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Psychologically Plausible Models in Agent-Based Simulations of Sustainable Behavior

Samer Schaat, Wander Jager, and Stephan Dickert

Abstract Agent-based modelling (ABM) proves successful as a methodology for the social sciences. To continue bridging the micro-macro link in social simulations and applying ABM in real-world conditions, conventional and often simplified models of decision-making have to be utilized and extended into psychologically plausible models. We demonstrate the contribution of such models to enhance validation and forecasts in social simulations with two examples concerned with sustainable behavior. We start with the Consumat framework to demonstrate the contribution of an established psychological plausible decision-making model in various scenarios of sustainable behavior. Then we use the SiMA-C model to explain how different psychological factors generate social behavior and show how a detailed model of decision-making supports realistic empirical validation and experimentation. A scenario of social media prompting of environmental-friendly behavior exemplifies the details of how individual decision-making is influenced by the social context. Both examples, Consumat and SiMA-C, emphasize the importance of psychological realism in modelling behavioral dynamics for simulations of sustainable behavior and provide explanations on the psychological level that enable the development of social policies on the individual level.

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1 Towards Psychologically Plausible Social Simulations

As is common in modelling approaches, ABSS (Agent-Based Social Simulations) strive to abstract and reduce information. The first step to tackle the micro-macro gap in ABSS is done abstractly (following a top-down approach in science) and has brought important methodological insights in showing how the paradigm of agents—as heterogeneous individuals with frequent interactions—is able to tackle emergent social phenomena. However, oversimplification in ABSS is increasingly criticized (e.g. [1, 2]) since their unrealistic assumptions often impede their evaluation and application in real-world conditions. Additionally, in reducing social simulations on the interactional aspect, conventional approaches often neglect how social interactions are generated. These weak points are recently tackled by different approaches, which consider psychological processes that generate social interactions. Such psychologically plausible agents in ABSS can overcome these limitations and bridge the gap between psychological and sociological perspectives by providing a platform for their integration.

The discussion between sociological, economical, and psychological approaches is reflected in the discourse between social simulations and cognitive simulations. Similarly to sociology, conventional ABSS approaches argue that macro-level phenomena are better explored using abstract micro-specifications. Typical arguments against sophisticated decision-making models include that sometimes an agent’s properties at the psychological level are assumed to be constant and that often the processes that give rise to the agent’s action (and their alternatives) are not relevant [3, p. 430]. That is, in such cases it does not matter why the agent decided the action, but only that the agent does it in the given context.

Recently different approaches in ABSS and cognitive science (e.g., [4, 5]) argue against the usage of simplified, psychologically implausible decision models in ABSS. Typical arguments are that many macro-level phenomena are caused by the dynamics between the micro and macro level, which is not captured by (too) simplified models [4]. Another key argument is that replicating macro-level phenomena in conventional ABSS does not imply that the relevant micro-specifications are considered in the model. In extreme cases, “right” phenomena are replicated due to “wrong” assumptions. Regarding validation, simplified abstract micro-specifications are difficult to compare against established psychological models or even against empirical observations [5, p. 17]. This limits the usage of conventional ABSS in real world applications (e.g., for policy testing). ABSS supports understanding the dynamics in social simulations and identifying emergent, i.e., unpredictable, phenomena. Hence ABSS is helpful as a starting point to identify turbulent states in complex systems but is limited in addressing them. For instance, to be able to compare the model’s parameter to empirical data and in turn inform policies of how to tackle the phenomenon, psychologically plausible models are necessary. In the end, a tradeoff is always necessary, since on the one hand a model implies abstraction, but on the other hand we cannot know the causes of a phenomenon *a priori*, but we can tackle the structure that generate these causes,

which is the human mind. This is particularly the case with counter-intuitive emergent phenomena. One possibility for a trade-off is to use basic building blocks of cognitive models as foundations and, dependent on the concrete research question at hand and insights about emergent behavior from prototypical simplified ABSS, to decide on their detail of specification and extension.

The integration of social and psychological aspects with psychologically plausible models in agent-based social simulations support deeper explanations and better forecasting. In particular, it provides deeper process explanations which contribute to a more adaptive management of less predictable (complex) developments. As general in science, top-down or bottom-up approaches in integrating social and psychological levels in simulations are possible. A top-down approach would start with a simplified social simulation that informs the necessity and detail of specifications in the psychological layer. However, often (wrong) explanations are possible on the social level. Additionally, often docking from the social level to the psychological level is difficult to do, in particular due to the counter-intuitive aspect of emergence. The bottom-up approach would start with representing a psychologically plausible representation of human decision-making, being the source of all behavioral phenomena, and identifies the (often unexpected) causes of the social phenomena. Here simplification would be done after exploring the model in simulations. A bottom-up approach—starting with assumed building blocks—would also resemble a generative approach, which is one of the core-theme in ABSS.

Overall, reaching the limits of social simulations, one conclusion is that deeper explanations and realistic forecasts require sophisticated models of human decision-making.

Next, we demonstrate the Consumat approach as an established psychologically plausibly model to explore sustainable behavior. After that we use the SiMA-C approach to demonstrate details of considering the social context in individual decision-making using an example of prompting to switch to environmental-friendly energy providers in social media.

