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How beliefs on food and climate change impact the dietary adoption ? An agent-based approach

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Abstract. This paper introduces G-Impact, an agent-based model that combines modelling of household consumption and belief diffusion. Household decisions integrate personal impacts (quality, cost), perceived consequences (climate change, human responsibility), and social norms. The evaluation of these different criteria relies on household beliefs, which can be exchanged during social interactions. These beliefs can be used to explain household decisions on a macro and micro scale, and thus to target information or incentive policies. The model is applied to dietary choice in France, among the omnivorous diet (INCA3), the flexitarian diet and the vegetarian diet. The costs and greenhouse gases emissions of the different diets are initialized from real data. The initial beliefs of households are derived from opinion surveys. In the control simulation, we observe a significant increase in the proportion of flexitarians, and a slight increase in the proportion of vegetarians. We also illustrate the need to properly inform households with the emergence of fake news.

Keywords: Agent-Based Model · Consumer Behavior · Opinion Dynamics · Social Norms · Dietary Adoption.

1 Introduction

Given the growing climate risks on a global scale and the involvement of human activities in global warming, it is urgent to act. It is necessary to know which individual and collective behaviors are the most damaging – or virtuous – for the environment, in order to adapt our daily actions. Most climate simulations model human activity in an aggregate way, in the form of a typical behavior representing all individuals. These approaches do not model the complexity and variability of human behaviour or the social interactions that influence individuals' decisions, thus lacking explicability at the micro level.

To move in that direction, we designed G-Impact, an agent-based model of household consumption, which integrates belief diffusion. Beliefs are the support of product (or service) adoption, and are diffused on a social network, where agents will exchange information on the productions, including their impacts on climate, i.e. greenhouse gas (GHG) emissions. In this paper, we apply G-Impact on dietary adoption, and show how beliefs help us to understand why a particular diet is adopted, and also the impact of fake news. The model is based on real data, found in various surveys among the French population.

2 Background

Numerous models are available to simulate the ecological impact of a population at the macroscopic scale. These models are generally based on the resolution of differential equations until an equilibrium is reached. The most recent dynamical systems (e.g. En-roads [12]) integrate numerous human activities and their impact on the climate.

These approaches are very useful to study the behaviour of these systems, as well as to propose possible scenarios, but lack explicability at the micro level, as they do not represent individuals and their decision-making processes.

Different psychological frameworks are frequently used to model decision-making, such as the Theory of Planned Behaviour (TPB) [1], the Norm Activation Model (NAM) [11] or the Theory of Reasoned Action (TRA) [2]. Several macro-models are grounded in one of these theories, e.g. traditional food consumption in six European countries [9]. Similar models exist in other domains.

To take population heterogeneity into account and to model individuals or households, their decisions and their social interactions, the agent-based approach is the most suitable. Such a model has, for example, been proposed for meat consumption in Britain [10], grounded in TRA. Agents are individuals, they can choose to eat meat or not depending on their concerns. They are influenced by their household members and their co-workers by a process of peer influence.

The BENCH model [8], grounded in NAM, is focused on household energy decision making. Households exchange information about their electricity use and make decisions based on personal norms, global warming awareness, and feelings of guilt and responsibility.

Most models are domain or study specific, but more generic models exist. The Consumat approach [6] is a generic framework based on the notions of need and satisfaction, including personal tastes, existential and social needs. Depending on its satisfaction and its uncertainty, an agent will use different cognitive processes among : repetition, imitation, inquiring and optimising.

The presence of different cognitive processes provides richness of behaviour, although these processes are simple. Various models have taken Consumat as their basis, for example the STECCAR model [7] of electric vehicles diffusion.

The Argumentation Framework, applied to vegetarian diet diffusion in [13] goes further into explicitness, detailing the arguments that drive agents' opinions. Each agent has a set of arguments, represented as an argumentation graph. An agent's opinion on a topic is determined from this argumentation graph. Agents have social interactions, and exchange arguments with agents having an opinion close to their own.

Nevertheless, this approach requires to build the graph of attacks between arguments and it also imposes a particular form of logical reasoning, based on arguments.

