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Alternative scenarios of green consumption in Italy: An empirically grounded model

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ABSTRACT

Any transition towards a more environmentally sustainable world will strongly depend on people's willingness to adopt the best available practices. We present here the *Consumption Italy* (*CITA*) model, an empirically grounded agent-based model designed to represent household consumption in Italy and to estimate the related greenhouse gas emissions under different environmental policy scenarios. We explored the effect of a price increase for high impact goods and services (e.g., because of the introduction carbon taxes) and of a change of agents' environmental concern (e.g., because of information campaigns). We found that both kind of actions can orient people consumption in the desired direction. However, their target and intensity should be carefully calibrated to produce significant effects at an acceptable cost.

1. Introduction

Shaping a sustainable path of development represents a major challenge that will lead to important changes in the production and consumption processes of the upcoming decades (e.g., Jackson, 2009; Rockström et al., 2009; Stern, 2007; Volk, 2008). While many environmental issues, including climate change, can be addressed by available technologies (Pacala and Socolow, 2004; Patrinos and Bradley, 2009), any transition towards a more sustainable world will strongly depend on people's willingness to adopt the best available practices. However, research showed that environmental concern does not directly translate into actual green behaviour and that consumption patterns often present strong lock-in features (e.g., Dietz et al., 1998; Diekmann and Preisendörfer, 1998, 2003; Jager, 2000). The problem here is that people's behaviours are interdependent and that changes are costly. Individuals affect each others in their consumption choices and social comparison is an important factor in decision making processes. Moreover, structural and institutional constraints often prevent significant behavioural change even when a clear willingness is present.

Due to these self-reinforcing processes, it can be difficult, although not impossible, to motivate people to change their usual behaviours and to adopt existing green alternatives. Indeed, past research on the impact of green consumption policies on consumers' behaviour led to mixed findings. On the one hand, some studies argued that economic incentives and structural arrangements are more efficient in reducing environmental impact than intervening on environmental consciousness or ecological knowledge, especially when the costs linked with the transition towards more sustainable behaviours are significant (Diekmann and Preisendörfer, 1998, 2003; Polhill et al., 2013). Moreover, Dunlap and McCright (2008) and Schultz (2000) showed that a significant part of the western population has little sensitivity to informational or educational campaigns, making price-based policies more effective.

On the other hand, Jackson (2005), reviewing the outcomes of current environmental policies, argued that the evidence for a significant effect of environmental taxes on consumer behaviour is weak. For instance, it has been estimated that achieving significant

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and steady reductions in energy use would require a rise in prices by 3–5% per year (Michaelis, 1997). More generally, a sustained reduction in resource use at the global level would require price levels that are even difficult to propose in the current political arena (ECMT and OECD, 1995).

Jackson and Michaelis (2003) held a more optimistic view of public policies based on information and persuasion. They reported about the effects of a UK public campaign that led to a significant rise in the awareness of the link between individual behaviour and the environment. Other authors similarly argued that informational and normative-based policies are more effective than economic stimuli in producing behavioural change (Dobson, 2007; Sheth et al., 1991; Sutcliffe et al., 2008). Nevertheless, the value-action gap remains a widely recognized issue, suggesting that a raise in environmental awareness could have little effect in producing an actual change in consumers' behaviour (DEFRA, 2006; Stern et al., 1996; Young et al., 2010) and recommending more focused information campaigns—along with the change of structural limits, e.g., through increased availability of green products—to obtain significant results (Jackson, 2005).

To better understand the link between consumers' attitudes and behaviours, social influence, and green policies, it is hence crucial to design credible models of the consumers' response to green stimuli. In this paper, we tested the effect of alternative policy options on a virtual sample of Italian households. Through an empirically-grounded agent-based model (ABM), called *Consumption Italy* (*CITA*), we studied whether price-based or information-based policies are more effective in motivating people to reduce their greenhouse gases (GHG) emission in three domains, namely food, transports and energy consumption.

The remaining of the paper is organized as follows. Section 2 defines the model. Section 3 grounds it into empirical data. Section 4 presents the model calibration and the outcomes resulting from a number of different policy scenarios. Finally, Section 5 discusses the results.

2. Methods

Agent-based models are simulated systems including the following elements: (i) an environment, i.e., a set of objects which may be displaced, created, deleted or modified by the agents; (ii) a set of active agents; (iii) a set of relationships linking objects and/or agents together; (iv) a set of operators allowing the agents to interact with the objects. Agents are entities able to perform autonomous actions within their environment and to interact with other agents. Their decision making process is not necessarily based on rational choice and their representation of the environment may be inaccurate (Ferber, 1999; Gilbert, 2008; Grimm, 1999).

ABMs represent a valuable alternative to represent complex systems formed by a large number of heterogeneous agents, where traditional forms of modelling (e.g., mathematical, statistical) present significant shortcomings like analytical intractability or unacceptable assumptions (Railsback and Grimm, 2005). Due to their flexibility, ABMs are especially well adapted to model social-ecological systems (Filatova et al., 2013; Janssen and Ostrom, 2006; Poteete et al., 2010; Schreinemachers and Berger, 2011). They are especially useful to integrate the influence of micro-level decision making into the system dynamics and, hence, to study the emergence of collective responses to policies (Balbi and Giupponi, 2009; Hare and Deadman, 2004; Matthews et al., 2007). One particular advantage of using ABMs in the study of consumers' behaviour is the possibility of modelling agents holding heterogeneous preferences and following a broader pattern of decision rules than simply the profit-maximization one (Jager, 2000). Moreover, agents can be developed to reflect the empirical distribution of preferences, motivations and environmental concern resulting from surveys or other studies based on statistical samples of the target population (Boero and Squazzoni, 2005; Janssen and Ostrom, 2006; Gilbert, 2008; Smajgl et al., 2011).