2 Simulations of Sustainable Behavior with the Consumat Model

The Consumat approach has been developed as a generic conceptual framework to guide the development of social simulation models that include different human needs and decision strategies.

The basic drivers of behavior in the Consumat framework are *needs* and the fulfilment of needs resulting in *satisfaction*. Humans have multiple needs as indicated by Maslow [6] and Max-Neef [7]. In developing a simple social simulation model we often want to reduce the number of needs, hence we make a basic distinction between three main need forces: *existence*, *social* and *personality*. *Existence* relates

to having means of existence, food, income, housing and the like. Agents act in order to avoid depletion of these resources over time. *Social* relates to having interactions with others, belonging to a group, and having a social status. *Personality* relates to satisfying one's personal taste with respect to overall life values and norms, such as environmental protection, altruism, or enjoyment of life. Depending on how important these needs are for an agent (personality) and how satisfied/depleted these needs are, the agents have a motivation to perform a particular behavior out of a range of possible behaviours (or behavioural options).

To perform a particular behavior, an agent possesses *abilities*, which relate to its capacity to actually use particular behavioral options. This relates to e.g. income, land possession, availability of tools, cognitive capacity and other possible abilities that are a prerequisite for performing a particular behavior.

Decision-making on what behavior to perform is a key element of the Consumat approach [8]. The uncertainty and satisfaction of the agent drive its type of decision-making. The lower the satisfaction of an agent, the higher the motivation to elaborate on alternative behaviors that improve satisfaction. And the more uncertain the agent is, e.g., due to the complexity of the decision and the many options to choose from, the more likely it will use other agent's behavior as a source of information. In the consumat approach this is conceptualized in four basic decisional strategies; repetition, imitation, deliberation and inquiring. In case of low uncertainty and high satisfaction, agents engage in *repetition*, which is the mechanism behind habitual behavior. A high uncertainty combined with high satisfaction results in *imitation*. When satisfaction is low, the agents are more motivated to invest effort in improving their situation. Hence when they are certain but dissatisfied they will engage in *deliberation*, which is a form of optimizing or homo-economicus kind of behavior. Dissatisfaction combined with uncertainty results in *inquiring*, where the behavior of comparable others is evaluated and copied when expected satisfaction increases. The interactions between the agents during social decision-making can focus on a more normative influence (imitation) or informative (inquiring), thus capturing the two main social interaction mechanisms as distinguished in the social sciences (e.g., [9]). Social decision-making is usually directed at similar others, where similarity is related to abilities. Agents have a memory for behavioral opportunities and other agents' behavior and abilities, which is only updated if cognitively demanding strategies are being used. Figure 1 gives an overview of the Consumat architecture.

The Consumat provides a generic framework that can be applied to different domains. Depending on the domain and the available data, the Consumat approach can guide the development of a specific social simulation model. In the following sections, we will briefly discuss a number of applications of the Consumat approach in different domains that are relevant in the context of sustainable development.

Fig. 1 Overview of the consumat framework

2.1 Simulating Consumer Behavior

The Consumat approach has been used to study consumer behavior in a variety of settings. Examples are the diffusion of “green” products [10], changes in sustainable life styles in Italy [11] and sustainable transport choices by US households [12]. In the following we will discuss very briefly four applications related to household lighting, the diffusion of electric cars, farmer crop choices and a transition in an artificial society. A relevant difference here is that household lighting is a domain where consumer choice is less important (financially, socially), whereas the diffusion of electric cars is a more complicated domain, including technology and charging network development.

2.1.1 Household Lighting: The Diffusion of LED's

In the last decade, governments and environmental groups have tried to promote energy-efficient lighting to consumers. With the rise and subsequent lowering of retail prices of LED-lamps, which are extremely durable and energy-efficient, the reasons for continuing use of the incandescent light bulbs are diminishing. The newer LED lamps are more economically attractive to the general consumer and can be more aesthetically pleasing compared to incandescent lamps because their colour spectrum can be configured. Despite these advantages and the pressure of governments and interest groups, consumer adoption of LED lights has proven to be low. Many governments around the world have even resorted to a (partial or complete) ban on incandescent lighting in an effort to reduce energy-use.

The behaviour of consumers in the lighting market is interesting, because it seems as if consumers need to be convinced to act in their own interest. In exploring possible scenarios to stimulate the diffusion of LED a Consumat application addressed consumer behaviour in this domain [13]. Based on empirical data a Consumat model was formalised. When a light broke down the agent replaced it by a LED, Halogen, CFL/ or incandescent light. The agent focused here on price, energy efficiency, colour discrepancy and ramp-up time. The importance of these aspects depended on the function of the light: functional as in a garage, versus spherical in the living room.

Depending on satisfaction and uncertainty, the agent would engage in (1) repetition: the broken lamp is replaced with exactly the same type, (2) imitation: the agent will select a close peer and pick a lamp of the inventory of this other agent (unless being anti-conformist), (3) optimization: look at all available lamps and select the best lamp considering all criteria, and (4) inquiring: select a close peer and select the best lamp from the other agent's inventory (unless being anti-conformist).