Our aim is to propose a flexible, generic (i.e. to specific to food adoption), easily extensible model, and applicable on existing data (e.g. opinion surveys).

It is inspired by TPB and is based on household beliefs and their diffusion. These beliefs can be easily extracted from existing surveys. Moreover, the model includes the notions of global warming awareness and responsibility.

3 G-IMPACT model

The population is divided into households. The latter have activities to perform and must choose how to perform them. For each activity, they have several options from which they choose: we call it "modalities".

Households have both beliefs and cost estimates about the modalities, allowing them to choose the most appropriate one for each activity. They can be enriched through social interactions, during which households exchange beliefs and information. Households are also sensitive to social norms.

3.1 Household representation

Household agents Household agents are representative of the households of the population. Each household has the following attributes:

- the list of household members, along with their attributes: age, gender, employment status, socio-professional category, income
- the beliefs of the household as well as the estimated costs of the modalities
- the share of the budget allocated to each type of activity
- the household's social network
- an information base, derived from social interactions, indicating the modality choices of other households as well as received beliefs

Activities Households perform activities in different areas, for example: food, transportation, housing, other consumption. These activities are representative of the population's consumption behavior. Each activity is repeated regularly, some activities may be daily and others less frequent. Households choose how they will carry out each activity: each possible option is a modality. Each modality has a (financial) cost, which households estimate, and a real GHG impact, unknown to households.

Beliefs A belief is an elementary piece of information, considered to be true. We denote $B_a(o, X)$ the value of a belief for household a between the social object o (product, alternative ...) and a evaluation criterion X . This value is a continuous value in $[-1, 1]$, where 1 denotes a full agreement that X is true for o , and -1 a full disagreement. For instance $B_a(\text{organic}, \text{healthy}) = 1$ means that agent a strongly believes that organic food is healthy.

However, each belief has a *reliability* level, to modulate its impact. The reliability depends on its source, from most to less believable: direct experience is most reliable, then comes indirect experience, plausible and then advertising.

Each household has a set of beliefs that allow it to evaluate the modalities and estimate their consequences. We represent beliefs about:

- the modalities: pleasure, impact on health, time saving and GHG reduction¹.
- the climate: the human responsibility in climate change and the perceived impact of global warming on humans.

The beliefs of the households will be represented using associative networks as in the CoBAN [14] model. Each household will have an IAN (Individual Associative Network) representing all its beliefs.

Estimated costs Households are provided with a table, containing for each modality the expected cost per individual for each age category. A level of reliability is associated with this table.

3.2 Social interactions

At each tick, each pair of connected households in the social network have a probability p_{inter} to have a social interaction. These interactions consist of the exchange of messages that may contain beliefs and cost estimates about certain social objects, and the modalities chosen by the household.

Households discuss the climate but also the modalities that interest them out of proactivity (preferred modalities) or out of curiosity (missing information). Each topic of interest has a probability $p_{diffusion}$ to be discussed.

Integration of beliefs and estimated costs received When a household receives a message in a social interaction, the beliefs as well as the estimated costs it contains are filtered by decreasing their reliability level.

Then, a belief is directly added to the IAN with a probability p^{new} if it did not exist. Otherwise, there are two cases:

- if the received belief is the same than existing belief and has a higher reliability, then belief is preserved and the maximum reliability level is kept
- if the received belief contradicts the existing belief, then the existing belief will be revised with some probability, depending on the reliability level of the current and received beliefs (using a probability table)

The same procedure applies to the estimated costs table.

The probabilities of revision according to the reliability of the existing belief and that of the new belief are presented in a table, provided as a model parameter. Then, the revision of beliefs is based on Bounded-Confidence model [4] that we have enriched with Assimilation-Contrast theory [5, 3] :

$$c \leftarrow c + \text{sign}(r - c) \times \gamma \quad (1)$$

with c the household's current belief value, r the received belief value, and γ drawn uniformly $\in [0, 0.5 - 0.5 \times (|(r - c) - 1|)^{1.3}]$.

All received beliefs are also aggregated into a normative IAN, used to construct the average perceived social representation of each modality.

