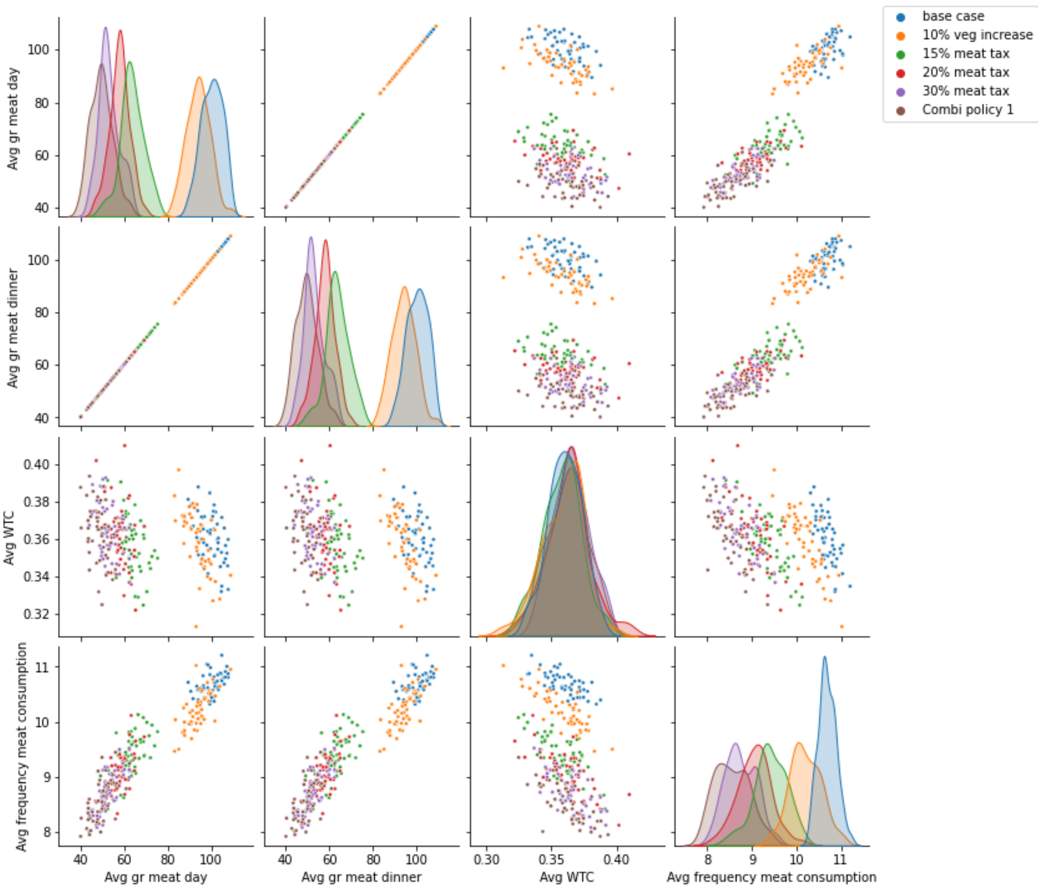

Figure 15. Outcome simulation studies on meat price increase and vegetarian choice increase, after 2000 days/ ± 6 years (50 runs per policy). The scatter plots visualise respective results for a pair of the four KPIs, whereas the diagonal cells show a density distribution of the KPI in the x-axis.

Figure 16 visualises the outcomes of the simulation experiments with a social marketing campaign on social norms, and the campaign combined with a meat price increase and vegetarian choice increase. The first two density plots (upper-left) are most policy pathway effectiveness interpretation. The activation of the social marketing campaign in the model did not result in a reduced overall meat consumption or frequency of meat consumption, when compared to the base case scenario in Figure 15. When the social marketing campaign was combined with a 20% meat price increase, this resulted in a consumption of ≈ 60 grams per day. A combination of the social marketing campaign with a 20% meat price increase and a 10% vegetarian representation in the choice increase resulted in a consumption of ≈ 50 grams per day. These outcomes indicate that the social marketing campaign did not have a significant effect on the amount of meat consumed. This might be attributed to the fact that the extent to which the social norm plays a role in the meal selection process is too minimal to have its desired effect. The scatter plots show a similar correlation between KPIs as was observed as in Figure 15.

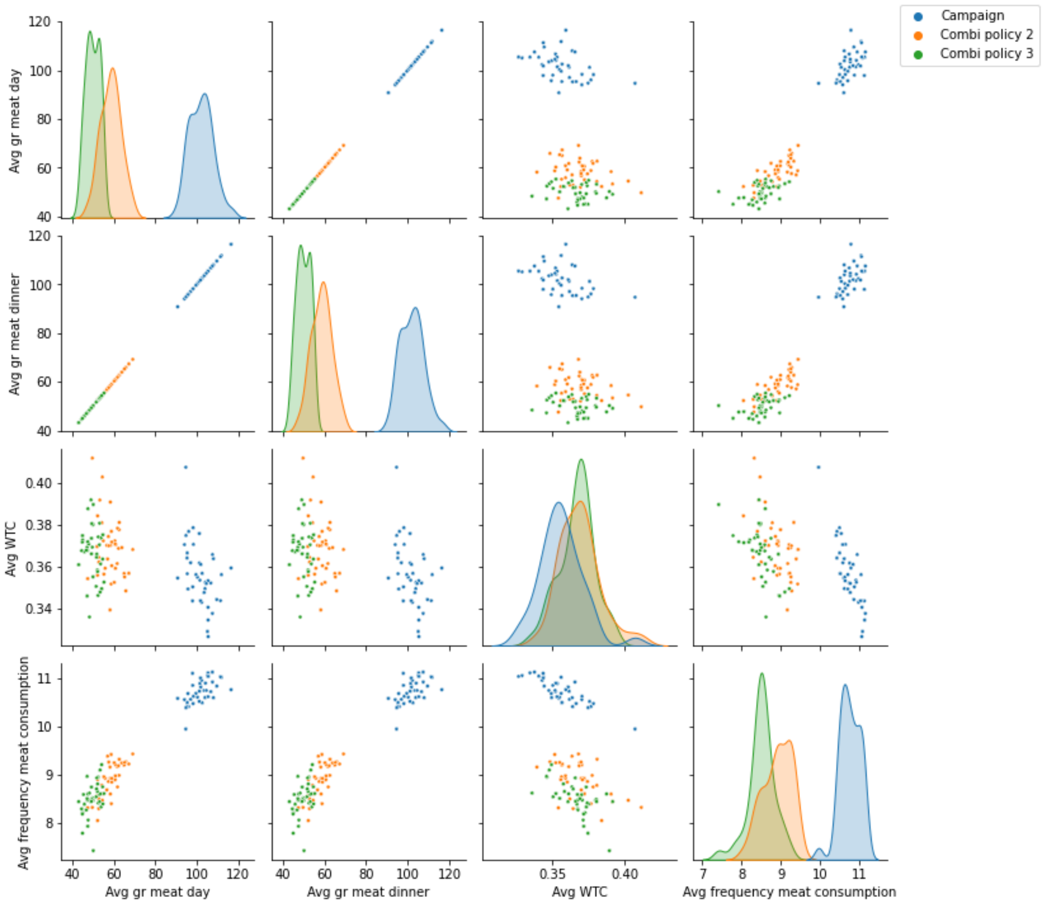

Figure 16. Outcome simulation studies on social marketing campaign (blue), combined with 20% meat price increase (orange), and combined with 20% meat price increase and 10% vegetarian choice increase (green), after 2000 days/ ± 6 years (50 runs per policy). The scatter plots visualise respective results for a pair of the four KPIs, whereas the diagonal cells show a density distribution of the KPI in the x-axis.

4.2.5 SOBOL SENSITIVITY ANALYSIS

The input parameter values that were ranged during the generation of 300 scenario simulations were described in section 3.2.9. Figure 17 visualises the outcomes of the sensitivity indices resulting from the Sobol analysis for the average daily amount of meat consumed. The first six parameters (from the left) directly influence the individual meal selection process of the ABM, whereas the other three parameters, thus the number of agents and update times of reflection processes do not, but possibly have an indirect effect on the meals selected. It can be observed that the 'alpha desired meat consumption' contributes most to variance of the model output. This parameter is calculated based upon the one's frequency of meat consumption and intention to eat meatless. The model's high sensitivity to this model output can be attributed to the fact that this parameter was assumed to have the most influence on the meal selection process. The second most influential parameter is the 'alpha descriptive norm', which is computed as the extent to which the agent perceives a meat consumption reduction in their social circles.

For all nine parameters, the total-order (S_T) values are significantly higher than the first-order (S_1) values. As the S_1 refers to the individual contribution of the parameter, and S_T refers to the contribution of the parameter in interaction with all other parameters, this demonstrates the parameters contribute more to the outcome variance when interacting with the other factors. Four out of nine parameters resulted in a negative S_1 index. When negative indices are generated, this might indicate that the sample size was insufficient and should be increased.

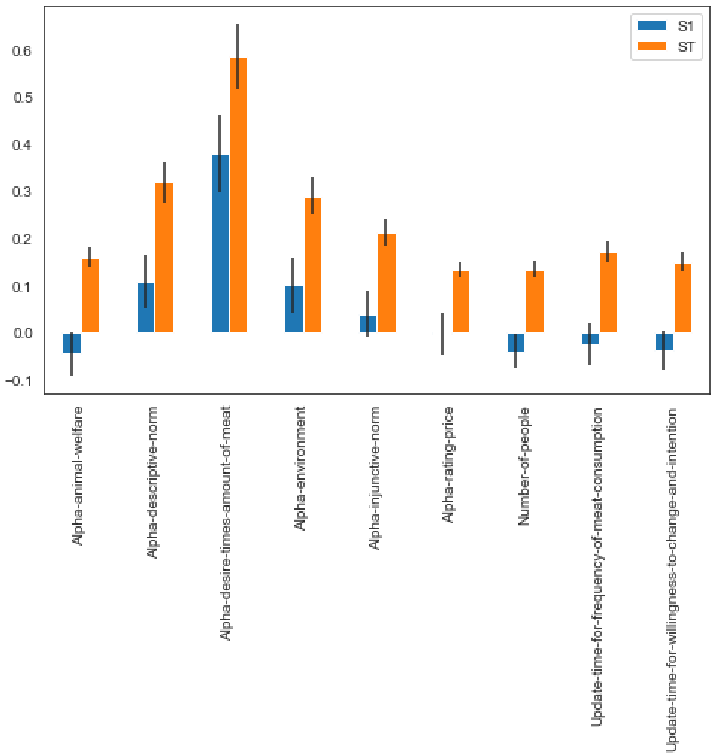

Figure 17. Sobol indices for the variance in model output 'average daily amount of meat consumed' in year 2027-2028 (300 scenarios). The whiskers indicate the 95% confidence interval.

The Sobol indices for the frequency of meat consumption (Figure 18) show a very different distribution than the average amount of meat consumed. The most influential parameter is the update time for the frequency of meat consumption. This finding indicates that how often the reflection process occurs, highly affects the individual's frequency of meat consumption. In turn, the frequency of meat consumption showed to be a highly determining factor of the average amount of meat consumed. From this can be concluded that the reflection process indirectly influences the model outcomes to a great extent. The other parameters show a comparable level of influence on the frequency of meat consumption in the range of 0.3 – 0.4. Here again, the negative S_1 indices are likely to be an indication of insufficient sample size.

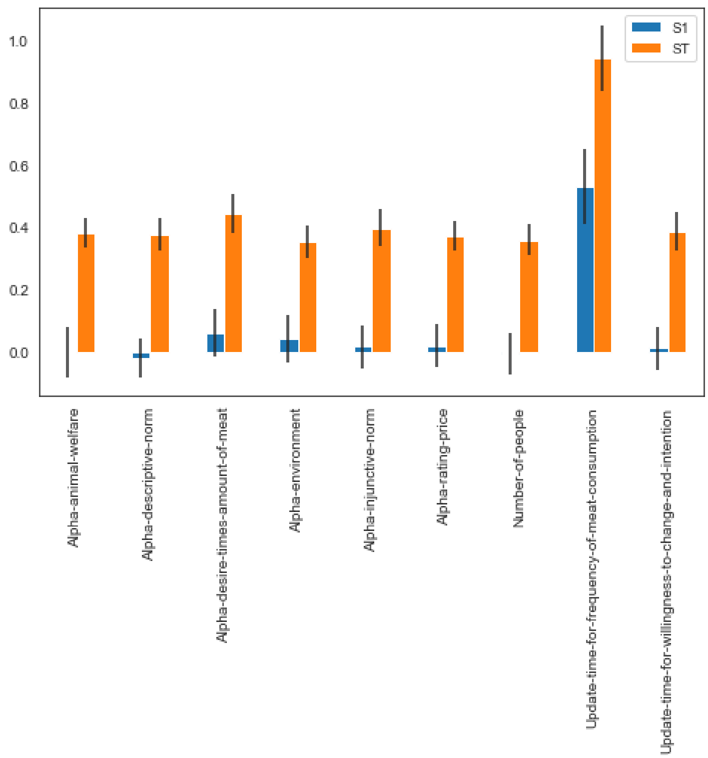

Figure 18. Sobol indices for the variance in model output 'frequency of meat consumption' in year 2027-2028 (300 scenarios). The whiskers indicate the 95% confidence interval.

5. DISCUSSION & RECOMMENDATIONS

In this chapter, the participatory modelling process and results, the model outcomes and validity are discussed. The strong and weak elements of this study are highlighted and recommendations that can improve the quality of the research are given.

5.1 REFLECTION ON PARTICIPATORY MODELLING PROCESS

The PM process took around six months in total from pre-assessment to report writing. The tools and methods used during the scoping and envisioning phase were chosen based on individual experience and available time and resources. This approach has shown to be successful, as the outcomes have led to model improvements that increase the policy relevance of the ABM. However, other instruments can be used during this phase to increase understanding of the system components and the transition, such as role playing games, serious games or the development of causal loop diagrams (Voinov et al., 2016).

To further increase model quality, more intermediate group sessions in which the adjusted concepts are brought back to participants for further discussion and improvement should be planned. The time horizon and stakeholder availability in this study allowed to only organise two workshop sessions. The final communication phase with stakeholders during which the experimental quantitative model outcomes are presented and discussed in detail, was quite limited. As ABM is a technique that generally comes with low transparency compared to other PM methods, more time should be scheduled for this essential phase (Voinov et al., 2018). Increasing the time horizon of the project to e.g. one year is expected to benefit the outcomes of a PM study on ABM development greatly. Extending the timeframe allows the organisation of additional stakeholder workshops and sessions, in which the model can also be used by participants. It was also found that the project timing influences the study progress, as in this study the organisation and timing of the second workshop was dependent on participant availability around summertime.