After a series of experiments replicating historic developments, a number of experiments addressed the stimulation of the adoption of LED's. This involved subsidising LED, giving 2 LED's for free, taxing incandescent lights and a yearly campaign (opinion boost). Considering this setting we experimented with a projected time horizon of 10 years. Figure 2 shows the results for this experiment.

The "no intervention" scenario shows that, while LED lamp prevalence does steadily climb, the penetration is slow. This behaviour shows that a new product appearing on the market alone does not strongly influence the consumer, basically because most consumers replace a broken lamp with an identical one (repetition). Whereas the financial and opinion boost strategies have some effect, the simulation shows that offering 2 LED lamps for free has the strongest impact. However, after the initial boost this provides, the same slow continuation is seen as with the "no intervention" progression. This is due to the updating of opinions of agents only when a lamp breaks. Combined with the longevity of LED lamps, this means the opinions of the agents are very slow to shift in favour of LED lamps.

Fig. 2 Proportion of LED lamps in the house for different policies

This application of the Consumat approach demonstrated how it can be applied to explore the efficacy of different policies, acknowledging the possible impact of consumer decision-making strategies.

2.1.2 Diffusion of Electric Cars

A next application of the Consumat addresses the diffusion of electric cars, specifically plug-in hybrid vehicles (PHEVs) and full battery electric vehicles (BEVs). The transition from fuel cars to electric cars is a large-scale long-term process involving many consumers and other stakeholders. To explore how policies may stimulate the transition towards a more sustainable transport system a Consumat application, called STECCAR, has been developed [14, 15]. In STECCAR, detailed data of 2974 representative Dutch respondents were used to parameterise an agent architecture based on the Consumat architecture. The data includes individual characteristics of the respondents, their current vehicle, and driving behavior, as well as perceptions and evaluations of various attributes of full electric cars, attitudes towards full electric technology, the likelihood of adopting a full electric car, and the adopter type regarding innovative cars.

Experiments were conducted with different policies, such as taxing fuel cars, subsidising BEV and PHEV cars and expanding the network of fast chargers. The results demonstrated that single policies do not result in very large effects. Interestingly, combining different policies resulted in an overall effect that was larger than the sum of the individual effects. From an emissions perspective it makes a difference if PHEV's or BEV's dominate the market. Hence experiments were conducted supporting both types of cars versus BEV only. In Fig. 3 you see the diffusion of PHEV's and BEV's over a period of 20 years.

Fig. 3 Diffusion of PHEVs and BEV for stimulating both (a) or only BEV (b). The *solid line* represents the average diffusion over ten runs, the *lighter area* represents the standard deviation at each moment. The average diffusion process during the default scenario is added for reference (*dotted line*)

The results of this simulation exercise indicate that—given consumer decision-making processes—a diffusion process can be a relative slow process, and different policies could be implemented ensemble in order to create a stronger aggregated effect. Also it is clear that a good timing is important (sequencing of policies) and a clear long-term determination, because of the slow effects. Experiments indicate that effective policy requires a long-lasting implementation of a combination of monetary, structural and informational measures. The strongest effect on emission reduction requires an exclusive support for full battery electric cars, and no support for hybrid cars. As a general conclusion this study showed the possibility of studying technology development, economic policy and behavioral effects in combination using a social simulation model.

2.1.3 Simulating Farmer Behaviour and Land Use

The consumat approach is also been used beyond the domain of consumer behavior. In an early application the overharvesting of common-pool resources was explained from a behavioural dynamic perspective [16]. Responses to floods were also being explored using the Consumat by Brouwers and Verhagen [17]. In particular a number of applications have been developed targeting farmer behaviour. For example, Speelman [18] address the type of crop and individualistic versus cooperative behaviour of farmers in Mexico in relation to e.g. developments in the international market. Acosta-Michlik and Espaldon [19] and Mialhe et al. [20] studied the vulnerability of farmers in the Philippines for climate change.

Van Duinen et al. [21] studied how farmers in the south-west delta area of the Netherlands would adopt to an increasing risk of drought and salinization of the soil. Due to climate change droughts are expected to occur more frequently and to become more severe in the future, threatening crop production. Farmers need to adapt to these possible draughts in order to secure their income. However, among

farmers there is a lot of uncertainty about the future frequency and severity of droughts. A survey based on a potential sample of 1474 members of a Dutch agricultural organization (the LTO) was conducted to elicit farmers' drought risk perceptions, adaptive behavior and socio-economic characteristics. These data were used to create an empirically based agent population based on the Consumat framework. The aim of the simulation study was investigating the effects of empirical social networks and different behavioral rules on farmers' choices under drought risk and its impacts on several macroeconomic indicators such as the rate of adaptation and income of the agricultural sector.

Farm agents operate in an environment consisting of the biophysical and socio-economic sphere. Their decisions depend on and affect both of these environments. In simulation experiments the degree of adopting irrigation technologies was being studied for a period of 30 years. This was being done for conditions of a stable climate and for a KNMI'06 climate change scenario developed by the Royal Dutch Meteorological Institute. Moreover, a comparison was made between the traditional economically optimizing agent versus agents that would employ all four decisional strategies as implemented in the Consumat. Figure 4 shows the results are presented for the resulting 4 conditions, each condition representing 30 model runs.