¹ We limit ourselves to these four criteria for the moment, which are applicable to all types of consumption and for which we can generally find data.

3.3 Household cognition

Evaluation of beliefs Households can evaluate their beliefs. This mechanism allows them to extract from the IAN the value of a belief between a social object and a desired concept. A belief must have a reliability higher than $\sigma^{threshold}$ to be evaluated: information that is too unreliable is not taken into account.

Update of estimated costs If a household does not have an estimate of the cost of the modality it is evaluating, it will fill in this missing information using the mean cost estimate of the other modalities for this activity.

When a household adopts a modality, its estimated cost is updated:

- when no estimate of the cost is available, it is initialized as a random number around the real price, with a maximum percentage of error *max_init_error*.
- when an estimate is available, it is adjusted to be closer to the real price (using a linear interpolation between the current estimate and the real cost, where the adjustment coefficient is drawn uniformly in $[0,1]$).

Decision making We define the following notations:

- a the household concerned (the one which evaluates the modality)
- act^m the modality m of the activity act
- abbreviations: *CC* for Climate Change, *HR* for Human Responsibility, *PCC* for Perceived Climate change Consequences, *GR* for GHG Reduction

Households assess the usefulness (U) of each modality according to the criteria of personal impacts (PI), the perceived consequences (PC), and social norms (N). The chosen modality is the one with the highest utility value. Changing modality is binding, a resistance to change factor is applied in this case.

Personal Impacts (PI) are related to costs and quality. A modality must be within budget and prices affect decisions. The quality of a modality is assessed based on beliefs about the pleasure, health, and time-saving.

Perceived consequences (PC) are related to climate change consequences and household responsibility. The more a household feels responsible in climate change, the less it will positively evaluate a modality associated with a weak reduction in GHG emissions.

Norms (N) considered are descriptive and injunctive norms: the more a modality is used and appreciated by the population, the more it is considered socially accepted.

$$U_a(act^m) = ca(act^m) \times \left(1 + \frac{PC_a(act^m) + PI_a(act^m) + N_a(act^m)}{3} \right) - 1 \quad (2)$$

with $ca(act^m) \in [0, 1]$ the change acceptance factor, $ca(act^m) = 1$ if act^m is currently used, else $ca(act^m) = (1 - \rho)$; $\rho \in [0, 1]$ the resistance to change factor.

Perceived consequences (PC)

$$PC_a(act^m) = B_a(act^m, GR) \times AR_a(act^m) \times B_a(CC, PCC) \quad (3)$$

Estimated responsibility of a household (AR)

$$AR_a(act^m) = \left(\frac{B_a(CC, HR) + RR_a(act^m)}{2} + 1 \right) \times \frac{1}{2} \quad (4)$$

Relative responsibility of a household (RR)

$$RR_a(act^m) = \begin{cases} 0 & \text{if } nb_a = \emptyset \\ \frac{\sum_{n \in nb_a} (C_a(act_{mod(n, act)}) - C_a(act^m))}{2 \times |nb_a|} & \text{else} \end{cases} \quad (5)$$

Personal impact (PI)

$$PI_a(act^m) = CU_a^{sp}(act^m) \times QU_a^{sq}(act^m) \quad (6)$$

with $sp \in [0, 1]$ the sensitivity of PI to the price, $sq \in [0, 1]$ the sensitivity of PI to the quality (depends on the household category).

Cost utility for a household (CU)

$$CU_a(act^m) = \exp\left(\frac{-price_a(act^m)}{(1 - bp) \times mean_price}\right) \quad (7)$$

with $price_a(act^m) \in R^+$ the net (including any subsidies) estimated costs of act^m for the household; bp the households sensitivity to low prices; $mean_price$ the average estimated price among all possible modalities (all activities included). If the price is out of budget, we give CU the value $-\infty$.

Quality utility for a household (QU)

$$QU_a(act^m) = \frac{1}{|CR|} \times \sum_{i \in CR} \frac{1 + B_a(act^m, i)}{2} \quad (8)$$

with $CR = \{health, time\ saving, pleasure\}$, the set of criteria for quality.