The interviews and workshops helped identifying the lack of knowledge that decision-makers have. These were linked to the ABM to increase the user relevance and explanatory power of the ABM. The main lack of knowledge identified, was on the socio-cultural factors that influence meat consumption, and how these can be targeted with interventions. Participants stated to be interested in gaining knowledge on the dynamics of behavioural consumption over time, and on increasing insight on why certain interventions are more effective than others. Other interesting lacks of knowledge were identified, but not touched upon in this study due to limited time and resources. Examples of these issues were: subsidies on meat alternatives, extending the market of cultured meat, changing culture-related behaviour, gaining insights on the heath effects of meat alternatives, and setting the whole market in motion.

This study showed that the PM process contributed to an increased understanding of ABM and its strengths and weaknesses on the participants side. To improve the model as a tool for social learning in the field of policy, a wider range of experts should be involved in the modelling process, to further increase the validity of the ABM and its outcomes. A higher number and diversity of involved experts during the various model phases is expected to further increase the model's validity and policy relevance. In this study, the focus was on the use of ABM in policymaking processes, and thus the stakeholders involved were experts from the field of policymaking, research, and academia. With this decision, stakeholders from financial institutions, food producers and distributors, citizens, NGOs, and retail were excluded. For the scope of this thesis, the variety of involved participants was considered sufficient. However, when ABM will be used for this transition with a slightly or entirely different scope or focus, the involvement of stakeholders from these other sectors should be considered, as they can provide useful insights and information from a different perspective.

It was interesting to perform this PM process during a time that the issue was in the newspapers (NOS, 2022). One day prior to the organisation of the first workshop session, a motion was adopted to not implement a tax on meat. This increased the urgency and need of participants to gain understanding on alternative interventions and their effectiveness.

5.2 REFLECTION ON ABM AS POLICY INSTRUMENT

Based on PM outcomes, it was decided that increasing the policy relevance and transparency of the ABM could be achieved by implementing the social and cultural influence on individual meat consumption behaviour in the model, while taking the COM-B wheel as an overarching theoretical framework (Michie et al., 2011). The framework supported both the empirical and theoretical grounding of the ABM. The questionnaire statements that were used as ABM input data, were categorized under the various components of the COM-B wheel. This structured division supported the empirical validation of ABM variables, and also the process of capturing meat consumption behaviour in its entirety.

It was chosen to perform the simulation studies on policy pathways with static input parameters. It is however possible to use the ABM for model-based decision support under deep uncertainty, by running the intervention studies with a (wider) range of ABM input parameters. The approach depends on the wishes of stakeholders. In this study, time constraints did not allow to discuss these various approaches, and it was decided to perform simulation with static input parameters. However, Sobol sensitivity analysis was performed to shed a light on the model's sensitivity to the input parameters. These results indicated that the daily amount of meat outcome is most sensitive to the individual desired meat consumption, whereas the frequency of meat consumption is mostly influenced by how often the reflection process takes place. The sensitivity of the ABM should be further investigated by increasing the sample size of scenarios under which the Sobol analysis is performed, and to test the sensitivity at various time intervals throughout the simulations. In addition, experts should be consulted to review and determine the parameter settings for these analyses. Once a clear picture is created on the model's sensitivity, it is recommended to also study the sensitivity of model outcomes under various policy pathways.

Compared to most other PM methods, ABM requires high systems knowledge, high expertise of the modeller, and high computer resources (appendix A.2). When the model will be further developed for support in decision-making processes, it is recommended to increase investment and resources on all three elements. The currently used parallel computing can be extended by the use of virtual machines for ABM calculations, as runs were heavy and time consuming. Originally, it was planned to run simulations until the year 2030, as this is generally a target year in policymaking. Due to heavy runs it was decided to decrease this time horizon to foresights until the year 2027-2028.

5.3 REFLECTION ON MODEL VALIDITY AND EXPERIMENTAL RESULTS

The base case simulations of the ABM resulted in an average daily meat consumption of 100 grams for the total population, 95 grams for the female population, and 110 grams for the male population. These findings are in line with the outcomes from the Voedselconsumptiepeiling (VCP), a longitudinal survey on food consumption behaviour (RIVM, 2020). The most recent VCP results (2012- 2016) indicate that men in the age group of 18 – 35 years consume around 120 grams of meat on a daily basis. For women in the same age group, this lies around 85 grams per day (RIVM, 2020). These results are comparable to the findings in this study. The VCP results show a slightly higher difference between the meat consumption of men and women than the ABM findings. This is likely to be a result of the fact that the model remains a simplification of the real world, which comes with numerous assumptions. As the model is grounded with data from a questionnaire study with a certain group of respondents, the deviation can also be resulting from behavioural differences between this group and the respondents of the VCP.

The correlation analysis results indicated that there are stronger influential ties for friends and household members than for colleagues or peers. These findings are in line with the study from de Castro (1994), who demonstrates that family and friends exert an effect on food choices beyond the influence from other companions (de Castro, 1994).

EXPERIMENTAL RESULTS

Assuming that the real world works the same as the ABM, of the three types of interventions simulated, the price interventions showed to be most effective on reducing the meat consumption. This is in line with the findings from Scalco et al. (2019) and Timmers (2021), where price interventions showed to be more effective than campaigns. A meat price increase of 30% reduced the average daily meat consumption from 100 grams to 55 grams. When the price intervention was combined with an increase of the vegetarian representation in the choice, even higher reduction was obtained. The policy pathway in which a 20% meat price increase was combined with a 10% increase of the vegetarian representation, reduced the daily meat consumption to 50 grams. Increasing the vegetarian representation in the choice with 10% effectively reduced the daily meat consumption to 90 grams.

The social marketing campaign promotes the message that 'Eating vegetarian is normal', by increasing the overall perceived injunctive norm that people in social networks find it normal to eat vegetarian meals. Messages on the attitude and behaviour of other consumers can activate social norms, motivating consumers to adhere to the desired social norm (Kwasny et al., 2022). It was thus expected that this intervention would indirectly lead to a reduced meat consumption. However, in this study, the campaign was not effective in reducing the frequency or amount of meat consumed. The mechanism behind the campaign was adopted from Zhang et al. (2014). In the studies from Scalco et al. (2019) and Timmers (2021), the campaign was targeted at environmental, animal welfare, and health concerns. In these studies, the campaign also showed modest to no effect on meat consumption. During the model verification process in this study, it was observed that the campaign is effective at increasing the level of the perceived norm that eating vegetarian is normal throughout the population. This indicates that the mechanism in which the injunctive norm affects the meal selection process should be revised together with bevioural experts.

During the simulations of meat price and vegetarian choice increases, the average WTC does not deviate away from the base case level. These findings indicate that the individuals are not decreasing their meat consumption due to reflective or automatic motivational reasons, but are rather forced to decrease meat consumption due to reduced capability. Weibel et al. (2019) identified that the most influential factors that have an effect on the WTC are attitude, perceived behavioural control, personal norm, and awareness. It is recommended to increase understanding on what factors influence the WTC and how the reflection process of this variable can be improved.

5.4 STUDY LIMITATIONS: ABM AS POLICY INSTRUMENT

In order to capture consumer behaviour in a simulation model, behavioural elements and values have to be quantified. The quantification of behaviour comes with uncertainties as behavioural rules are extremely complex and diverse in real world populations (Hinker et al., 2017). In this study, behavioural rules are based on a systemic theory of behaviour, and made in consultation with experts, but this ABM inevitably comes with these uncertainties too.

With the development of the ABM, simplifications and assumptions had to be made that affect model outcomes. Several assumptions had to made in order to initialise agent profiles, to generate social eating networks, to let the agents select eating locations, to let the dispensers generate meal options, to let the agents select a meal, and to let the agents reflect on their consumption behaviour. A few assumptions are highlighted and elaborated on, to illustrate the limitations that come with the agent-based model.

The agent profiles are created based on those questionnaire statements that showed to have a statistically significant relationship with the self-reported frequency of meat consumption. A selection of statements with the highest regression coefficients was made to set up agent variables. The selection sufficed in covering all behavioural elements of the COM-B framework to a certain extent. However, making the selection does leave out a list of behavioural elements that possibly also determine one's meat consumption, albeit to a smaller extent.

To select a meal, the individual rates a meal with a certain meat content based on the individual's desired meat consumption, meal price, perceived social norms, and concerns on environment and animal welfare. The effect sizes of the factors influencing the meal selection process were estimated based on the multi-linear regression outcomes. However, in the ABM the factors do not have a direct influence on the frequency of meat consumption, but on the process of meal rating. In the model, all agents experience the same effect sizes of determinants, whereas in reality differ greatly per individual. Literature indicates that all abovementioned factors play a certain role in meat consumption (Stoll-Kleemann & Schmidt, 2017). However, the implementation of social norms affecting meal choices should be considered exploratory, as the perception of a different norm does not have to imply behavioural changes (Zia et al., 2019). In this study, it is assumed that various factors directly influence the meal selection and thus meat consumption behaviour. The model does not take into account individual traits and characteristics such as the intention-behaviour gap, behavioural control, and cognitive dissonance (De Krom et al., 2020). These behavioural concepts can be built into the model with the support of behavioural scientists.

5.5 RECOMMENDATIONS FOR FURTHER RESEARCH

5.5.1 PARTICIPATORY PROCESS AND POLICY SUPPORT

In this study, three types of intervention were simulated. The model's supportive power in ex-ante policy evaluation increases when a more diverse mix of interventions is studied. It is thus recommended to look into what other types of policies can be simulated with the model. The structure and mechanisms of the ABM allow simulation of e.g. a reduction of meal portion sizes and social marketing campaigns on emotions such as environmental or animal welfare concerns. Inspiration for the design of additional policy pathways targeted can be taken from the literature review of (Kwasny et al., 2022).

Another recommendation is to study what are the effects of various policies when targeting specific consumer groups. The current ABM allows to observe how various policies affect individuals in the age range of 18-35 years, but it does not make a distinction between various target populations. The explanatory power of the ABM can be increased with ensuring high sociodemographic variety of respondent data that is used to create the agent profiles. An overview of the sociodemographic variables of the respondents that were used as model input in this study is given in

Once the use of ABM techniques in decision-making processes of governmental institutions becomes more accepted and widespread, it is recommended to look at the spectrum of available software tools that can be used for model development and simulation, in order to select one that fits the purpose best (Abar et al., 2017). In this study, NetLogo was selected as tool for designing and developing the ABM based on the provided ABM and experience, but numerous other tools are available, differing in the ease of model development and computational modelling strength. NetLogo is considered a tool that requires relatively low modelling effort, but is not the best tool in terms of model strength and capability (Abar et al., 2017).

5.5.2 AGENT-BASED MODEL

One version of a simulation model generally raises new questions (van Dam et al., 2013). This iterative process of allows for continuous improvement of quality and extension of the model. Whether these newly raised questions need to be studied depends on the scope of the research and lack of knowledge the simulation model is supposed to provide answers to (van Dam et al., 2013). The ABM developed in this study also resulted in various unanswered questions. Various recommendations are given to further increase the explanatory power and quality of the ABM.

It is recommended to revise the quantification of determinants of the meal selection process together with various behavioural experts. As this process largely defines the model outcomes, it is crucial that this process is further studied and validated. For example, the mechanism behind the influence of price on consumer choice should be further investigated with experts and previous studies on price elasticity.

Another recommendation is to make certain agent variables dynamic. The individual concerns and perceived social norms that play a role in the meal selection process are static when no campaign is activated. This limits the agent adaptation over time. The reflection process can be extended by allowing more advanced information sharing between individuals. In the current model, the concerns on environment and animal welfare of agents in the eating networks are considered during the individual reflection process. However, in the real world, reflection processes are way more complex and consider more factors than are included in this study. Information sharing between agents could be made more advanced by setting up scale-free networks. The current eating networks do not suffice for realistic information sharing. Scale-free networks would be a better alternative, as these follow a power-law degree distribution of the number of connections a person has to other individuals (Artico et al., 2020).

5.6 SOCIETAL AND SCIENTIFIC RELEVANCE

The issue of reducing meat consumption was a much debated subject in the country during execution of this project. The main reason for the commotion was a letter from the Minister of Agriculture, Nature and Food Quality to the Dutch parliament (Staghouwer, 2022). In this letter, it is stated that the Ministry has plans to explore various methods aimed at reducing meat consumption in The Netherlands, amongst which a price increase of meat products. The fact that this commotion arose is an indication of the societal relevance of increasing understanding on the matter.

Currently, there is a lack of understanding of what role ABM can play in decision-making processes on meat consumption behaviour. Despite its strengths, the technique is generally not used yet in this field, due to limited understanding and practical knowledge and information. Literature on case studies were an ABM is developed in a PM process is still limited (Halbe et al., 2020). This study adds to literature by performing a case study in which various methods and tools that can be used in an PM on ABM development are presented. The social learning process anticipated on the policy-science gap that exists around this method, by increasing the knowledge on, and familiarity with ABM methods of people working in the field of both policy and research.

This study is helpful for decision makers and researchers in the field of food and behaviour by providing an in-depth example of how complex consumption behaviour can simulated in an ABM. This study increased the accuracy and transparency of an ABM on meat consumption behaviour by linking the model to the COM-B framework. The policy relevance was increased by the empirical validation of input data, implementation of social norms into the model, and a more realistic simulation of behavioural processes that make up meat consumption behaviour. Besides its purpose of increasing the quality and communication of the ABM, the use of the COM-B wheel allows to link interventions and policies to target behavioural components. This can be especially relevant for potential users of the simulation model. Initially, the model can be used to identify certain behavioural dynamics and development, to subsequently observe whether an intervention reaches its intended goals, i.e. targets the expected behavioural component it is supposed to target.

Compared to previous ABM studies on meat consumption, this ABM covers a more complete range of behavioural components and processes, which can provide new insight on meat consumption behaviour and the effects of interventions. The ABM contains mechanisms that allow agent adaptation over time. In addition, the model allows the simulation of various types of interventions, that can possibly provide additional useful information that policymakers and researchers require to effectively intervene in the system. The approach that was used by (Scalco et al., 2019) and (Timmers, 2021) lacks the inclusion of behavioural elements such as knowledge and skills, automatic motivation, and social opportunity. The study from (Timmers, 2021) simulated the development of social norms as the process in which agents can influence the concerns on environment, animal welfare, and health of individuals in their social networks. However, there is more to social influence and norms around meat consumption than these concerns that can be categorised under automatic motivation. In this study, the cultural and social norms around meat consumption were defined, empirically grounded, and processed in the ABM.