The *rate of adopters* gives insight in the dynamics of the adaptation process, see Fig. 4. The rate of adopters is measured as the share of farm agents who adopt irrigation on at least one of his fields.

The results indicate that when farm agents rely on heuristics and social networks the adoption process follows a different path than under optimization. The adoption process takes more time as farmers rely on information flows within their social network to inform their decisions. When agents do not observe a satisfactory number of adopters in their social network they remain uncertain and are reluctant to adopt. Once a critical threshold of number of farmers has adopted the technology, the

Fig. 4 Rate of adoption of irrigation techniques for optimizing (*top*) and consumat (*below*) agents under conditions of current and changing climate

diffusion of the technology takes off. Uncertainty about the effects of climate change slows down the adoption process. Hence, in case of climate change, more severe draught events reduce the uncertainty and stimulate a faster diffusion of irrigation technology.

This application of the Consumat approach demonstrates the relevance of including behavioural decision-making strategies in models, as they give a different, and possibly for policy making relevant perspective on how farmers respond to climate change.

2.1.4 Transitions in a Virtual Society

Formalising behavioural theory also offers a perspective on integrating social and environmental sciences. An early demonstration of this possibility is done by Jager et al. [8], who explored how psychologically more realistic agents would manage an “artificial world”. The basic question was if such formalizations of behaviour would result in different human–environment interactions compared to standard economically optimizing agents. An artificial world called Lakeland was constructed based on a simple integrated model comprising two natural resources: a fish stock in a lake and a nearby gold mine. Mining would pollute the lake and have a negative effect on the fish stock. The model also included an economical submodel, allowing the agents to sell fish and gold, and to buy food and status-enhancing products. The model comprised only 16 agents that were equipped with four needs: (1) subsistence, to be satisfied with fish or gold, (2) identity, expressed as the relative amount of money an agent owns in comparison to a subset of agents having about similar abilities, (3) leisure, referring to the share of the time spent on leisure, and (4) freedom, associated with the total amount of money owned. Following the Consumat approach, the satisfaction and uncertainty experienced by these agents led them to employ different decisional strategies.

In an experiment we started with all agents being fisher, and opening the gold mine at $t = 1$. Because the agents differed in their abilities—their skills in both fishing and mining—the agents could decide on changing behaviour. We formalised both the *homo economicus*, that would exclusively engage in optimising, and the *homo psychologicus*, that would employ all four decisional strategies from the consumat approach.

For both the *homo psychologicus* and the *homo economicus* condition, 100 simulation runs were performed. In Fig. 5 the proportion of time spent fishing and mining for both the *homo economicus* and *homo psychologicus* are presented. The transition from a fishing to a mining society was more complete for the psychologically realistic agents. Due to processes of imitation and social comparison, many more agents started working in the mine than was optimal from an economical point of view. This instigated extra pollution of the lake, which led to a decreasing fish stock. As a consequence, the relative harvest from the mine was larger, thereby propagating the completion of the transition. These results confirmed the idea that macro level indicators of sustainability, such as pollution and fish harvest, are strongly and predictably affected by behavioural processes at the micro level.

Fig. 5 Time spent fishing and mining for the homo economicus and psychologicus conditions

This Consumat application demonstrates that the incorporation of a microlevel perspective on human behavior within integrated models of the environment yields a better understanding of the processes involved in environmental degradation. In particular, the large-scale transition toward mining was explained by processes of imitation and social comparison.

2.2 Future Challenges and Perspectives

The Consumat has been developed as a conceptual tool to facilitate the modelling of human behaviour. The key contributions reside in the coupling of different behavioural principles in a single structure. This allows for modelling behavioural dynamics such as habitual behaviour. For example, if agents are satisfied, they can continue their behaviour habitually despite the presence of better alternatives. When their satisfaction decreases due to worse outcomes they may reconsider their behaviour. Also when they become uncertain due to friends changing behaviour, they may engage in social processing. These are routes that may cause a behavioural change, and if the new behaviour is satisfactory a new habit may emerge. Aggregating these behavioural processes over a population of heterogeneous agents will result in outcomes that may deviate significantly from the rational actor approach. Especially when dealing with a transition towards a sustainable society, it is important for policy development to take into account such behavioural dynamics. A deeper understanding of these dynamics may contribute to a better identification of possible barriers for change, and may provide insights that contribute to more effective policies. In providing students and managers an environment that contributes to their understanding of these complex dynamics, the consumat has been implemented in a gaming context (see [22]). Here players have to manage a transition towards sustainability in the energy sector, playing the roles of companies and political parties that have to interact with a consumat based artificial population.

3 Examination of Environmental-Friendly Behavior with SiMA-C

When examining psychological reasons of sustainable behavior, the mental architecture SiMA (Simulation of the Mental Apparatus and Applications) [23] is a suitable means as a point of departure, since it provides a grounded explanation model of human behavior. Many commonalities with the Consumat approach can be identified (e.g. the motivational system and the consideration of different modes of decision-making), where the SiMA approach elaborates on some aspects, e.g. a process model of emotion and a detailed memory system.