Social norms (N)

$$N_a(act^m) = \frac{DN_a(act^m) + IN_a(act^m)}{2} \quad (9)$$

Descriptive norm perceived by a household for a modality (DN)

$$DN_a(act^m) = \begin{cases} 0 & \text{if } nb_a = \emptyset \\ \left(\frac{2}{|nb_a|} \times |\{n \in nb_a, \text{mod}(n, act) = m\}|\right) - 1 & \text{else} \end{cases} \quad (10)$$

with $\text{mod}(n, act)$ the modality chosen by household n for action act , and nb_a the neighboring households of a in the social network.

Injunctive norm perceived by a household for a modality (IN)

$$IN_a(act^m) = \frac{NQU_a(act^m) + NPC_a(act^m)}{2} \quad (11)$$

Normative quality utility (NQU)

$$NQU_a(act^m) = \frac{1}{|CR|} \times \sum_{i \in CR} \frac{1 + NB_a(act^m, i)}{2} \quad (12)$$

with $NB_a(o, x)$ the evaluation of the belief between the social object o and the concept x in the normative IAN.

Normative perceived consequences (NPC)

$$NPC_a(act^m) = NB_a(act^m, GR) \times \frac{NB_a(CC, HR) + 1}{2} \times NB_a(CC, PCC) \quad (13)$$

3.4 Course of the simulation

The simulation life cycle is decomposed into three steps: initialization, execution of each time step (tick), and ending. At each time step, the course is as follows:

1. Choice of modalities: for each activity to be performed, households evaluate all the modalities and choose which one they will use.
2. Execution of the modalities: all households execute the chosen modalities. Agents state and GHG emissions are collected.
3. Social interactions: households can interact with each other.
4. Beliefs and estimates update: households process all messages received and update their beliefs, cost estimates and normative IAN.

4 Application to dietary adoption

4.1 Actions and modalities

We applied² the G-Impact model to food consumption in France. Households must make several decisions about their food (excluding water):

² Model implemented in Scala using Akka toolkit.

- what they eat, i.e. their diet: INCA3 (the most common diet in France, omnivorous with meat), flexitarian (meat reduction) and vegetarian (no meat)
- the source of the food consumed: average French consumption mix (contains imports, French conventional food and a small share of organic), French conventional food, or French organic food
- if they take measures to reduce food waste: portion reduction or not

These decisions are made once a week and the decision applies for the entire week. We collected the GHG emissions and costs of every modality from national studies on the impact of food consumed and market prices in France.

4.2 Initialization of the population and beliefs

The strength of our instantiation of the model is to use as much data as possible on the French population, mainly between 2017 and 2019.

The cost and GHG emissions of the modalities were taken from different national and international studies (ANSES, INSEE, WWF).

Population and income are initialized from national INSEE data. Households are assigned price and quality sensitivity values (sp , sq , bp) according to their income and the individuals that compose them. Our population of 9943 agent households is representative of the French population.

To initialize the beliefs of the households, we convert Likert scales taken from several national opinion surveys into values of beliefs in $[-1, 1]$, which we distribute according to the proportions indicated. This information is supplemented with national studies when necessary. In the data used for the experiments, the initial beliefs of households about their own diet have the same distributions regardless of the diet, only the assumptions about diets other than theirs vary. We do not give the INCA3 dieters any preconceived notions about the impact of the vegetarian and flexitarian diets on health and the environment: we want to study how, during the simulation, vegetarians and flexitarians manage to spread these beliefs to the whole population.

We draw for each household his initial diet according to the declared distribution in the real population. We will add a gaussian noise on the initial beliefs of the households.

Once the households have been generated, we generate the social network of the population, using a Small-World [15] network linking the households together.

4.3 Decisions

A meal is a combination of diet, source and portion size. A household therefore evaluate the value of its belief between a concept and a meal modality by aggregating its different beliefs for diet, portion and source using an average.