6. CONCLUSIONS

The motivation for this study was to test whether ABM has potential in supporting stakeholders in the transition towards a reduced meat consumption in the Netherlands. In line with RIVM's research programme SHIFT-DIETS, the study provided insights on how ABM can be used for the ex-ante evaluation of police, in the face of this complex transition. PM was performed, involving experts from the field of policy, consumption behaviour, nutrition, and complex systems science. There were a few motives for setting up the PM process in this specific study. The first reason was that the ABM can be difficult to understand for policymakers, and the process of taking them along in the modelling process can increase understanding of the technique, and strengths and weaknesses of the model. To a certain degree, social learning was promoted as there was much discussion on the ABM, its processes and assumptions during the PM sessions. Secondly, the quality and characteristics of a model aimed at supporting this complex transition, should be in line with the needs of those people that govern the transition. The model was made more relevant to policymakers by integrating additional concepts in the model, based on the identified lack of knowledge of participants.

The study was performed to answer the following question: *"How can a preliminary ABM on meat consumption behaviour be improved based upon insights obtained through a participatory modelling process, and what is the effectiveness of various policy pathways on meat consumption in The Netherlands as simulated with this improved ABM? "*

The first part of the research question can be answered with the results obtained during the PM process. The policy relevance of a simulation model can be defined by the extent to which the model generates insights that the potential users of the model require to gain understanding of the transition, to support their decision-making processes. In this study, involved participants identified the main lack of knowledge to be on the understanding of socio-cultural factors that influence meat consumption, and on what interventions are effective and why they are. The outcomes of the interviews and workshop sessions revealed that participants were not merely interested in gaining knowledge on what is the most effective policy pathway, but also desire to increase understanding on the complexity of meat consumption behaviour mechanisms and differences throughout the population. The policy relevance, and so the potential use of ABM in decision-making processes of governmental institutions, was increased by integrating socio-cultural factors in the ABM, albeit simplified, and by improvement of the model's theoretical and empirical basis. The COM-B framework was used as a guiding framework for integration of these newly formalised concepts with the ABM provided by RIVM.

The second part of the research question can be answered with the outcomes of the experimental studies. The ABM simulations resulted in an average daily meat consumption of 100 grams. This result showed to be in line with actual meat consumption of Dutch young adults. Of the interventions simulated, price interventions showed to be most effective. Increasing the vegetarian representation in the choice also effectively reduced the overall meat consumption, which was not the case for the social marketing campaign targeted at the injunctive norm that eating vegetarian is normal.

The participants were satisfied about the model performance and adjustments made. Participants commented that this study exceeded initial expectations, indicating that the PM process was performed successfully. Results of this study suggest that participatory modelling and the use of agent-based modelling techniques can be of added value for the development of an integral approach to set the transition towards reduced meat consumption in motion. This research succeeded in performing a collaborative study that benefitted both the modeller and involved participants. While this model provides a simplified version of reality, it can support the understanding and development of fair and effective policies required for this transition.

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A. PARTICIPATORY PROCESS

A.1 PARTICIPATORY MODELLING PROCESS DESIGN

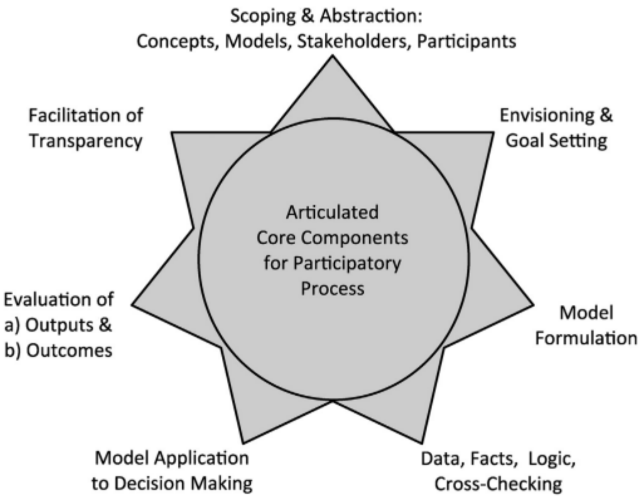


Figure 19. Components of the Participatory Modelling process (Voinov et al., 2016)

Table 2
Tools and methods of Participatory Modelling. See Table 1 for some application examples.

Main components	Tools and methods		References (with focus on papers that describe particular tools)
Scoping, envisioning, etc.	S1	Meetings, workshops, brainstorming, and group facilitation	Almost all
	S2	SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis	Ritzema et al., 2010
	S3	Participatory scenario development	Barnaud et al., 2013; Cobb and Thompson, 2012; Hossard et al., 2013; Labiosa et al., 2013
	S4	Imagineering, visioning and pathways	Barnaud et al., 2013 (integrative negotiation)
	S5	Visualization and graphics, 'rich pictures'	Barnaud et al., 2013 (critique maps)
	S6	Gaming	Fraternali et al., 2012
	S7	Mind mapping	Elsawah et al., 2015
Data	D1	Surveys, interviews, questionnaires	Many
	D2	Mobile applications	Fraternali et al., 2012
	D3	Wikis	Fritz et al., 2012
	D4	Role playing games	Barreteau et al., 2003
	D5	Tools for eliciting expert knowledge	Bastin et al., 2013; Fisher et al., 2012; Morris et al., 2014; Reichert et al., 2013; Scholten et al., 2013
Model development	M1	Agent-based modelling (ABM)	Barnaud et al., 2013; Murray-Rust et al., 2013
	M2	System dynamics	Leys and Vanclay, 2011; Sahin et al., 2014; Wieland and Gutzler, 2014
	M3	Bayesian network models	Catenacci and Giupponi, 2013
	M4	Scenario building	Cobb and Thompson, 2012; Murray-Rust et al., 2013
	M5	Human computation	Fraternali et al., 2012
	M6	Integrated modelling	Giupponi et al., 2013; Knapp et al., 2011
	M7	Conceptual and cognitive modelling (fuzzy cognitive mapping, signed di-graphs, etc.)	Elsawah et al., 2015; Gray et al., 2013; Halbrendt et al., 2014; Nyaki et al., 2014; Dambacher et al., 2009; Fulton et al., 2015.
	M8	Optimization	Kuhn et al., 2014; Gaddis et al., 2010.
	M9	Fuzzy modelling	Wieland and Gutzler. 2014
Presentation	P1	Interactive mapping	Arciniegas et al., 2013
	P2	Visualization, animations, visual analytics	Bizikova et al., 2011; Chen et al., 2013; Nino-Ruiz et al., 2013; Reichert et al., 2013
	P3	Web applications	Bastin et al., 2013; Nino-Ruiz et al., 2013
	P4	Games, role-playing	D'Aquino and Bah, 2013a, 2013b; Fraternali et al., 2012
	P5	Sensitivity analysis	Castelletti et al., 2012; Chen et al., 2013
	P6	Uncertainty analysis	Groen et al., 2014; Uusitalo et al., 2015

Figure 20. Overview of tools and methods participatory modelling (Voinov et al., 2016)

A.2 CAPABILITIES AND REQUIREMENTS VARIOUS PM METHODS

	Qualitative modeling methods					Semi-quantitative modeling methods				Quantitative modeling methods (aggregated)				Quantitative modeling methods (detailed)			
	Rich Pictures	Cultural Consensus	Role Playing Games	Causal Loop Diagrams and Cognitive/Concept Mapping	Decision Tree Analysis, Decision Focused Structuring	Social Network Analysis	Fuzzy Cognitive Mapping	Scenario Building	Analytic Hierarchy Process	Systems Dynamics	Empirical Modeling	Geographic Information Systems	Bayesian Modeling	Cost Benefit Analysis	Agent Based Modeling	Cellular Automata	Integrated Modeling
Spatial representation	M	L	L	L	L	L	L	L/M	L	L	L	H	L	L	H	H	H
Temporal representation (dynamic)	L	M	M	L	L/M	M	L	H	L	H	M	L	L	L/M	H	H	H
Qualitative forecast	L/M	M	M	L/M	L/M	M	M	H	L	H	M	L	M	L/M	H	H	H
Quantitative forecast	L	L	L	L	M	M	L	M	L	H	M	L	M	M	H	H	H
Ease of communicating results	H	H	M	M/H	M	H	M/H	H	M	M	M/H	H	L/M	M/H	M	L/M	L
Transparency	H	M	M/H	H	M/H	M/H	M/H	M/H	M	M	L	M	L/M	M/H	L	M	L
Ease of modification	H	M	H	H	H	L	H	H	L	M	L	H	M	M/H	M	M	L
Feedback loops supported	L	L	H	H	L	M	H	M	L	H	M	L	L	L	H	H	H
Handling uncertainty	L	M	M	L	L	L	L	H	L	H	H	L	M	L	H	M	M

Figure 21. Capabilities of various PM methods, rated from Low (L) to Medium (M) to High (H). Assumptions made for creating the overview: each method is considered in the context of the same problem with approximately same level of detail and complexity (Voinov et al., 2018)

	Qualitative modeling methods					Semi-quantitative modeling methods				Quantitative modeling methods (aggregated)				Quantitative modeling methods (detailed)			
	Rich Pictures	Cultural Consensus	Role Playing Games	Causal Loop Diagrams and Cognitive/Concept Mapping	Decision Tree Analysis, Decision Focused Structuring	Social Network Analysis	Fuzzy Cognitive Mapping	Scenario Building	Analytic Hierarchy Process	Systems Dynamics	Empirical Modeling	Geographic Information Systems	Bayesian Modeling	Cost Benefit Analysis	Agent Based Modeling	Cellular Automata	Integrated Modeling
Time and cost	L	M	L/M	L	M	M	L	L/M	M/H	M/H	M	M	M/H	M	M/H	M/H	H
Data (Empirical)	L	M	L	L	M	H	L	L/M	L	L/M	H	H	M	M/H	L/M	M	H
Systems Knowledge (Conceptual)	L/M	M	L/M	L/M	M	M	M	M/H	M/H	H	L	L/M	M	L/M	H	H	H
Expertise of modelers	L	M	M	L	M	M	M	M	M	H	M/H	M	M/H	L/M	H	H	H
Methodological expertise of stakeholders	L	L	L	L	M	L	L/ M	L/M	L	M	L/M	L	M	L	L/M	M	M
Computer resources	L	M	L	L	L	M/H	M	L/M	M	H	M/H	H	M	M	H	H	H

Figure 22. Requirements for implementing various PM methods, rated from Low (L) to Medium (M) to High (H). Assumptions made for creating the overview: each method is considered in the context of the same problem with approximately same level of detail and complexity (Voinov et al., 2018)

A.3 ANONYMISED SUMMARY EXPLORATORY INTERVIEWS

Interview 1

Interviewee: senior policy advisor on nutrition

The governmental institution where the interviewee is employed, focuses on healthy nutrition for Dutch consumers. The 'wheel of five' is leading in their work, of which the protein transition is an element. In terms of health, the reduction of the consumption of red and processed meat is most urgent. As a reduction of meat consumption supports health benefits, the interests are parallel to the interests of institutions where the main focus lies on sustainable agriculture and nature.

The protein transition states that the current ratio of plant-based protein to animal-based protein of 40/60 should be shifted to 60/40. There are a few health issues that need to be taken into consideration when talking about meat consumption reduction. Uncertainties that the institution deals with are: "Is a 60/40 protein ratio a good idea for all population groups, including the weak, elderly and sick?", "What are the effects of the dietary shifting on the micronutrient intake, e.g. iron?" It is clear that a 50/50 ratio is a good idea, but the 60/40 ratio still comes with some uncertainties and lacks of insights in terms of health effects. More research and knowledge is desired on this part of the transition.

It is important to gain public support. The main challenge of policymakers in this transition is on how to gain support and cooperation from all different types of population groups. The letter on Dutch food policy from the Minister Henk Staghouwer to the parliament resulted in commotion and both public and political resistance. Reactions showed that people feel threatened and are afraid that they will lose their ability to afford the products that compose their dietary preferences. Some people cannot afford to worry about the climate. It is crucial that possible interventions come with this public support. It is challenging to receive widely public support when implementing collective measures as meat pricing or a prohibition of selling 'kiloknallers'. There is expected to be more public support when considering measures as subsidies on fruits and vegetables.

Both public and political support should be achieved which is dependent on the quality and price of meat product alternatives. Alternatives should be better, not only more plant-based. The nutritional value of the entire product is important, as it can contain relatively new products that are then consumed in high quantities. Allergy information etc. should be named on the products. Processed meat substitutes are indicated to contain a lot of salt. The alternatives to eating meat should be safe and approved before put on the market and before being promoted.

The focus is mainly on the Dutch consumer. The focus is not only on education and information provision, but also on what is offered in the food environment. The institution needs cooperation and support from the parties that provide food to the consumers. With producers it is different, they can see market opportunities in a transition. Once there is enough support both on the public and political plane, the question is how to realise the transition. Questions are: "What is the role of both the social and physical environment?" and "How to deal with cultural factors and food routines?". When we do not take into account the cultural elements, the measures are expected to be less effective. When we apply fiscal measures, communication helps.

Dutch governmental institutions take into account the regulation and governance on the European level. EU regulation studies the food safety of e.g. insect consumption. The Farm to Fork (F2F) strategy is in line with the interests of Dutch governmental institutions. The F2F proposes an EU framework legislation for sustainable food systems. It would be helpful to have established and transparent guidelines on logo's and ecological information on food products that can either help the consumer to recognise good products or that can support the improvement of products in order to receive the logo. The many different actors and stakes are different throughout EU as there are many animal-based products with high emotional and cultural value. The EU Corporate Sustainability Reporting Directive and the collective agricultural policy play a role.

When looking at the use of simulation models in this type of transition, it is important that these are not black boxes. It should be transparent what goes in and what comes out. For this, clear visualisation helps. It is very crucial that it can be explained properly what happens in these models as certain parties or stakeholders can experience disadvantages due to its outcomes. The choices and assumptions that are made have to be justified and communicated.

A good communication between policy and science definitely helps. Involvement of policymakers can be important but research should not become biased by policy interests and opinions, it must stay independent. It is important to increase knowledge on culture and the relationship it has with food consumption.