3.1 SiMA Approach

The SiMA approach aims to develop a functional equivalent model of human information processing. Different than conventional cognitive architectures higher-level cognition and decision-making is based on low-level mechanisms, such as bodily needs and emotion, since it is assumed that such an embodied, holistic and functional model is better able to account for human decision-making.

The functional model (see Fig. 6) has four inputs, two for drives and two for perception, and an output for the decided actions. Drives represent the agent's desires stemming from bodily needs. Perception is distinguished in body-perception and environment perception. Drives and perception are compared and associated with the agent's experience to give a basis how the system may satisfy its desires in the perceived external world. In the defense track desires may lead to conflicts

Fig. 6 SiMA model at the track level [24]

with internalized rules. The conflicts are handled by so called defense mechanisms, which may transform desires to social accepted ones. Next, goals are generated from desires and the affordances of the external environment. Finally, the best evaluated goal is chosen, a plan and action is selected that satisfies the different demands in the current situation best. In the action track this action is finally executed.

3.2 *SiMA-C Model*

The SiMA model provides a platform to transform concepts from psychoanalysis, psychology, and neuroscience into a computational model. However, for applications in social simulations a simplified version, SiMA-C (SiMA-Compressed), is developed [25, 26]. A basic psychological assumption is that decisions are fundamentally affected by emotion, which—in the context of decision-making—can be regarded as a valuation mechanism, e.g., a means of cost-benefit calculations (e.g., [27, 28]). Another psychological assumption considers the relevance of social norms in motivating behavior and their constitution by emotion. In this regard it is possible to distinguish norms that inform us about what is typically approved/disapproved (injunctive norms) and those that inform us about what is typically done (descriptive norms; [9]).

The SiMA-C model solves the problem of goal selection based on valuated memories that are activated by conflicting internal and external sources, representing demands and affordances, and possible reflections of this selection using emotion as a representation of an agent's current state of pleasure, displeasure, and conflict [26]. Model processing is triggered by a change in bodily needs or the external world, which causes data activation by two sources: Demands and affordances (see Fig. 7). Hence the activation process determines possibly relevant data for the current internal or external situation.

Two types of demand sources are distinguished: physical (bodily demands represented by drives and pain from body perception) and psychological (activated memorized norms). Both demand sources activate memorized goals and norms—directly by triggered activation or indirectly by spreading of activation—that are expected to bring pleasure by satisfying these demands. Goals may also be memorized with expected displeasure, if an (activated) goal would prevent the fulfillment of a demand or if a goal's object is expected to bring harm.

Beside demands, affordances are the second source of data activation. They activate memories that are similar to the current external world and—indirectly via spreading of activation—norms that are valid for the current external situation.

The relevance of activated goals for the current internal and external situation is determined by different valuation processes, triggered by the different activation sources, and considering the goal's memorized valuation for these sources. Hence a goal may have different valuations of expected pleasure and displeasure regarding the different activation sources. The current relevance of the single valuation is determined by the caused activation from that source. Besides memorized normative

Fig. 7 SiMA-C model overview [26]

valuation, activated by normative sources, and bodily valuation, activated by bodily sources, perceptive valuation, activated by external perception are distinguished. The first two types of valuations correspond to an expected short-term fulfillment of bodily or normative demands, the latter uses a goal's memorized summary valuation, which provides integrative holistic information about all aspects of how a goal changed the agent's state, considering long-term expectations and context. The resulting data from the valuation process can be termed effective or affective, in an etymological sense, meaning that this data should have an impact (on the decision).

Contradicting valuations in a goal (e.g., expected pleasure for normative demands, but expected displeasure for bodily demands) cause conflicts. Additional conflicts are caused by contradictions between demands and affordances or between contradicting goals. For example, if an internalized norm is activated, goals unrelated to the norm would prevent its fulfillment. Therefore, they would be marked by a conflict. Two types of conflicts are distinguished: normative and reality conflicts, with ownership conflicts being a specialization of the latter. The different kind of conflicts are addressed in processes of mediation, which operate by changing the different valuations in a goal. The result can be called arranged data.

Parallel to these processes, the generated displeasure from the different demands and activated data, the currently experienced pleasure and conflict intensity together form the agent's state indicator, representing the agent's current emotional state. A share of the displeasure from drives is used as so-called neutralized intensity for reflective processes, regulating the grade of dual processing.

Based on the reactive processes described so far, evaluative reasoning processes, which relate the different valuations to the state indicator, are possible. The separation between valuation and evaluation corresponds to a dual processing model of the human mind (e.g., [29]). The degree of evaluation is dependent on its necessity in case of ambiguities between goals, and the agent's neutralized intensity. The overall process corresponds to weighing the different valuations in integrating them to a single relevance value. This evaluation corresponds to a multi-criteria aggregation aiming for displeasure minimization and pleasure maximization, while considering a goal's conflicts and the agent's confidence in the valuations. However, the guiding principle is that of a satisficing, not an optimizing agent (cf. [30]). Overall, the evaluation process results in determining the most relevant goal for the current internal and external conditions.