4.4 Experiments

Control simulation We ran 30 simulations with a basic set of parameters over 5 years. We used $p_{inter} = 0.02$, $p_{diffusion} = 0.05$, $\rho = 0.08$, $p_{new} = 0.9$, $max_init_error = 20\%$, $\sigma^{threshold} = \text{'advertising'}$. The filtering of received beliefs reliability is the following: direct experience become indirect experience, and indirect experience become plausible. With respect to the reliability of the current belief, the probabilities of revision are 1.0 if the received reliability is higher, 0.9 if it is equal, 0.01 if it is just below, 0.001 if it is even lower. Households have an average of 10 neighbors in the social network.

We see in Table 1 that the proportion of practitioners of the INCA3 diet has significantly decreased at the end of the simulation (-11.05 percentage points), in favor of flexitarian and vegetarian diets (+8.24 and +2.81 percentage points respectively), leading to a reduction of annual GHG emissions from food associated with diet choice of 5 % between the first and the last year. We can see in Table 2 that a significant proportion of vegetarians and flexitarians eventually became practitioners of the INCA3 diet (respectively 33.56 % and 36.15 %). The proportion of vegetarians who have maintained their diet is only 40.64 %, thus representing the difficulty in maintaining this diet.

diet	initial	final
INCA3	74.46 % (± 0.45)	63.41 % (± 1.39)
flexitarian	20.35 % (± 0.50)	28.59 % (± 1.48)
vegetarian	5.18 % (± 0.20)	7.99 % (± 0.63)

Table 1: Distribution of the different diets at the start and at the end of the simulation (mean and standard deviation)

		Final diet			Total
		INCA3	flexitarian	vegetarian	
Initial diet	INCA3	73.47 % (± 1.24)	20.41 % (± 1.28)	6.12 % (± 0.53)	100 %
	flexitarian	33.56 % (± 1.47)	59.89 % (± 1.77)	6.55 % (± 0.79)	100 %
	vegetarian	36.15 % (± 2.98)	23.22 % (± 2.57)	40.64 % (± 2.75)	100 %

Table 2: Proportion of final diet for each initial diet

What are the belief profiles of adopters of different diets? We display the average final beliefs of households about the diet they follow in Table 3. Following the diffusion of household beliefs, three belief profiles emerge corresponding to the three diets. There are two major criteria for INCA3 diet, which are pleasure and health. Flexitarian diet has three more homogeneous criteria, which are health, GHG reduction and pleasure. Vegetarian diet has two major criteria: health and GHG reduction. The choice of the INCA3 diet is then more associated with "selfish" criteria, flexitarian diet on a more multicriteria and balanced

decision, and for the vegetarian diet it is a more "altruistic" choice since it is based on only two major criteria, including the reduction of GHG emissions.

	GHG reduction	health	pleasure	time saving
INCA3	0.317 (\pm 0.008)	0.387 (\pm 0.008)	0.457 (\pm 0.011)	0.133 (\pm 0.013)
flexitarian	0.436 (\pm 0.015)	0.527 (\pm 0.012)	0.486 (\pm 0.011)	0.165 (\pm 0.015)
végétarien	0.473 (\pm 0.030)	0.541 (\pm 0.025)	0.261 (\pm 0.024)	0.043 (\pm 0.031)

Table 3: Households average beliefs depending on final diet (mean and standard deviation)

What caused these transitions from the INCA3 diet to the flexitarian diet? We observe in Fig. 1d that the households initially practicing the INCA3 diet that have finally adopted a flexitarian diet had a rather poor opinion about the INCA3 diet compared to those who maintained this diet, in particular its ability to reduce GHG emissions and the time savings associated with it. Households that finally adopted the flexitarian diet also received beliefs with higher values about that diet: they have been more convinced of the benefits of the flexitarian diet.