Interview 2

Interviewee: senior policy officer on agro-economy

The interviewee is interested in what can be achieved with various system analysis techniques. What knowledge can be generated with methods such as fuzzy cognitive mapping and agent-based modelling. The governmental institution is looking into what are the future possibilities on the internalisation of external costs (covering the environment, health, animal welfare, farmer income) of meat products. Ideally you would use a tax to add the price where these external costs arise. This is mainly on the production, but also consumption side. The goal of the tax is to reduce meat consumption and to realise that the meat products that are still consumed have as little external costs as possible. The goal is not to apply a tax but to change consumer behaviour. An extensification of agriculture is not a goal.

Questions that arise are: “What is the public and political support?”, “How do we get the system to work on reducing its meat consumption?”, “How to implement various flanking policy measures and what is the effectiveness?”, and “How can a meat tax be processed and recirculated effectively through the entire production and consumption chain, and what does this entail for parties such as supermarkets and restaurants?”.

The focus now is still on the consumer and to change its behaviour. However, 70% of the meat production is for export purposes, and this is not targeted with consumer taxes. How to get the system to change its behaviour is a complex question that should be approached both from a system and design perspective.

The interviewee is curious what research has been performed already. Are there already models built, how do they work and what knowledge can they generate? There is interest in agent-based modelling as this technique can deal with autonomous individuals with non-rational behaviour. However, is it not clear what is the significance of these models and thus for what purposes these can be used. The ABM must reflect reality in order to be able to draw correct conclusions. It would be interesting to compare the ABM outcome data with literature and expert opinions. Other interests are to gain knowledge on the various meat sectors separately. What are the differences for various meat products such as pig, poultry, beef. It is desired to better understand behavioural differences and heterogeneity between various subpopulations. It would be good to study the societal complexity that is always a part of the discussion. Maybe ABM could also be used as a storytelling mechanism to increase understanding of the system. Instead of solely predicting the effectiveness of various interventions through calculations, it is desired to gain understanding of the underlying complexity and mechanisms. Ideally, there would be a modelling technique that is advanced enough to capture complexity, but simple enough for transparent communication.

A.4 WORKSHOP SESSION 1: DIGITAL MIND MAP RESULTS

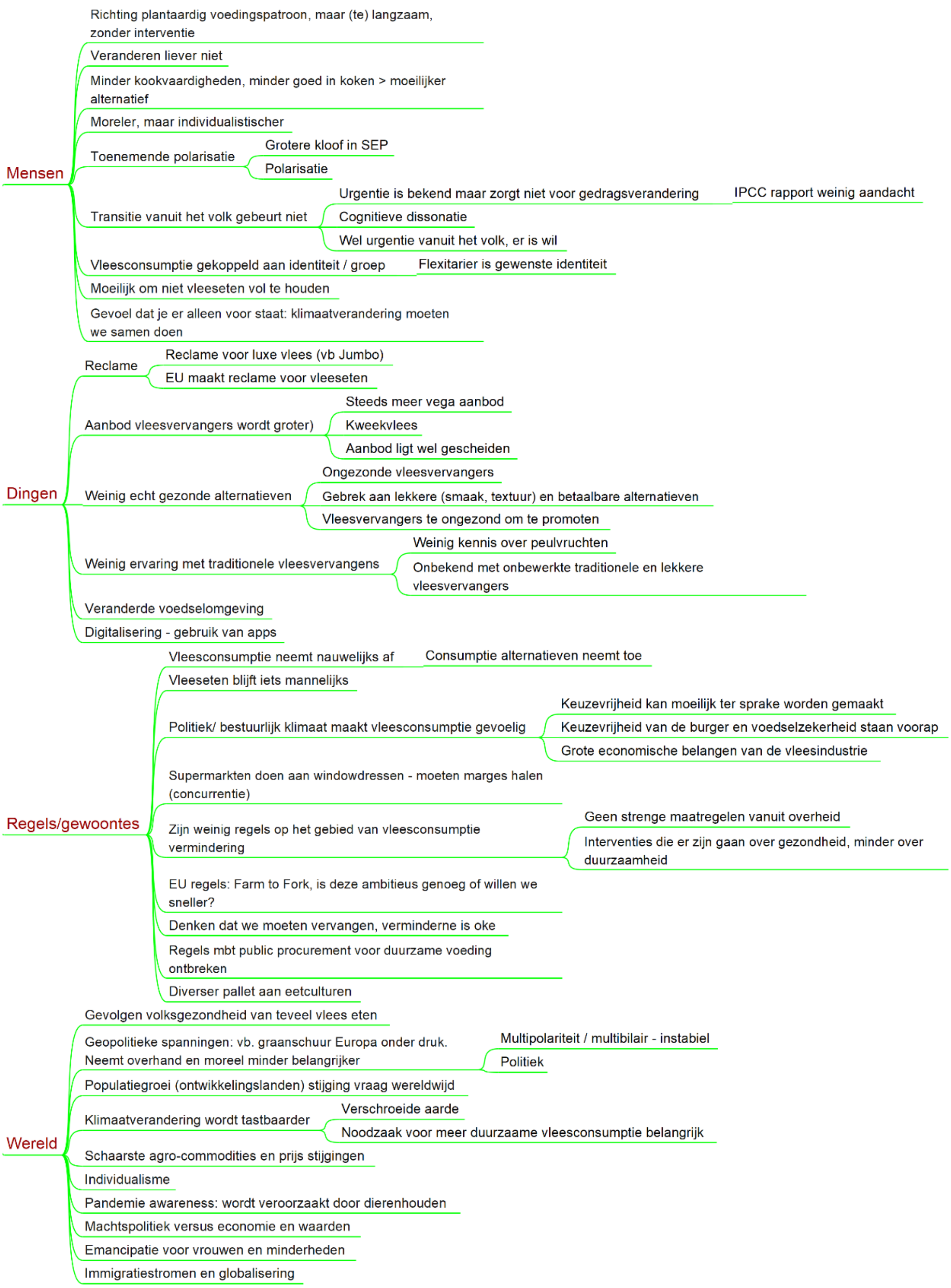


Figure 23. Output brainstorm session round 1: What do we observe related to meat consumption?

Figure 24. Output brainstorm session round 2: What do we worry about?

Figure 25. Output brainstorm session round 3: In what ways can we intervene & What do we want but can we not do, due to lack of knowledge? & round 4: What questions do we want to give priority to? (indicated with exclamation marks; higher number indicates higher priority)

A.5 WORKSHOP SESSION 1: REFLECTION

Table 11. Average scores of reflection form after workshop session 1

	Oneens			-		Eens
	1	2	3	4	5	6
Ik heb een goed gevoel over de sessie					x	
De sessie heeft mij nieuwe inzichten gegeven				x		
De sessie heeft geresulteerd in nuttige resultaten				x		
Ik heb beter zicht gekregen op het probleem				x		
Ik ben het eens met de resultaten van de sessie				x		
Ik heb een beter beeld gekregen van wat agent-based modellen inhouden				x		
Ik geloof dat agent-based modellen kunnen helpen in deze transitie					x	
Het was mogelijk om de vragen te stellen waar ik mee zat					x	
De sessie was efficiënt georganiseerd					x	
Ik zou graag vaker een vergelijkbare sessie bijwonen					x	
Ik heb het gevoel dat mijn aanwezigheid wat heeft bijgedragen aan dit onderzoek					x	
Ik begrijp wat er gaat gebeuren met de uitkomsten van deze sessie				x		
Ik wil graag op de hoogte worden gehouden van de voortgang van het onderzoek						x

B. EMPIRICAL AND THEORETICAL GROUNDING

B.1 OVERVIEW OF INTERVENTIONS AND POLICIES AS DEFINED BY THE COM-B FRAMEWORK

Table 1 Definitions of interventions and policies

Interventions	Definition	Examples
Education	Increasing knowledge or understanding	Providing information to promote healthy eating
Persuasion	Using communication to induce positive or negative feelings or stimulate action	Using imagery to motivate increases in physical activity
Incentivisation	Creating expectation of reward	Using prize draws to induce attempts to stop smoking
Coercion	Creating expectation of punishment or cost	Raising the financial cost to reduce excessive alcohol consumption
Training	Imparting skills	Advanced driver training to increase safe driving
Restriction	Using rules to reduce the opportunity to engage in the target behaviour (or to increase the target behaviour by reducing the opportunity to engage in competing behaviours)	Prohibiting sales of solvents to people under 18 to reduce use for intoxication
Environmental restructuring	Changing the physical or social context	Providing on-screen prompts for GPs to ask about smoking behaviour
Modelling	Providing an example for people to aspire to or imitate	Using TV drama scenes involving safe-sex practices to increase condom use
Enablement	Increasing means/reducing barriers to increase capability or opportunity[1]	Behavioural support for smoking cessation, medication for cognitive deficits, surgery to reduce obesity, prostheses to promote physical activity
Policies		
Communication/ marketing	Using print, electronic, telephonic or broadcast media	Conducting mass media campaigns
Guidelines	Creating documents that recommend or mandate practice. This includes all changes to service provision	Producing and disseminating treatment protocols
Fiscal	Using the tax system to reduce or increase the financial cost	Increasing duty or increasing anti-smuggling activities
Regulation	Establishing rules or principles of behaviour or practice	Establishing voluntary agreements on advertising
Legislation	Making or changing laws	Prohibiting sale or use
Environmental/ social planning	Designing and/or controlling the physical or social environment	Using town planning
Service provision	Delivering a service	Establishing support services in workplaces, communities etc.

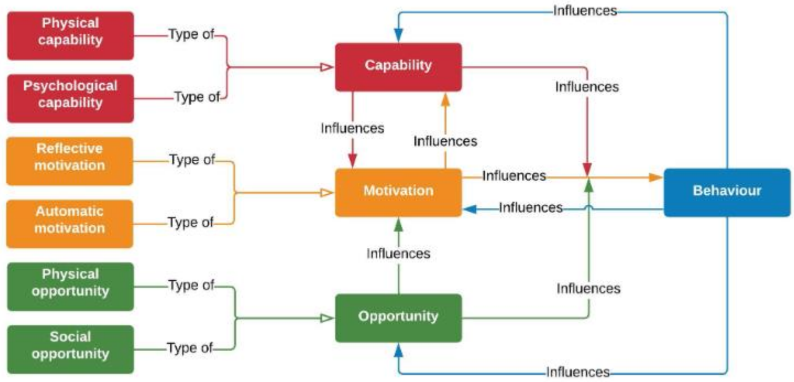
[1]Capability beyond education and training; opportunity beyond environmental restructuring

Figure 26. Categories of interventions and policies as defined by (Michie et al., 2011)

Table 3 Links between policy categories and intervention functions

	Education	Persuasion	Incentivisation	Coercion	Training	Restriction	Environmental restructuring	Modelling	Enablement
Communication/ Marketing	√	√	√	√				√	
Guidelines	√	√	√	√	√	√	√		√
Fiscal			√	√	√		√		√
Regulation	√	√	√	√	√	√	√		√
Legislation	√	√	√	√	√	√	√		√
Environmental/social planning							√		√
Service Provision	√	√	√	√	√			√	√

Figure 27. Links between policy categories and intervention functions as defined by (Michie et al., 2011)



Capability is an attribute of a person that together with opportunity makes a behaviour possible or facilitates it.

Opportunity is an attribute of an environmental system that together with capability makes a behaviour possible or facilitates it.

Motivation is an aggregate of mental processes that energise and direct behaviour

Behaviour is individual human activity that involves co-ordinated contraction of striated muscles controlled by the brain.

Physical capability is capability that involves a person's physique, and musculoskeletal functioning (e.g. balance and dexterity).

Psychological capability is capability that involves a person's mental functioning (e.g. understanding and memory).

Reflective motivation is motivation that involves conscious thought processes (e.g. plans and evaluations).

Automatic motivation is motivation that involves habitual, instinctive, drive-related, and affective processes (e.g. desires and habits).

Physical opportunity is opportunity that involves inanimate parts of the environmental system and time (e.g. financial and mterial resources).

Social opportunity is opportunity that involves other people and organisations (e.g. culture and social norms).

Figure 28. Detailed explanation of behavioural components in the COM-B framework (Michie et al., 2011)

B.2 QUESTIONNAIRE STATEMENTS

Table 3
(Adjusted) means for the statements on capability, opportunity, and motivation to reduce meat consumption for the total population and split by meat consumption groups and gender (n = 1670).[1,2]

	Total population *mean(sd)*	Vegetarian	Meat consumption groups *mean (se)*[3]			
			Low	Middle	High	*P-value*[5]
Psychological capability (Cronbach's Alpha[4] = 0.52)						
1. I know how to replace meat in a dish with plant-based alternatives	3.43 (1.06)	4.57 (0.10)	3.62 (0.07)	3.19 (0.07)	2.83 (0.07)	***
2. I find it hard to come up with a dish without meat	2.72 (1.19)	1.39 (0.11)	2.47 (0.07)	3.01 (0.07)	3.63 (0.08)	***
3. I know which consequences meat consumption has on the environment	3.73 (0.92)	4.42 (0.09)	3.72 (0.06)	3.59 (0.06)	3.30 (0.07)	***
4. I know how much meat I am allowed to eat according to the Wheel of Five	2.88 (1.06)	2.66 (0.11)	3.08 (0.08)	2.94 (0.08)	2.84 (0.08)	***
Physical capability (Cronbach's Alpha = 0.58)						
5. I find it difficult to replace meat in a dish with plant-based alternatives	2.97(1.21)	1.57 (0.12)	2.76 (0.08)	3.10 (0.08)	3.61 (0.09)	***
6. I find it easy to locate plant-based alternatives for meat in the (online) stores	3.54(1.04)	4.31 (0.11)	3.59 (0.08)	3.29 (0.08)	3.17 (0.08)	***
7. I find it easy to locate plant-based alternatives for meat in restaurants	3.15(1.09)	3.50 (0.12)	3.24 (0.09)	3.07 (0.09)	2.83 (0.09)	***
8. I find it easy to locate plant-based alternatives for meat at takeaways and delivery restaurants	2.93(1.07)	3.29 (0.12)	2.97 (0.09)	2.80 (0.09)	2.76 (0.09)	***
9. I find it easy to prepare a meal with a smaller portion of meat than I am used to	3.58 (0.98)	3.93 (0.16)	3.74 (0.07)	3.65 (0.07)	3.17 (0.08)	***
Physical opportunity (Cronbach's Alpha = 0.43)						
10. It takes less time to prepare a meal without meat than to prepare a meal with meat	2.95 (1.00)	3.60 (0.11)	3.35 (0.07)	2.90 (0.07)	2.84 (0.08)	***
11. It takes too much time to prepare a meal with a plant-based alternative of meat	2.52 (1.07)	1.73 (0.11)	2.62 (0.08)	2.85 (0.08)	2.86 (0.08)	***
12. The (online) stores offer satisfying plant-based alternatives for meat	3.71 (0.88)	3.91 (0.10)	3.58 (0.07)	3.50 (0.07)	3.38 (0.07)	***
13. Restaurants offer satisfying plant-based alternatives for meat	3.27 (0.99)	3.26 (0.11)	3.21 (0.08)	3.21 (0.08)	2.99 (0.08)	**
14. Takeaways and delivery restaurants offer satisfying plant-based alternatives for meat	3.05 (0.98)	3.11 (0.11)	3.00 (0.08)	2.92 (0.08)	2.78 (0.09)	**
15. The canteen at work or school offers satisfying plant-based alternatives for meat	2.93 (1.14)	2.75 (0.15)	2.84 (0.10)	2.91 (0.10)	2.80 (0.11)	N.S.
16. Plant-based alternatives of meat are more expensive than meat	3.61 (0.98)	3.32 (0.11)	3.62 (0.08)	3.87 (0.08)	3.85 (0.08)	***