3.3 Applying the SiMA-C Model in Social Media Prompting of Environmental-Friendly Behavior

The applicability of using the SiMA-C model to examine the mechanisms and impact factors of environmental-friendly behavior is explored in the CogMAS (Cognitive Multi-Agent System Supporting Marketing Strategies of Environmental-Friendly Energy Products) project [25]. We chose to use a scenario of social media communication to explore the requirements and assumptions for the SiMA-C model in the CogMAS context. In a next step we structured and concretized this description into a data model for the social media scenario. The analyzed parameters are mapped into survey questions to gather empirical data to calibrate the model. Simulations show that the assumptions behind our model are indeed capable of generating and determining the targeted behavior (e.g., switching to green electricity in a social media scenario, see Sect. 3.3.2). By demonstrating that the behavior of the simulation model stands in line with the survey data, we show that the model is a valid explanation of the people's decision-making process. Going beyond the possibilities of a survey, the simulations is used to address additional questions (see the section "Experimentation").

3.3.1 Gathering Empirical Data for Agent Parametrization

The empirical data for the agent parametrization was based on our general assumptions that norms and emotions are key factors in social decision-making (i.e., decisions that are influential and influenced by the social context one operates in).

We reasoned that this should also be the case for environmental decision-making such as the choice between green and grey energy providers. The goal of collecting this empirical data was to be able to use concrete parameters which—in combination with the data they activate and value— influence the SiMA-C agent's decision to switch to green electricity or not.

For this, a survey on green electricity was designed and implemented to explore the reasons that encourage the decision for green energy consumption. The survey consisted of a questionnaire about the general attitude towards the environment, social norms and personality indicators of the participants themselves. Additionally, we included a brief experiment of the awareness of social media as a suitable communication channel about switching from grey to green energy.

To identify empirical evidence for decision factors of agents, a number of characteristics and attitudes were defined and tested in the survey. To give an overview, based on the required parameters for the SiMA-C model, the following seven categories of possible influencing factors were formed: (1) Personality factor (i.e., intuitive vs. reflexive decision-making), mapped to personality parameters in the SiMA-C agent; (2) initial internal state (e.g., happy, sad, hungry, . . .), mapped to the agents' state indicator; (3) previously activated data (i.e., daily plans and relevant activities), mapped to the agents' initial activation values of memories; (4) attitude, trust and prior knowledge about green energy, (5) emotions related to green energy (e.g., pride, envy, guilt), mapped to associated memories, confidence, and summary valuation of green energy; (6) social norms related to environmental behaviour (i.e., descriptive and injunctive norms), mapped to memorized norms and their strength and implemented by different ways in activating norms; and (7) self-efficacy in relation to environmental protection, mapped to the agents' personality parameters. In the next step, exploratory analyses were conducted to see whether any of these variables can predict participants' choice of green versus grey energy consumers.

Regression analyses revealed that the perceived ease of switching energy providers, personal involvement, and higher descriptive norms (i.e., how many people in one's social environment already use green energy) explain 43 % of the variance in participants' current energy choice (i.e., which energy source they currently use). These predictors correctly identify 75 % of green and 90 % of grey energy consumers.

Additionally, people's intentions to switch from grey to green energy can be predicted by participants' attitude towards green energy (i.e., more favorable attitudes are connected with stronger intentions to switch), personal involvement, and injunctive norms (i.e., whether one *should* switch). These three predictors can explain 28 % of the variance in intentions to switch from grey to green energy, and they correctly forecast 86.4 % of those people who are willing to switch and 57.3 % of those who are not willing.

Finally, these variables as well as emotion variables (such as pride, envy, and guilt) were used to create different clusters of energy consumers, which can later be used as a blueprint for specific agents. To do so, three analyses were done with different variable combinations. In the first analysis the variables ease of

switching, involvement and descriptive norms were used to form the following four homogenous clusters on base of the current energy resource: (Cluster 1) Grey energy consumer with high involvement, (2) Grey energy consumer with low involvement, (3) Green energy consumer with low descriptive norms, and (4) Green energy consumer with high descriptive norms. In the second analysis, the variables attitude, involvement, injunctive norms, pride, envy and guilt were used to form four homogenous clusters on basis of the willingness to switch: (5) High willingness to switch with weak emotions, (6) High willingness to switch with strong emotions and high descriptive norms, (7) Mixed group with weak emotions, and (8) High willingness to switch with strong emotions and low descriptive norms. Finally, the third analysis used the variables attitude, involvement, injunctive norms, descriptive norms, ease of switching, pride, envy and guilt to form three homogenous clusters on base of the willingness to switch: (9) Mixed group with weak emotions, (10) High willingness to switch, and (11) Low willingness to switch with low involvement.

To sum up, the results show three main decision factors which will influence the agent's acting in the simulation. These include the attitude towards green energy, personal involvement, and injunctive norms. An agent who is willing to switch therefore should have a positive attitude towards energy and prior knowledge. The agent should also be interested in this topic and willing to collect a variety of information about different energy providers. Furthermore, agents ought to place importance on behavior which is typically approved or disapproved in the society.

3.3.2 Simulation

To replicate the findings of the survey, agents were parametrized according to the clusters from the survey. We normalized the Likert scale (1–5) used in the survey to a range of 0–1 and parametrized the agents' variables according to the mapping described above. Using a social media scenario in simulations (where an agent gets a message from a friend about switching to green electricity, details see below), the goal's relevance to get green electricity is compared to the participants' tendency to get green electricity, which reflects a question in the survey (see Fig. 8).