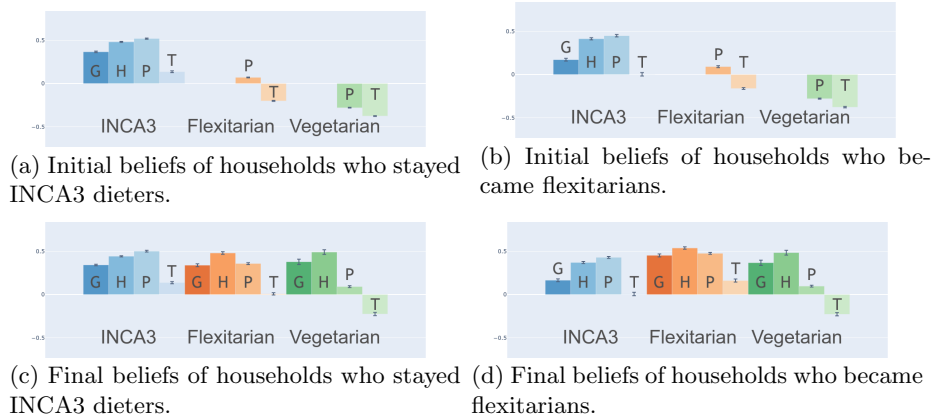


Fig. 1: Average beliefs (and its standard deviation over the simulations) of households initially INCA3 dieters. For each diet, beliefs are: GHG reduction (G), health (H), pleasure (P) and time saving (T).

Diffusion of a fake news We will now illustrate the impact that a minority of the population can have on the whole population, through the spread of fake news. It is a known social phenomenon, which is also emerging in our model. To illustrate this more visibly, we attribute to all households an extreme value of -1 for the belief on the perception of the impact of global warming (PCC):

households thus believe that the latter will only have positive effects on humans. Other initial beliefs are not changed.

We then observe that a minority of vegetarians and flexitarians, who believe that their diet does little to reduce GHG emissions (and therefore that it allows global warming, perceived as favorable here), very strongly disseminate these beliefs out of proactivity. This is illustrated in Fig. 2, where households initially INCA3 practitioners received beliefs close to 0 concerning the reduction of GHG emissions from the vegetarian or flexitarian diet that they finally chose. The impact of this diffusion is significant: at the end of the simulation 34.5 % of the population is flexitarian and 19.5 % is vegetarian, ironically leading to a reduction of GHG emissions from food associated with diet choice of 14 % compared to the control simulation (comparison over the last year). In this experiment, the fake news (vegetarian or flexitarian diet do not help to reduce GHG) entails a virtuous choice, but for a wrong and paradoxal reason, when some essential information is missing (climate change is not good).

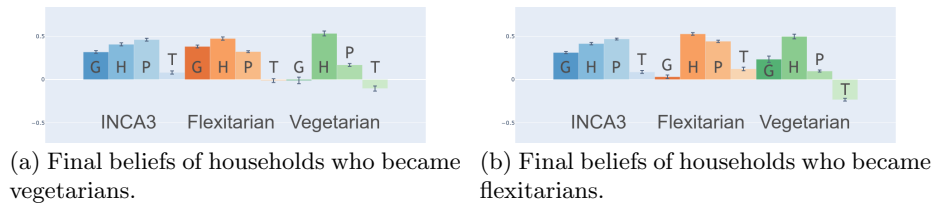


Fig. 2: Average final beliefs (and its standard deviation over the simulations) of initially INCA3 diet practitioners who have adopted another diet. For each diet, beliefs are: GHG reduction (G), health (H), pleasure (P) and time saving (T).

5 Discussion

In this paper, we have presented the outline of G-Impact, an agent-based model that combines modelling of household consumption and belief diffusion. The method used to apply the model to food can be followed to apply the model to other types of consumption (simultaneously or not).

The strength of our approach is that it provides a descriptive but also explanatory analysis, notably via beliefs, at the macro and micro levels. The objective of this model is to enable the design and testing of information and incentive policies to reduce GHG emissions, in particular policies targeting specific population groups.

Preliminary experiments highlight the important impact of the diffusion of beliefs and social interactions on household consumption behavior. We have seen that a minority of the population, ill-informed about their own practices, can spread false information to a large part of the population. It is therefore very important to inform the population widely about their own practices, even when they are in the minority.

Several elements of the model can still be improved, such as adding weights on the criteria, incorporating personal norms and ethical criteria, or allowing households to acquire beliefs after choosing a modality, using a feedback loop.

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