Figure 29. Overview of questionnaire statements used as input data ABM (van den Berg et al., 2022): part 1

Social opportunity (Cronbach's Alpha = 0.76)						
17. My friends find it important to eat meat	3.32 (1.01)	3.03 (0.11)	3.24 (0.07)	3.56 (0.07)	3.90 (0.08)	***
18. My household finds it important to eat meat	3.39 (1.07)	2.80 (0.13)	3.15 (0.08)	3.61 (0.08)	3.90 (0.09)	***
19. My family finds it important to eat meat	3.46 (1.00)	2.85 (0.11)	3.30 (0.07)	3.57 (0.07)	4.03 (0.08)	***
20. My colleagues/ fellow students find it important to eat meat	3.24 (0.97)	3.25 (0.11)	3.33 (0.08)	3.40 (0.08)	3.71 (0.08)	***
21. Eating meat is part of my culture	3.31 (1.18)	1.98 (0.11)	3.15 (0.08)	3.62 (0.08)	4.06 (0.08)	***
22. My friends accept people who want to eat less meat	3.87 (0.86)	3.97 (0.09)	3.81 (0.06)	3.63 (0.06)	3.50 (0.07)	***
23. My household takes people who want to eat less meat into account	3.65 (1.02)	4.54 (0.13)	3.92 (0.08)	3.63 (0.08)	3.29 (0.09)	***
24. My colleagues/ fellow students accept people who want to eat less meat	3.86 (0.82)	3.74 (0.09)	3.70 (0.07)	3.66 (0.07)	3.60 (0.07)	N.S.
25. My family takes people who want to eat less meat into account	3.67 (0.96)	4.33 (0.10)	3.85 (0.07)	3.53 (0.07)	3.36 (0.08)	***
26. I can decide for myself whether I eat meat or not	4.31 (0.74)	4.71 (0.08)	4.27 (0.05)	4.20 (0.05)	4.31 (0.06)	***
27. People in my environment eat less and less meat	3.38 (1.02)	3.72 (0.11)	3.55 (0.07)	3.22 (0.07)	2.85 (0.08)	***
Reflective motivation (Cronbach's Alpha = 0.80)						
28. The environment plays an important role in my decision whether to eat meat	3.18 (1.19)	4.35 (0.12)	3.62 (0.08)	3.10 (0.08)	2.51 (0.08)	***
29. Animal welfare plays an important role in my decision whether to eat meat	3.25 (1.18)	4.59 (0.12)	3.67 (0.08)	3.15 (0.08)	2.65 (0.08)	***
30. My health plays an important role in my decision whether to eat meat	3.29 (1.07)	3.71 (0.12)	3.58 (0.08)	3.28 (0.08)	3.30 (0.08)	***
31. My decision whether to eat meat is mainly based on price	2.55 (1.08)	1.48 (0.11)	2.66 (0.08)	2.81 (0.08)	2.61 (0.08)	***
32. My decision whether to eat meat mainly depends on what I enjoy eating	3.71 (1.02)	1.95 (0.10)	3.66 (0.06)	3.98 (0.06)	4.11 (0.07)	***
33. A dish without meat lacks flavour	2.59 (1.22)	1.53 (0.11)	2.48 (0.08)	2.85 (0.08)	3.41 (0.08)	***
34. Eating meat is important to stay healthy	3.25 (1.11)	1.54 (0.10)	3.20 (0.07)	3.52 (0.07)	3.92 (0.07)	***
35. A plant-based alternative of meat is healthier than meat	3.03 (1.03)	4.20 (0.10)	3.34 (0.07)	2.92 (0.07)	2.60 (0.08)	***
36. I like trying vegetarian dishes	3.46 (1.18)	4.63 (0.11)	3.86 (0.07)	3.42 (0.07)	2.62 (0.08)	***
37. A meal without meat is not satisfying [filling]	2.64 (1.23)	1.64 (0.12)	2.59 (0.08)	3.00 (0.08)	3.45 (0.09)	***
38. It is natural to eat meat	3.57 (1.01)	2.05 (0.09)	3.42 (0.06)	3.79 (0.06)	4.23 (0.07)	***
Automatic motivation (Cronbach's Alpha = 0.79)						
39. I enjoy eating meat	4.00 (1.03)	1.69 (0.08)	3.75 (0.06)	4.11 (0.06)	4.44 (0.06)	***
40. I enjoy a meal with meat more than a meal with a plant-based alternative of meat	3.31 (1.26)	1.76 (0.11)	3.08 (0.08)	3.75 (0.07)	4.26 (0.08)	***
41. I enjoy a meal with a small portion of meat as much as a meal with a normal portion of meat	3.50 (1.03)	2.50 (0.13)	3.72 (0.07)	3.62 (0.07)	3.17 (0.08)	***
42. Eating meat is my habit	3.31 (1.19)	1.39 (0.10)	3.12 (0.07)	3.70 (0.07)	4.02 (0.07)	***
43. I thoughtlessly add meat to my meals	3.00 (1.26)	1.41 (0.11)	2.76 (0.08)	3.48 (0.08)	3.91 (0.08)	***
44. When meat is offered to me, I accept it	3.77 (1.09)	1.18 (0.08)	3.53 (0.06)	3.97 (0.06)	4.30 (0.06)	***
45. I feel guilty when eating meat	2.40 (1.21)	4.34 (0.12)	2.72 (0.07)	2.25 (0.07)	1.77 (0.08)	***

Figure 30. Overview of questionnaire statements used as input data ABM (van den Berg et al., 2022): part 2

DLNMID	Deelname ID
tEINDdag	Eindtijd deelname in dagen
Q1_1	Q1_1 Wat zijn volgens jou plantaardige alternatieven voor vlees? Vegetarische stukjes, balletjes en burgers
Q1_2	Q1_2 Wat zijn volgens jou plantaardige alternatieven voor vlees? Noten en pinda's
Q1_3	Q1_3 Wat zijn volgens jou plantaardige alternatieven voor vlees? Peulvruchten (bijvoorbeeld bruine bonen, kidneybonen, linzen en kikkererwten)
Q1_4	Q1_4 Wat zijn volgens jou plantaardige alternatieven voor vlees? Pitten en zaden
Q1_5	Q1_5 Wat zijn volgens jou plantaardige alternatieven voor vlees? Tofu, tempeh en seitan
Q1_99999996	Q1_99999996 Wat zijn volgens jou plantaardige alternatieven voor vlees? Anders, namelijk:
Q1_99999996t	Q1_99999996t Wat zijn volgens jou plantaardige alternatieven voor vlees? Anders, namelijk:
Q1_99999997	Q1_99999997 Wat zijn volgens jou plantaardige alternatieven voor vlees? Weet niet / geen mening
Q2_1	Q2_1 In hoeverre ben je het eens met: Ik weet hoe ik vlees in een maaltijd kan vervangen door plantaardige alternatieven
Q2_2	Q2_2 In hoeverre ben je het eens met: Ik vind het moeilijk om een maaltijd zonder vlees te bedenken
Q2_3	Q2_3 In hoeverre ben je het eens met: Ik weet welke gevolgen vlees eten heeft voor het milieu
Q2_4	Q2_4 In hoeverre ben je het eens met: Ik weet hoeveel vlees ik zou mogen eten volgens de Schijf van Vijf
Q3_1	Q3_1 In hoeverre ben je het eens met: Ik vind het moeilijk om vlees in een maaltijd te vervangen door plantaardige alternatieven
Q3_2	Q3_2 In hoeverre ben je het eens met: Ik vind het makkelijk om plantaardige alternatieven voor vlees te vinden in de (online) winkels
Q3_3	Q3_3 In hoeverre ben je het eens met: Ik vind het makkelijk om plantaardige alternatieven voor vlees te vinden in restaurants
Q3_4	Q3_4 In hoeverre ben je het eens met: Ik vind het makkelijk om plantaardige alternatieven voor vlees te vinden bij afhaalrestaurants of bezorgrestaurants
Q3_5	Q3_5 In hoeverre ben je het eens met: Ik vind het makkelijk om een maaltijd te bereiden met een kleinere portie vlees dan ik gewend ben
Q4_1	Q4_1 In hoeverre ben je het eens met: Het kost minder tijd om een maaltijd zonder vlees te bereiden dan om een maaltijd met vlees te bereiden
Q4_2	Q4_2 In hoeverre ben je het eens met: Het kost teveel tijd om een maaltijd te bereiden met een plantaardig alternatief voor vlees
Q4_3	Q4_3 In hoeverre ben je het eens met: De (online) winkels bieden goede plantaardige alternatieven voor vlees
Q4_4	Q4_4 In hoeverre ben je het eens met: Afhaalrestaurants en bezorgrestaurants bieden goede plantaardige alternatieven voor vlees
Q4_5	Q4_5 In hoeverre ben je het eens met: Restaurants bieden goede plantaardige alternatieven voor vlees
Q4_6	Q4_6 In hoeverre ben je het eens met: Plantaardige alternatieven voor vlees zijn duurder dan vlees
Q4_7	Q4_7 In hoeverre ben je het eens met: De kantine op werk of school biedt goede plantaardige alternatieven voor vlees
Q5_1	Q5_1 In hoeverre ben je het eens met: Mijn vrienden vinden het belangrijk om vlees te eten
Q5_2	Q5_2 In hoeverre ben je het eens met: Mijn huisgenoten vinden het belangrijk om vlees te eten
Q5_3	Q5_3 In hoeverre ben je het eens met: Mijn familie vindt het belangrijk om vlees te eten
Q5_4	Q5_4 In hoeverre ben je het eens met: Mijn collega's/mede-studenten vinden het belangrijk om vlees te eten
Q5_5	Q5_5 In hoeverre ben je het eens met: Vlees eten is een onderdeel van mijn cultuur
Q5_6	Q5_6 In hoeverre ben je het eens met: Mijn vrienden hebben begrip voor mensen die minder vlees willen eten
Q5_7	Q5_7 In hoeverre ben je het eens met: Mijn huisgenoten houden rekening met mensen die minder vlees willen eten
Q5_8	Q5_8 In hoeverre ben je het eens met: Mijn collega's/mede-studenten hebben begrip voor mensen die minder vlees willen eten
Q5_9	Q5_9 In hoeverre ben je het eens met: Mijn familie houdt rekening met mensen die minder vlees willen eten
Q5_10	Q5_10 In hoeverre ben je het eens met: Ik kan zelf bepalen of ik vlees eet
Q5_11	Q5_11 In hoeverre ben je het eens met: Mensen in mijn omgeving eten steeds minder vlees
Q6_1	Q6_1 In hoeverre ben je het eens met: Het milieu speelt een belangrijke rol bij mijn keuze of ik vlees eet
Q6_2	Q6_2 In hoeverre ben je het eens met: Dierenwelzijn speelt een belangrijke rol bij mijn keuze of ik vlees eet
Q6_3	Q6_3 In hoeverre ben je het eens met: Mijn gezondheid speelt een belangrijke rol bij mijn keuze of ik vlees eet
Q6_4	Q6_4 In hoeverre ben je het eens met: Mijn keuze om wel of geen vlees te eten is voornamelijk gebaseerd op prijs
Q6_5	Q6_5 In hoeverre ben je het eens met: Mijn keuze of ik vlees eet hangt voornamelijk af van wat ik lekker vind
Q6_6	Q6_6 In hoeverre ben je het eens met: Een maaltijd zonder vlees heeft weinig smaak
Q6_7	Q6_7 In hoeverre ben je het eens met: Vlees eten is belangrijk om gezond te blijven
Q6_8	Q6_8 In hoeverre ben je het eens met: Een plantaardig alternatief voor vlees is gezonder dan vlees
Q6_9	Q6_9 In hoeverre ben je het eens met: Ik vind het leuk om vegetarische gerechten te proberen
Q6_10	Q6_10 In hoeverre ben je het eens met: Een maaltijd zonder vlees vult onvoldoende
Q6_11	Q6_11 In hoeverre ben je het eens met: Het is natuurlijk om vlees te eten
Q7_1	Q7_1 In hoeverre ben je het eens met: Ik vind het lekker om vlees te eten
Q7_2	Q7_2 In hoeverre ben je het eens met: Ik vind een maaltijd met vlees lekkerder dan een maaltijd met een plantaardig alternatief voor vlees
Q7_3	Q7_3 In hoeverre ben je het eens met: Ik vind een maaltijd met een kleine portie vlees even lekker als een maaltijd met een normale portie vlees
Q7_4	Q7_4 In hoeverre ben je het eens met: Ik eet vlees uit gewoonte
Q7_5	Q7_5 In hoeverre ben je het eens met: Ik voeg vlees aan mijn eten toe zonder hierover na te denken
Q7_6	Q7_6 In hoeverre ben je het eens met: Als ik vlees krijg aangeboden, dan eet ik dat
Q7_7	Q7_7 In hoeverre ben je het eens met: Ik voel me schuldig als ik vlees eet
Q8	Q8 Hoeveel dagen per week eet je gemiddeld vlees bij de warme maaltijd?
Q9	Q9 Hoeveel dagen per week eet je gemiddeld vlees of vleeswaren buiten de warme maaltijd om?