We achieved a good replication of the empirical data without any model calibration: The tendency to get (or have) green electricity can be predicted by the SiMA-C model. However, analyzing the relevant variables in the clusters that are not replicated well (e.g., cluster 2 and 11), we assume that the interplay of valuation and evaluation (see Sect. 3.2) does not sufficiently cover the interplay of intuitive and reflective decision. This seems especially the case for considering variables of involvement.

Experimentation

The survey's experimental part showed some indication that manipulating the visual cues given by the message's background picture influenced participants' expressed

Fig. 8 Comparison of simulation and survey results in the CogMAS project

Fig. 9 Visual cues influence willingness to switch to and recommend green energy (Y-axes denote absolute frequencies)

willingness to switch to green electricity (see Fig. 9). Apparently, people are more willing to switch to green energy when they are prompted with a background picture that displays nature. However, displaying the picture has no significant impact on the willingness to recommend green energy to friends.

We further tested the impact of a background picture of nature in simulations and observed if the SiMA-C model is able to propose reasons for its impact on the decision. We extended the model to consider the impact of state-perception on decision-making. This functionality is triggered by perceiving an object (nature) or agent's (message-sender) state. For instance, another agent may indicate pleasure by corresponding bodily expressions. Based on the memorized relation and valuation of that object or the other agent (which can be parametrized according to the survey), the agent's pleasure and displeasure state (represented by the state indicator, see Sect. 3.2) is altered, which influence evaluation of goals. This process can be described as affective empathy.

Similar to the survey's findings about the presence of visual cues about nature, simulations show an impact on the decision when perceiving a message with a background picture of nature (see Fig. 10). Additionally, the state of nature in the

Fig. 10 Impact of perceiving different states of nature on the tendency to switch to green energy

picture only slightly changes the tendency to switch to green energy. Hence although it may seem counterintuitive, the state of nature in a background picture of a social media message does not seem to have an impact on the tendency to switch to green electricity (see Fig. 10, where an agent associates different states of displeasure and pleasure for the different pictures).

An analysis using our model provides candidate explanations: The manipulation of the agent’s state (e.g., increase of displeasure due to the bad state of nature in a background picture) does not consider the concrete reasons of the current state, but only the abstract sources (normative, perceptive, bodily). In other terms: Unconscious affective empathy alone is not sufficient, the agent also has to reflect on the concrete reasons of its current state to decide which goal will have the best effect on its state. That is, the message has to emphasize the relation of the agent’s state and the environments state and nudge the agent to reflect about that.

Model Walk-Through Using a Social Media Scenario

Next we will use different visualizations (generated in simulations) for a walk-through in the simulations to demonstrate the causal chain in decision-making and how the various impact factors of environmental friendly behavior are covered by the generic SiMA-C model [26]. For demonstration purposes, we use a concrete social media scenario that considers all mentioned impact factors [31]. Victoria is currently working and gets a social media message from her friend Caroline about switching to green electricity and how good this felt. The configuration of simulations includes creating memories. Victoria memorizes several internalized norms, e.g., to appreciate friendship, improve the world, and protect the environment. Part of the memories are also the knowledge about how she satisfies her needs, pleasurable thoughts and her relation to nature and to other people, e.g., to Caroline. Victoria’s initial internal state is configured as hungry and a bit exhausted. But nevertheless Victoria is in an overall joyful state. Her conflict state is quite high (which does not exclude the joyfulness) since she has not confirmed to her own

Fig. 11 Overview of goal selection in a social media scenario

norms recently. The personality factors of Victoria informs about her general norm conformity and how intuitive she is in general. Due to the simulation scenario, the goal to work is configured as pre-activated.

Figure 11 gives an overview of why the goal to get green electricity is highly ranked, given the agent’s current internal and external situation.

The high relevance value in red is mainly due to valuation (light red), evaluation does not affect the overall goal relevance. Norms that are associated with green electricity are highly activated and impact the decision (green bar). Due to the effort to get green electricity mainly reality conflicts exist. Unsurprisingly the primary source of valuation are norms (in magenta) and the secondary source are direct activations from perception (blue). Figure 12 shows concretely how the goal to get green electricity is activated after perceiving the social media message.

Perceiving the prompt from Caroline to switch to green electricity directly activates the corresponding goal. Caroline is memorized as a close friend (i.e., high association strength and positive summary valuation), which is why her normative prompt is activated highly. An additional activation comes from the perceived high number of “Likes”. These two aspects can be described as following a descriptive norm. Due to direct and indirect activation of the norm to protect environment (which is activated directly to the message and indirectly due its associations with the perceived message’s background picture of nature and the prompt to get green electricity) the goal gets most of its activations from normative sources. This corresponds to following an injunctive norm. Hence these norm types are distinguished by the type of activation.

Due to the high activation by perception and memorized valuations perceptive and normative valuation has the highest impact. This reflects the relevance of an agent’s attitude and norms (indicated by the survey), which is represented in the model by summary valuation and a configured pre-activation value.