Figure 31. Metadata description of questionnaire statements used as input data ABM (van den Berg et al., 2022)

B.3 CORRELATION ANALYSIS ON QUESTIONNAIRE DATA

Index	Q8	Q9
Q1_1	-0.200651	-0.16024
Q1_2	-0.175358	-0.117397
Q1_3	-0.182792	-0.151642
Q1_4	-0.170083	-0.109222
Q1_5	-0.217839	-0.173882
Q1_99999996	0.0376638	0.0242287
Q1_99999997	0.118111	0.0679506
Q2_1	-0.477499	-0.367998
Q2_2	0.5471	0.399426
Q2_3	-0.326033	-0.263104
Q2_4	-0.024755	0.0241324
Q3_1	0.464769	0.388147
Q3_2	-0.324675	-0.253375
Q3_3	-0.155098	-0.0811556
Q3_4	-0.131175	-0.0547826
Q3_5	-0.24597	-0.200836
Q4_1	-0.237158	-0.10521
Q4_2	0.335557	0.335064
Q4_3	-0.173309	-0.155967
Q4_4	-0.0586183	-0.00280037
Q4_5	-0.0431002	0.01725
Q4_6	0.223538	0.163622
Q4_7	0.033242	0.0763848

Index	Q8	Q9
Q5_1	0.338525	0.243661
Q5_2	0.355212	0.185807
Q5_3	0.386589	0.244719
Q5_4	0.201104	0.144341
Q5_5	0.459842	0.350801
Q5_6	-0.212132	-0.193004
Q5_7	-0.332457	-0.231529
Q5_8	-0.0988916	-0.11356
Q5_9	-0.277538	-0.208068
Q5_10	-0.119113	-0.0718193
Q5_11	-0.367223	-0.248465
Q6_1	-0.497388	-0.35708
Q6_2	-0.479072	-0.356359
Q6_3	-0.119851	-0.0704423
Q6_4	0.163035	0.21326
Q6_5	0.400524	0.31436
Q6_6	0.49531	0.406132
Q6_7	0.479328	0.387015
Q6_8	-0.385135	-0.260438
Q6_9	-0.540934	-0.396379
Q6_10	0.470044	0.399856
Q6_11	0.510589	0.368311
Q7_1	0.519476	0.375146

Index	Q8	Q9
Q7_1	0.519476	0.375146
Q7_2	0.577984	0.426427
Q7_3	-0.137123	-0.100528
Q7_4	0.509497	0.375612
Q7_5	0.54065	0.422945
Q7_6	0.529729	0.400402
Q7_7	-0.474358	-0.31393
Q8	1	0.545912
Q9	0.545912	1

Figure 32. Correlation matrix outcomes. Q8 = the frequency of meat consumption with hot meal, Q9 = the frequency of meat consumption besides hot meal.

B.4 MULTI-LINEAR REGRESSION ANALYSIS ON QUESTIONNAIRE DATA

```
                            OLS Regression Results
==============================================================================
Dep. Variable:                     Q8   R-squared:                       0.272
Model:                            OLS   Adj. R-squared:                  0.257
Method:                 Least Squares   F-statistic:                     17.64
Date:                Mon, 18 Jul 2022   Prob (F-statistic):           7.00e-30
Time:                        21:55:41   Log-Likelihood:                -1044.0
No. Observations:                 531   AIC:                             2112.
Df Residuals:                     519   BIC:                             2163.
Df Model:                          11
Covariance Type:            nonrobust
==============================================================================
                 coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------
const          5.7337      0.750      7.640      0.000       4.259       7.208
Q5_1           0.1363      0.096      1.423      0.155      -0.052       0.325
Q5_2           0.2006      0.095      2.110      0.035       0.014       0.387
Q5_3          -0.0901      0.106     -0.852      0.395      -0.298       0.118
Q5_4           0.0225      0.094      0.239      0.811      -0.163       0.208
Q5_5           0.5577      0.085      6.551      0.000       0.390       0.725
Q5_6          -0.0520      0.105     -0.494      0.622      -0.259       0.155
Q5_7          -0.2617      0.099     -2.632      0.009      -0.457      -0.066
Q5_8           0.2390      0.102      2.347      0.019       0.039       0.439
Q5_9          -0.1104      0.101     -1.093      0.275      -0.309       0.088
Q5_10         -0.1998      0.111     -1.799      0.073      -0.418       0.018
Q5_11         -0.3436      0.090     -3.800      0.000      -0.521      -0.166
==============================================================================
Omnibus:                       14.551   Durbin-Watson:                   1.066
Prob(Omnibus):                  0.001   Jarque-Bera (JB):               15.124
Skew:                          -0.412   Prob(JB):                     0.000520
Kurtosis:                       3.075   Cond. No.                         120.
==============================================================================
```

Figure 33. Multivariate regression outcomes for the category social opportunity

```
                            OLS Regression Results
==============================================================================
Dep. Variable:                     Q8   R-squared:                       0.263
Model:                            OLS   Adj. R-squared:                  0.250
Method:                 Least Squares   F-statistic:                     20.65
Date:                Mon, 18 Jul 2022   Prob (F-statistic):           7.50e-30
Time:                        22:05:45   Log-Likelihood:                -1047.3
No. Observations:                 531   AIC:                             2115.
Df Residuals:                     521   BIC:                             2157.
Df Model:                           9
Covariance Type:            nonrobust
==============================================================================
                 coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------
const          5.2119      0.656      7.950      0.000       3.924       6.500
Q2_1          -0.1960      0.098     -1.994      0.047      -0.389      -0.003
Q2_2           0.5488      0.083      6.624      0.000       0.386       0.712
Q2_3          -0.0590      0.103     -0.572      0.568      -0.262       0.144
Q2_4          -0.0422      0.079     -0.534      0.594      -0.198       0.113
Q3_1           0.2626      0.083      3.148      0.002       0.099       0.426
Q3_2          -0.1881      0.092     -2.050      0.041      -0.368      -0.008
Q3_3          -0.1422      0.089     -1.600      0.110      -0.317       0.032
Q3_4           0.0137      0.091      0.150      0.881      -0.165       0.193
Q3_5           0.1234      0.090      1.367      0.172      -0.054       0.301
==============================================================================
Omnibus:                        4.303   Durbin-Watson:                   1.052
Prob(Omnibus):                  0.116   Jarque-Bera (JB):                3.892
Skew:                          -0.145   Prob(JB):                        0.143
Kurtosis:                       2.697   Cond. No.                         87.5
==============================================================================
```

Figure 34. Multivariate regression outcomes for the categories physical and psychological capability

```
                            OLS Regression Results
==============================================================================
Dep. Variable:                     Q8   R-squared:                       0.360
Model:                            OLS   Adj. R-squared:                  0.349
Method:                 Least Squares   F-statistic:                     32.63
Date:                Mon, 18 Jul 2022   Prob (F-statistic):           1.92e-45
Time:                        22:11:08   Log-Likelihood:                -1009.6
No. Observations:                 531   AIC:                             2039.
Df Residuals:                     521   BIC:                             2082.
Df Model:                           9
Covariance Type:            nonrobust
==============================================================================
                 coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------
const          5.9412      0.614      9.677      0.000       4.735       7.147
Q6_1          -0.3166      0.085     -3.744      0.000      -0.483      -0.150
Q6_2          -0.1644      0.080     -2.051      0.041      -0.322      -0.007
Q6_3          -0.0552      0.077     -0.718      0.473      -0.206       0.096
Q6_4           0.0701      0.074      0.944      0.345      -0.076       0.216
Q6_5           0.4999      0.084      5.979      0.000       0.336       0.664
Q6_6           0.1405      0.077      1.825      0.069      -0.011       0.292
Q6_7           0.2451      0.085      2.887      0.004       0.078       0.412
Q6_8          -0.1903      0.083     -2.285      0.023      -0.354      -0.027
Q6_9          -0.2448      0.087     -2.801      0.005      -0.416      -0.073
==============================================================================
Omnibus:                        1.869   Durbin-Watson:                   1.109
Prob(Omnibus):                  0.393   Jarque-Bera (JB):                1.864
Skew:                          -0.094   Prob(JB):                        0.394
Kurtosis:                       2.778   Cond. No.                         87.0
==============================================================================
```

Figure 35. Multivariate regression outcomes for the category reflective motivation

```
                            OLS Regression Results
==============================================================================
Dep. Variable:                     Q8   R-squared:                       0.457
Model:                            OLS   Adj. R-squared:                  0.450
Method:                 Least Squares   F-statistic:                     62.90
Date:                Mon, 18 Jul 2022   Prob (F-statistic):           2.09e-65
Time:                        22:27:36   Log-Likelihood:                -966.15
No. Observations:                 531   AIC:                             1948.
Df Residuals:                     523   BIC:                             1982.
Df Model:                           7
Covariance Type:            nonrobust
==============================================================================
                 coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------
const          1.4169      0.488      2.902      0.004       0.458       2.376
Q7_1           0.2296      0.105      2.177      0.030       0.022       0.437
Q7_2           0.2777      0.078      3.569      0.000       0.125       0.431
Q7_3          -0.0371      0.070     -0.531      0.596      -0.175       0.100
Q7_4           0.2772      0.079      3.529      0.000       0.123       0.431
Q7_5           0.1726      0.074      2.325      0.020       0.027       0.319
Q7_6           0.5158      0.094      5.495      0.000       0.331       0.700
Q7_7          -0.2595      0.065     -4.022      0.000      -0.386      -0.133
==============================================================================
Omnibus:                        1.819   Durbin-Watson:                   1.175
Prob(Omnibus):                  0.403   Jarque-Bera (JB):                1.875
Skew:                          -0.139   Prob(JB):                        0.392
Kurtosis:                       2.915   Cond. No.                         69.2
==============================================================================
```

Figure 36. Multivariate regression outcomes for the category automatic motivation

C. MODEL CONCEPTUALISATION AND FORMALISATION

C.1 INPUT DATA

The data used as model input was adopted from the agent-based model that was provided by RIVM (Groot et al., 2021). The data is categorised into meal data, a weekly eating schedule, and information for eating network generation.

Table 12. Meal data for the different meal dispensers (adopted from RIVM preliminary model)

Type of dish or metric	Meat per meal (g)	Price per meal (€)	Fresh fruit/ vegetables (g)	Required level knowledge & skills
Supermarket				
Breakfast meat meal				
Average	23.3	1.4	39.5	0.0
Stdev	17.9	0.7	50.4	0.0
Breakfast vegetarian meal				
Average	0.0	1.1	19.8	0.0
Stdev	0.0	0.4	25.8	0.0
Lunch meat meal				
Average	31.5	2.0	43.5	0.0
Stdev	16.6	0.6	35.6	0.0
Lunch vegetarian meal				
Average	0.0	1.0	27.0	0.0
Stdev	0.0	0.4	35.0	0.0
Dinner meat meal				
Average	95.0	2.6	100.0	0.0
Stdev	49.1	0.9	64.5	0.0
Dinner vegetarian meal				
Average	0.0	2.1	132.5	1.1
Stdev	0.0	0.6	107.1	0.9
Take-away				
Breakfast meat meal				
Average	40	5.9	39.5	0.0
Stdev	10	1.0	50.4	0.0
Breakfast vegetarian meal				
Average	0.0	5.5	19.8	0.0
Stdev	0.0	1.0	25.8	0.0
Lunch meat meal				
Average	40	5.9	43.5	0.0
Stdev	10	1.0	35.6	0.0
Lunch vegetarian meal				
Average	0.0	5.5	27.0	0.0
Stdev	0.0	1.0	35.0	0.0
Dinner meat meal				
Average	100	11.5	100.0	0.0
Stdev	20	1.5	64.5	0.0
Dinner vegetarian meal				

Average	0.0	7.5	132.5	0.0
Stdev	0.0	1.5	107.1	0.0
Restaurant				
Breakfast meat meal				
Average	25	10.3	39.5	0.0
Stdev	5.0	1.0	50.4	0.0
Breakfast vegetarian meal				
Average	0.0	6.9	19.8	0.0
Stdev	0.0	1.0	25.8	0.0
Lunch meat meal				
Average	118	9.2	43.5	0.0
Stdev	10	1.0	35.6	0.0
Lunch vegetarian meal				
Average	0.0	10.2	27.0	0.0
Stdev	0.0	1.0	35.0	0.0
Dinner meat meal				
Average	133	18.8	100.0	0.0
Stdev	10	2	64.5	0.0
Dinner vegetarian meal				
Average	0.0	18.25	132.5	0.0
Stdev	0.0	12	107.1	0.0

Table 13. Weekly eating schedule (adopted from RIVM preliminary ABM)

Meal moment	Chance of eating meal (%)	Chance eat alone (%)	Chance eat with family (%)	Chance eat with friends (%)	Chance eat at work (%)
Breakfast	95	52	45	1	2
Lunch	99	33	32	4	31
Dinner	99	17	79	3	1

Table 14. Information used to create sizes of social eating groups (adopted from RIVM preliminary ABM)

Type of eating network	Average	Stdev
Family	2	1
Friend	5	2
Work	7	3

C.2 OVERVIEW OF ASSUMPTIONS PER SUB-PROCESS

The assumptions per model process were adopted from the ABM provided by RIVM (Groot et al., 2021).

Table 15. Literature review and assumptions for initialisation process

Name of attribute	Source	Conclusion
Frequency of meat consumption	(Fessler, Arguello, Mekdara & Macias, 2003; Harvey, 2001)	Meat consumption correlates negatively with age and women eat less meat than men. This study also found that reasons for not eating meat were based on the importance people attach to ethical and environmental aspects of meat, and that these overlap with factors such as animal cruelty and conservation, factors that strongly influence the ideological reasoning of vegetarians.
Influence of power relations on meal choice	(Furst, Connors, Bisogni, Sobal & Falk, 1996)	People base their food choice on the composition of their social context. Within a household, people have specific roles in nutrition behavior. Furthermore, there are certain people who make more effort to change the behavior of others within their group. These power relationships within the group influence the eating choices that are made within the group. Often in a family there is one person responsible for the food, yet within other types of households, more than one person is jointly responsible. By using weighted relationships between persons, this difference will be indicated, so the opinion of one person will outweigh the opinion of another.
Socio-demographic and personal factors	Assumption	People have a gender, income, age, persuasiveness and network of family, friends and colleagues.
Rating	Assumption	The rating that agents give a meal is a good approximation of the experience that agents have with a meal. Ratings of vegetarian and meat meals can be directly compared.

Table 18. Literature review and assumptions for sub-process 1

Process	Name	Source	Conclusion
1.1	Relation between type of meal and people who eat this meal	(Voedingscentrum, 2019)	Every meal, a certain number of people do not eat this meal. In the model, these people are therefore not included in the scheduling of the eating groups.
1.2	Generate an eating group based on a meal schedule	Assumption based on the interviews with acquaintances	People have a rather stable eating pattern from which they only deviate in a few cases. In the model, this will mean that people have a routine per day of the week and therefore a kind of weekly meal schedule.
1.3	Meal schedule	(Marshall, 2005)	The choice of a particular meal is fixed by routine and traditions and is not very variable. Often this routine is only based on what is normally eaten.
1.3	Meal schedule	(Voedingscentrum, 2019)	A multi-person household with or without children always eats the evening meal 96-97% with the family. 33% of the people eat lunch alone, and 33% of the people eat it with family members. About 52% of people eat breakfast alone and 45% of people have breakfast with their partner / family members. This regularity can be seen especially at dinner. This regularity is captured in the model in the *meal schedule*.

Table 17. Literature review and assumptions for sub-process 2

Process	Name	Source	Conclusion
2.1	Average eating location choices	(Voedingscentrum, 2019)	21% of people eats out once a week or more. 38% of people orders / takes out food once a week or more.
2.1	Average eating location choices	Assumption	It is assumed that of the people who do not eat out once a week, they eat out every three weeks. Further, it is assumed that the people who do not take out food once a week, they do this on average every two weeks.
2	Decision-maker	Assumption	Within an eating group, one person is the decision-maker.
2	Eating locations	Assumption	People can acquire their meal via three ways: doing groceries and cooking, a restaurant or ordering/taking out food.

Table 16. Literature review and assumptions for sub-process 3

Process	Name	Source	Conclusion
3.1	Assumption about generating multiple meals	(Hartmann & Siegrist, 2020)	The available meal options influence the choice of a particular meal. This argues in favour of giving agents a choice in the model between different meal options.
3.1	Meal generation parameters determine meal choice	(Phan & Chambers, 2016)	External factors determine the range of meals offered; the *taste*, quality and *price* of the meals offered determine what a person ultimately chooses. These factors are modelled as properties of a meal; by changing these properties, a different kind of external environment can be modelled.
3.1	Relation between desired meat consumption and boundary conditions of a restaurant or take-out	(Auty, 1992)	The type of food is the most important consideration when choosing a restaurant. So when for a meal it is chosen to eat at a restaurant, the type of food the restaurant offers will determine where an agent is going to eat in the model. This will be shown as the amount of meat meals offered at the restaurant.
3.1	Vegetarian food on offer in a supermarket	Assumption	The number of vegetarian meals that a person gets offered in the supermarket does not depend on the preferences of the person, because the food on offer in a supermarket depends on the food market and a person cannot "shop between" majorly different supermarkets in terms of meat / vegetarian products on offer.

Table 19. Literature review and assumptions for sub-process 4

Process	Name	Source	Conclusion
4.1	Subsetting of meals based on price and knowledge and skills	(Furst et al., 1996)	The resources a person has determine a person's food choice; this can be physical resources (money) and non-physical resources (skills and time). These resources are often the limiting factor that limit which meals are available to an individual. Time and money, in particular, are often weighed against each other. In our model, time is represented as a need for convenience and money as the average price of a meal.
4.2	Relation between nutrition considerations and meal choice	(Jones, 2018; Myung, McCool & Feinstein, 2008)	A survey of mothers found that the type of restaurant the mothers are in determines meal choice; mothers are not so concerned with choosing according to their concerns in a restaurant. For example, they don't pay much attention to the importance of health when they eat out. They choose what they like. In addition, dietary patterns turned out to be a good predictor of what the mothers chose to eat in the restaurant. Another study that looked at which factors factor into the decision-making process of people in a restaurant found that utility maximization, or highest price / return, is the most important factor in the decision, followed by habit. In our model, decision-making is the same for restaurant and supermarket meals. Meals rate themselves according to the agent's preferences. Each agent weighs their concerns and the importance of the amount of meat in the dish individually and bases their choice on this.
4.2	Meal choice	(Connors, Bisogni, Sobal & Devine 2001; Malek & Umberger, 2021; Kamphuis, de Bekker-Grob & van Lenthe, 2015)	We can be brief about the role of values in food choice; values do play a major role in a person's diet, but daily food choice is mainly based on the following five factors: *taste, health, price, time and social relationships*. For this reason, the importance that someone attaches to the environment and animal welfare is of lesser importance than the valuation of price and the amount of meat in the meal; it adds a little bonus to the meal and perhaps makes the difference between two very similar meals.
4.3	Relation between meal choice and changing dietary history	Assumptions and model specification	When an agent has eaten a meal, it is added to his dietary history. This contains a fixed number of days of meals of the agent. His desired amount of meat is not being adjusted; we assume that one meal does not change a person's diet.
4.4	Meal choice	(Connors et al., 2001; Cruwys, Beverland & Hermans, 2015), Interviews.	Others influence what we eat. When a person cooks for others, he tends to take into account the group he is cooking for, even if he has to make different choices than if he were to eat alone. The extent to which vegetarians within a group are taken into account differs per person: some people cook differently when they know that a vegetarian is coming for dinner, while others think it makes more sense if the vegetarian simply leaves out the meat of the dish.
4.4	Homogeneity within eating group at home	Assumption	When an eating group eats at home, there will be homogeneity within the dining group in terms of meal choice. There can be heterogeneity between different eating groups. However, when someone follows a (mostly) vegetarian diet and someone in their eating group cooks a meat dish, there is a large chance that this person will eat the meal without the meat.
4.4	Heterogeneity within eating out-of-home group	Assumption	When an eating group chooses to eat in a restaurant or to pick up food, this will lead to heterogeneity in meal choice within an eating group. The different eating groups are also heterogeneous.

Table 20. Literature review and assumptions for sub-process 5

Process	Name	Source	Conclusion
5.1	Relation between information from group and reflection	(Rothgerber, 2020)	Exposure to information about the negative consequences of meat consumption can cause meat-related cognitive dissonance (CD). However, this is not always the case, as agents also have strategies for not having to experience CD. One of them is wilful ignorance. Wilful ignorance occurs in about 27% of all confrontations with information about meat. A second is do-gooder derogation; this means that when confronted with a vegetarian, a meat eater will have a (extremely) negative image of the vegetarian, so that he does not have to think about why he himself is not a vegetarian. When these strategies don't work and an agent experiences CD due to information exposure, he will either feel like he has to defend his belief that it is okay to eat meat and increase his meat consumption, or he will be more likely to change his behaviour. He can justify his choice to eat meat in several ways, namely by emphasizing the qualities of meat, seeing meat as a necessity and by denying the emotional life of animals. The latter could therefore lower his willingness to change. This paper speculates that the more value an agent places on his meat consumption, the greater the CD and meat consumption enhancing effect of confrontational information will be.
5.2	Relation between reflection and changed willingness to change	Assumptions Based on (Rothgerber, 2020)	As mentioned above, there are a number of possible outcomes of exposure to confrontational information about meat: - the information is ignored. Nothing happens. - the information is accepted. This happens if the agent is receptive to confrontational information about meat; in our model, this is when the agent's willingness to change is high. This slightly increases the willingness of the agent to change. - the information is rejected and counter arguments are given. This happens if the agent eats a lot of meat and has a low willingness to change.
5.2	Relation between willingness to change and intention to eat meatless	(de Boer, Schösler & Aiking, 2017; Graça, 2016)	Intention: an agent's *intention* for the next meal may be to eat vegetarian (negative intent, eating meat on purpose, is not modelled). *Intention* has been shown to be a good predictor of behaviour, especially when the intention aligns with a person's *habits* (behaviour change is difficult). The *intention* is influenced by the above factors, whereby the influence of positive *experiences* and *concerns* must be higher than the reverse *willingness to change*. Thus, a lot of *positive experiences* can outweigh a low *willingness to change* and thus create the *intention* to eat vegetarian the next time. For a change of *intention*, the *experience with vegetarian food* outweighs the *concerns*, because moral interests are less important in daily food choices.
5.3	Relation between experience, willingness to change and internal reflection	(Graça, 2016)	Here we borrow from the Theory of Planned Behaviour. This theory states that values and beliefs, among other things, lead to the intention to change behaviour. Values are presented through the agent's concern about health, environment and animal welfare. Beliefs are represented by experience (if an agent has many positive experiences with vegetarian food, he will have more positive beliefs about vegetarian food) and by willingness to change. Willingness to change, in this sense, is a kind of aggregated variable of all positive beliefs a person has about the properties that meat does have and vegetarian food does not (eg sufficient nutrients, good taste, etc.).
5.4	Relation between internal reflection and changed nutrition considerations	(Dagevos, 2014) Interviews.	Dietary pattern: for a change in an agent's dietary pattern, experience with vegetarian food must be built up; this must be greater than the reverse willingness to change.
5	New dietary pattern	Assumption	After 30 days of performing a new habit, a person actually changes their behaviour. We assume that adhering to a vegetarian diet for 30 days leads to the possibility of changing a person's dietary pattern.

C.3 PROCESSING QUESTIONNAIRE STATEMENTS INTO AGENT VARIABLES

Table 21. Method of processing questionnaire data (van den Berg et al., 2022) into ABM agent variables. Statements could be answered on five-point Likert scales ranging from ‘completely disagree’ to ‘completely agree’. Except for Q8 and Q9, where the frequency of meat consumption could be answered on a 9-point scale ranging from ‘never’ to ‘more than 6 days a week’.

Question	Agent variable	Scale	Rev?	Other responses	Method other responses
Q2_2: I find it hard to come up with a meal without meat	knowledge_and_ skills_to_reduce_ meat	1-5	Yes	None	N.A.
Q3_1: I find it hard to replace meat with plant-based alternatives	knowledge_and_ skills_to_reduce_ meat	1-5	Yes	Don’t know/ No opinion; N.A.	Don’t know/ No opinion get score of 3; N.A. is ignored
Q6_1: To what extent do you agree with: “the environment plays an important role in my choice to eat meat?”	concern_environ ment	1-5	No	Don’t know/ No opinion	Don’t know/ No opinion get score of 3
Q6_2: To what extent do you agree with: “animal welfare plays an important role in my choice to eat meat?”	concern_animal_ welfare	1-5	No	Don’t know/ No opinion	Don’t know/ No opinion get score of 3
Q7_1: I enjoy eating meat	willingness_to_ change	1-5	Yes	Don’t know/ No opinion	Don’t know/ No opinion get score of 3
Q7_2: I think a meal with meat tastes better than a meal with plant-based alternatives	willingness_to_ change	1-5	Yes	Don’t know/ No opinion	Don’t know/ No opinion get score of 3
Q7_4: Eating meat is my habit	willingness_to_ change	1-5	No	Don’t know/ No opinion	Don’t know/ No opinion get score of 3
Q8: How often do you eat meat with your hot meal?	frequency-of-meat-consumption	1-9	No	1 = never, 2 = <once a week, 3-9 form linear scale 1 to >6 days a week	Hard-coded conversion of score 1 to 0 and score 2 to 0.5
Q9: How often do you eat meat apart from your hot meal?	frequency-of-meat-consumption	1-9	No	1 = never, 2 = <once a week, 3-9 form linear scale 1 to >6 days a week	Hard-coded conversion of score 1 to 0 and score 2 to 0.5
Q5_2: To what extent do you agree with: “my household finds it important to eat meat”	perceived_norm_ veg_normal	1-5	Yes	Don’t know/ No opinion	Don’t know/ No opinion get score of 3
Q5_5: To what extent do you agree with: “eating meat is part of my culture”	perceived_norm_ veg_normal	1-5	Yes	Don’t know/ No opinion	Don’t know/ No opinion get score of 3
Q5_10: To what extent do you agree with: “I can decide myself whether I eat meat or not”	perceived_behavi oural_control	1-5	No	Don’t know/ No opinion	Don’t know/ No opinion get score of 3
Q5_11: To what extent do you agree with: “People in my environment eat less and less meat”	perceived_reduc tion_meat_consum ption	1-5	No	Don’t know/ No opinion	Don’t know/ No opinion get score of 3

C.4 VERIFICATION: CODE WALK-THROUGH

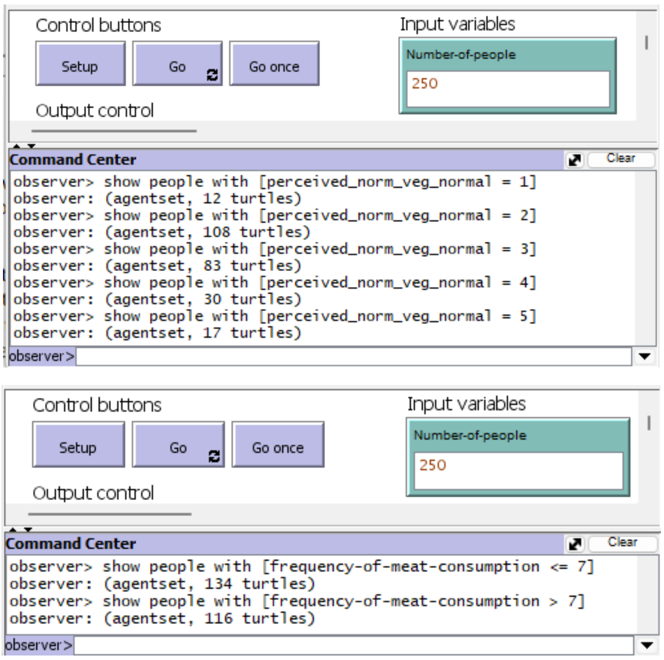


Figure 37. Example of code walk-through for verification. The process was performed for all agent variables.