Fig. 12 Activation pattern in associative memory for the social media scenario (screenshot)

Due to the set personality parameters of Victoria, she is more of an intuitive type, thus valuation is the main source for the goal’s relevance. Additionally the low uncertainty in valuations of different goals does not require an intensive reflection on their selection. However due to her hunger she has a high degree of neutralized intensity (which regulates dual processing, see chapter *SiMA-C model*) and reflects on her decision, i.e., conducts evaluation. As described, amongst others, evaluation also considers the conflict intensity of goals and consider the expected change of an agent’s state. Since Victoria is initially in a conflicting state, which is increased by current conflicts due to the social media message, her normative valuations additionally impact the goal’s relevance in evaluation. The current state, which is used in evaluation, has changed due to the current demands, activated data, and mediated conflicts. For instance, the high valuations of green electricity leads to an ownership conflict, since Victoria recognizes that Caroline, but not herself, has green electricity. Due to memorized association strength between Victoria and Caroline and positive summary valuations of Caroline, Victoria is able to identify with Caroline and imitate her behavior in getting green electricity. The resulting state

indicator corresponds to the descriptive emotions of envy and guilt. Additionally the evaluation process is able to consider variables of involvement (e.g. confidence). However, as indicated in Victoria's case, the decision to get green electricity is mainly a reactive one due to activation and valuation of corresponding memories.

4 Discussion and Conclusion

Agent-based modeling (ABM) is able to bridge the gap between psychological and sociological perspectives by providing a platform for their integration. To model the dynamics of human behavior in such integrative simulations, psychologically plausible agents are required. This is especially the case for sustainable behavior, which can only be explained realistically on the psychological level under consideration of the social context.

We presented two examples of psychologically plausible agent models, Consumat and SiMA-C, and their application to examine sustainable behavior. By showing how social dynamics are generated with dynamics on the psychological level and how the social context influences individual decision-making, we integrate psychological and sociological perspectives. Both present examples of how psychologically plausible agent models provide explanations on the psychological level that enable the development of social policies on the individual level. In case of the Consumat approach we saw how the consideration of different decision strategies is able to explain dynamics in sustainable behavior. Using the SiMA-C model we showed how a detailed model of decision-making supports realistic empirical validation. In simulation experiments we show how the translation of emotion into a model of valuation and psychological dual processing is able to explore psychological causes of (often unexpected) observed behavior and inform policies for environmental-friendly behavior. Hence both models provide deeper explanations than conventional ABM.

The communalities between Consumat and SiMA-C show the importance of considering a generative approach to motivations and different modes of decision-making. This is especially important when the motives, and the external (environment) and internal (personality, agent's state) conditions of sustainable behavior are at stake. Hence, in explaining sustainable behavior, both, psychological aspects (such as different demands from needs and norms) and social aspects (such as social pressure) and their integration have to be considered. The Consumat and SiMA-C approach are both able to provide a framework to integrate psychological and sociological perspectives and enable the explanation of behavioral dynamics by the interplay of multiple model variables.

Consumat and SiMA-C are similar in basing behavior on motivations and in considering heuristics. The Consumat integrates these aspects more explicitly. For instance, a core process addressed in the Consumat framework—the selection of a suitable decision strategy given the situation—is not explicitly considered in SiMA-C. However, as general in the generative-functional SiMA-C model, the

resulting interaction between its components is able to generate similar patterns of decision making as in Consumat. SiMA-C focusses on how these different strategies are generated by underlying mechanisms, most importantly emotion, a driver not explicitly addressed in the Consumat. Also within SiMA-C a more explicit modeling of the memory is formalized, allowing for the parameterizing of storage and retrieval of concrete memories. The higher degree of parametrization and memory-processing (e.g. spreading of activation) enables more detailed model exploration and experimentation, while it makes simulations (often unnecessarily) more complicated. Therefore, we expect that the Consumat model is more efficient in modeling the basic behavioral dynamics of a population that is interacting within an environmental relevant setting (e.g. resource use, consumption), whereas SiMA-C offers a possibility to experiment with strategies addressing the emotions and experiences of this population.

The compliance between the Consumat and the SiMA-C approach, and the partial difference in focus and level of details, provide possibilities to join the two approaches for deeper explorations of social phenomena. As Consumat provides a lightweight model, practical value in social simulations, and considers key factors of a psychological model, it can be used as a starting point to identify cases in simulations that require further exploration (e.g., because it identifies a wide variety of possible outcomes, or unexpected social barriers for change).

In such cases SiMA-C may be able to provide more insights of agents' decision-making processes in different personalities and concretize Consumat's variables where (assumedly) necessary. For instance, using a model of emotion in SiMA-C (and the dynamics of memory activation and valuation) detailed reasons for why agents choose goals can be provided. This also enables fine-grained parametrization with empirical data. Overall, Consumat enables a platform for broad policy testing, and may direct further explorations with SiMA-C, when it is assumed that the focus of SiMA-C provides detailed variables (for policies) to dock on. This would also support individually tailored policies and simulation experiments that address particular key-agents (e.g. opinion leaders) in a more precise way. Overall, as future work we aim to join the contributions of the Consumat and SiMA-C approaches to enhance exploration of social behavior in environmental contexts and harness the flexibility of using two compliant models with partial different focus and different levels of details.

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