C.5 VERIFICATION: RECORDING AND TRACKING AGENT BEHAVIOUR

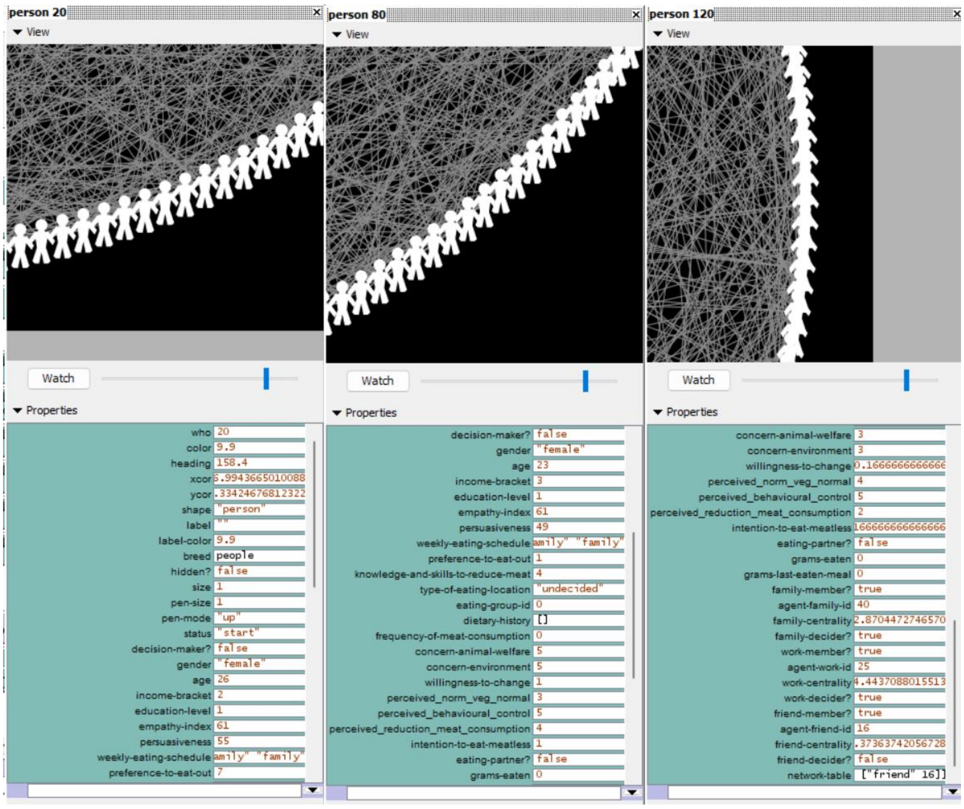


Figure 38. Example of keeping track of levels of agent variables throughout simulation experiments.

C.6 SINGLE-AGENT TESTING WITH PERSONAS

With the agent-based model, it is possible to not only make a distinction between either a die-hard meat eater or a vegan eater profile, but also the profiles in between, such as flexitarian, vegetarian, or a budget eater. To verify whether the agent set-up profiles are translated into the model mechanisms correctly, hypothetical agent profiles are created (Table 22).

Table 22. Persona set-up profiles for model verification

Eater profile/ persona	Income-bracket	Freq. meat cons.	Concern animal welfare	Concern environment	Willingness to change	Empa-thy	Education level	Knowledge and skills
Long-term vegetarian	4	0	4	5	1	15	3	5
Vegan	7	0	5	5	1	5	2	5
If I have to vegetarian	3	1	1	4	0.8	40	2	5
Conscious flexitarian	5	7	5	2	0.7	50	2	4
Unconscious flexitarian	6	9	3	3	0.7	75	1	5
Budget flexitarian	1	3	1	1	0.3	35	2	3
Die-hard meat eater	4	14	1	1	0	10	1	2
Casual meat-eater	6	12	3	2	0.2	15	3	3
Meat-eater don't like cooking	2	13	2	1	0.1	40	2	1

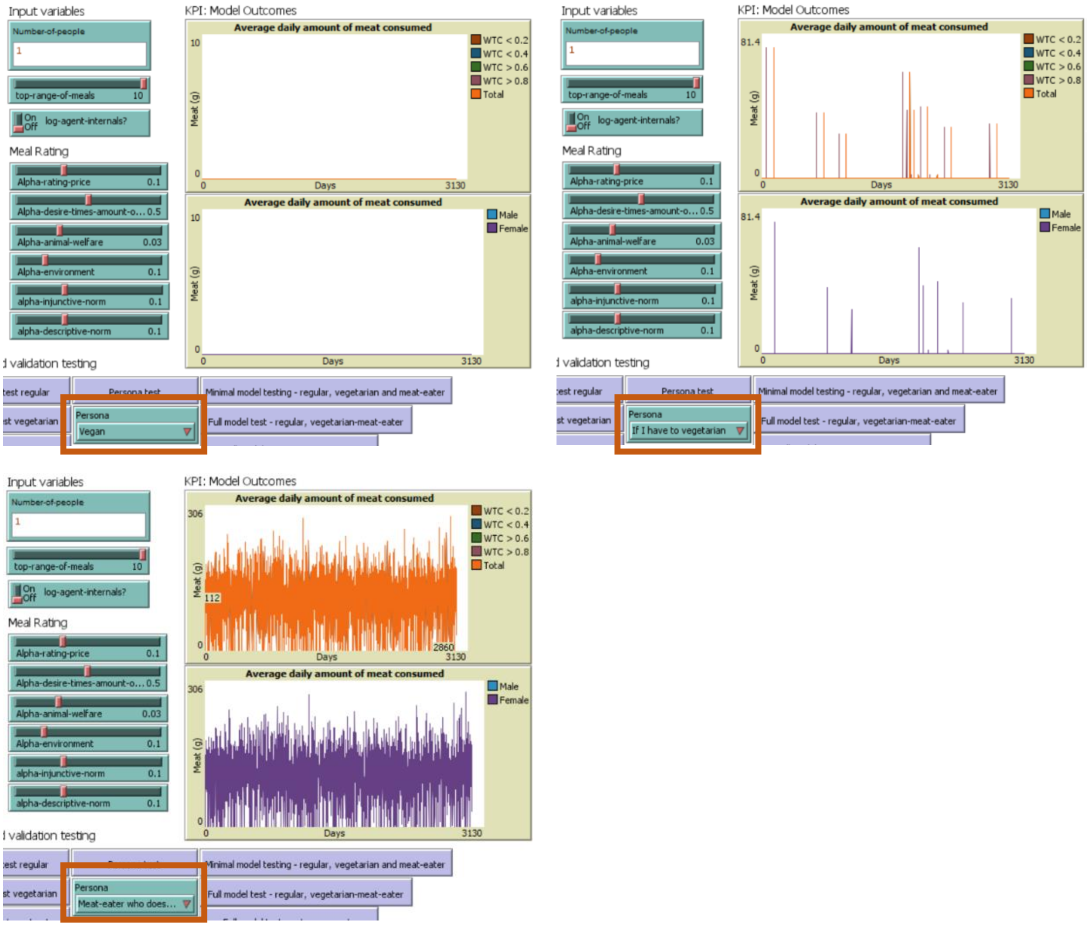


Figure 39. Examples of single-agent testing with various personas.

D. DETERMINANTS AND KPI'S MEAT CONSUMPTION

D.1 FACTORS INFLUENCING MEAT CONSUMPTION

Table 1 Table summarising barriers to and opportunities for reducing meat consumption

Factors	Barriers	Opportunities
Knowledge and skills	Low knowledge of the consequences of high meat consumption and reasons for reduced meat-eating behaviour; Lack of skills relating to practical issues (such as those related to vegetarian cooking); Denial mechanisms provided by cognitive dissonance, which block new knowledge	Campaigns based on emotional messages, specific arguments and with particular tools for targeted groups; Increasing skills that facilitate a plant-based diet; Mechanisms and tools to overcome cognitive dissonance (see below)
Values and attitudes	Low priority of values/attitudes which favour low meat consumption; Denial mechanisms provided by cognitive dissonance and social norms which block the incorporation of ethical food attitudes into behaviour	Campaigns based on emotional and symbolic messages; Mechanisms and tools to overcome cognitive dissonance (see below)
Emotions and cognitive dissonance	Cognitive dissonance blocks new knowledge and adequate values through denial and defence mechanisms	Emotional and symbolic messaging, promotion of new social norms (see below) Removing cognitive dissonance by changing behaviour to encourage reduced meat consumption
Habits and taste	Day-to-day food habits as unconscious routine; Taste preferences towards meat; The production and supply system has a major influence on food habits	Infrastructure supportive of plant-based diet: vegetarian-friendly shopping and dining environments (including canteens and hospitals) support the establishment of new habits
Sociodemographic variables and personality traits	Being male, elderly, belonging to a lower social class (in terms of income and/or education); Personality traits: being extravert, facing a lack of conscientiousness	Strong health argument for men and the elderly; Promoting flexitarianism as a new food style
Perceived behaviour control	Low perceived ability to control behaviour reduces the probability of behaving in the desired way	Increasing skills and self-esteem by stressing the role of vegan/vegetarian opinion leaders as role models
Culture and religion	Symbolism attached to meat: desire to express human power in order to dominate the natural world; Cultural belief that meat provides strength and vigour (in particular to men)	Taboos and prohibitions in several religions (e.g. the ahimsa concept); Promotion of new social and cultural norms (see below)
Social identity and lifestyles	Meat consumption as a social marker in the construction of social identities and lifestyles (e.g. as a sign of prosperity or masculinity)	Flexitarianism as a new food style; Enhancing social status of plant-based diets
Social norms, roles and relationships	Perceptions of normative behaviour by socially connected peers who favour meat consumption	Promotion of new social norms, e.g. by stressing the role of vegan or vegetarian opinion leaders as role models and community-based social marketing
Political and economic factors	Lack of political will; Powerful lobbies in agro-industry; High subsidies for the production of animal-based food; Low prices of animal-based products	Increasing prices (e.g. by eliminating harmful subsidies, internalising external costs and/or imposing taxes on animal production and products)
Food environment	No broad infrastructure that facilitates a plant-based diet; lack of vegetarian-friendly shopping and dining environments (including canteens, college refectories and hospitals), especially in rural areas	Increase in tasty and affordable vegetarian products in supermarkets, on the menus of restaurants, in hospitals, canteens and college refectories

Figure 40. Overview of factors influencing meat consumption (Stoll-Kleemann & Schmidt, 2017)

Table 2
Dependent outcome variables assessed in the reviewed studies.

DEPENDENT VARIABLES ASSESSED IN REVIEWED STUDIES		n	EXAMPLES
Empathy towards the animal	Emotional Response	2	Kunst and Hohle (2016)
Meat attachment	Emotional Response	1	Dowsett et al. (2018)
Affect towards meat	Emotional Response	1	Dowsett et al. (2018)
Attitudes towards meat	Attitudinal Response	13	Berndsen and Van Der Pligt (2005); Byrd-Bredbenner et al. (2010); Graham and Abrahamse (2017); Palomo-Vélez et al. (2018)
Consumer acceptance	Attitudinal Response	4	Spencer and Guinard (2018); Spencer, Cienfuegos, and Guinard (2018)
Antivegan/vegetarian attitudes	Attitudinal Response	2	Earle et al. (2019)
Concern for animals	Attitudinal Response	1	Dowsett et al. (2018)
Appetite for meat	Hedonic Response	3	Piazza et al. (2018)
Pleasantntess/experience of eating meat	Hedonic Response	3	Anderson and Barrett (2016)
Desire to eat meat	Hedonic Response	3	Tybur et al. (2016)
Liking of meat	Hedonic Response	1	Bertolotti et al. (2016)
Willingness to eat meat/to reduce meat consumption	Intentional Response	16	Earle et al. (2019); De Groeve et al. (2019); Tian et al. (2016); Zickfeld et al. (2018)
Intention to eat meat/to reduce meat consumption	Intentional Response	13	Byrd-Bredbenner et al. (2010); Cordts et al. (2014); Stea and Pickering (2019); Vainio et al. (2018)
Intention to purchase meat	Intentional Response	4	Wang and Basso (2019)
Likelihood of ordering meat/vegetarian	Intentional Response	2	Kunst and Hohle (2016); Sparkman and Walton (2017)
Intention to visit the restaurant	Intentional Response	2	Wang and Basso (2019)
Support for plant-based diet policies	Other Forms of Response	1	Whitley, Gunderson, and Charters (2017)
Non-compliance on vegetarian days	Other Forms of Response	1	Lombardini and Lankoski (2013)
Knowledge about meat	Other Forms of Response	1	Byrd-Bredbenner et al. (2010)
Self-reported meat consumption	Meat Reduction Behaviour	28	Allen and Baines (2002); Amiot et al. (2018); Carfora et al. (2017)
Food/meat sales	Meat Reduction Behaviour	8	Brunner et al. (2018); Flynn et al. (2013); Coucke et al. (2019)
Food choice	Meat Reduction Behaviour	7	Zhou et al. (2019); Campbell-Arvai et al. (2014); Saulais et al. (2019)
Actual food consumption (g)	Meat Reduction Behaviour	8	Anderson and Barrett (2016); Friis et al. (2017); Reinders et al. (2017); Rolls et al. (2010)

Figure 41. Overview of KPIs in studies on meat consumption behaviour (Stoll-Kleemann & Schmidt, 2017)

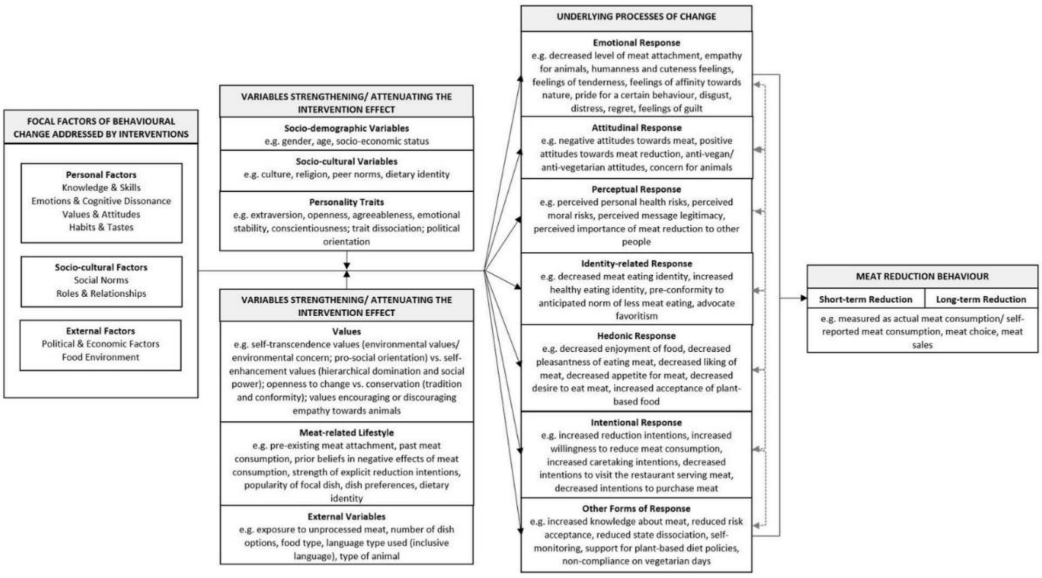


Figure 42. The meat intervention framework (Kwasny et al., 2022)