2.1. Model overview

Within the larger framework of the *Green Economy Research on the Mediterranean Environment* (GERME) project of the Collegio Carlo Alberto, two complementary models were developed: a hybrid Life Cycle–Environmental Input Output Analysis (*LCA–EIOA*) tool to assess GHG emissions and *CITA*, an empirically grounded agent-based model to estimate Italian household consumption under different environmental policy scenarios. The two models work in synergy to assess the effect of different environmental policy scenarios on Italian households' GHG emissions.

The first model is the *LCA–EIOA* tool, developed by Padovan et al. (2012) starting from the work of Wilting (1996). This method quantifies the total energy demand of households for a given population (e.g., a city, a region or an entire country) as a proxy of their environmental pressure. As highlighted in the international literature (e.g., Hertwich, 2011; Wiedmann, 2009), hybrid LCA–EIOA methods are preferable to standalone methodologies because they benefit both from the completeness of EIOA (Environmental Input Output Analysis), which uses a "top-down" approach, and from the specificity of LCA (Life Cycle Assessment), which instead adopts a "bottom-up" approach. Within the GERME project, the *LCA–EIOA* model has been applied to quantify the environmental requirements of specific household metabolic patterns (Kok et al., 2003), including the ones used by the *CITA* model.

The second model, *CITA*, takes inputs from the social and political realms and maps them into consumers' choices, hence creating variable scenarios depending on assumptions about future environmental policies and/or changes in the environmental concern of consumers.[1] The model is based on agents choosing between alternative "consumption patterns" (hereafter CP) depending on their own preferences, social influence and the relative price of the different patterns. A CP is here an *a priori* defined style of food, transport or energy consumption, which represent three separate aspects of a specific lifestyle that were selected according to their weight on households' GHG emissions (Hertwich, 2011). Note that the same CPs are used in both the *LCA–EIOA* and the *CITA* models, hence representing the direct interface between the two models.

Agents have preferences based on the ones expressed by real individuals in the Eurobarometer Survey, Wave 68.2 (hereafter EB 68.2) (see Eurobarometer, 2008). Politics enter the model by changing the relative price of different commodities (e.g., via carbon taxes or incentives for green products) or by modifying agents' preferences (e.g., via information campaigns) (Section 4.2). *CITA* hence represents a tool that can be used both to improve our understanding of the drivers of consumption and to create scenarios about the effects of alternative environmental policies.

2.2. The agents

Agents in *CITA* are based on Janssen and Jager's model of green product diffusion (Janssen and Jager, 2002). Each agent i possesses a set of preferences $P_i = \{p_{i1},\ldots,p_{im}\}$ including $m = 4$ dimensions. Here, p_{i1} refers to the environmental dimension of food production, p_{i2} to food health and safety, p_{i3} to sustainability in transportation and p_{i4} to sustainability in energy consumption. Each agent maps one of the Italian respondents of the EB 68.2 survey, with its preferences deriving from the answers given by the corresponding individual in the survey (see Section 3.1).

In each time step, agents choose among the available CPs in three different "domains": the first one concerning food, the second transportation and the third energy consumption. Agents have both personal and social needs, whose satisfaction is affected by their CPs. Personal need satisfaction depends on the difference between the dimension d_{jk} of CP k (note that each domain j can include a variable number of patterns) and the corresponding agent preference. Formally, the personal need satisfaction of agent i consuming pattern k of domain j is defined as

$$N_{ik}^{p} = 1 - \frac{\left|p_{ij} - d_{jk}\right|}{m} \qquad (1)$$

Note that, while CPs referring to transports and energy have only one dimension (environmental sustainability), CPs referring to food consumption hold two different dimensions, namely environmental sustainability and health (see Section 3.2). In this case, the agent satisfaction is simply computed by averaging Equation (1) over the two dimensions.

Agents are embedded in a social network. To build it, we followed a principle of homophily, i.e., agents have a higher probability to be linked with other agents having similar preferences (see Section 3.1). The underlying assumption is that agents are more likely to be influenced in their consumption choices by other agents sharing similar worldviews on environmental (or health) issues. More specifically, each agent created $l = 3$ undirected links with other agents having the lowest Euclidean distance over the m dimensions of the preference array. The above linking procedure produced a clustered network with similar agents closely linked together. Subsequently, a small proportion $p = 0.05$ of agents established random links with other agents to create the small-world like network that was also used in Janssen and Jager (2002) (for the details of the small-world network construction, see Watts, 1999; Watts and Strogatz, 1998).

Following Janssen and Jager (2002), we assumed that agents derive social satisfaction from their relations and prefer to have CPs similar to their neighbours'

[1] The *CITA* model is based on the Netlogo platform (Wilensky, 1999). Interested readers can download a copy of the model from the OpenABM (http://www.openabm.org/model/3708/version/1) repository, along with a complete description following the ODD protocol (Grimm et al., 2010).

ones. Social satisfaction is hence defined as the proportion of agents in the neighbourhood of i choosing the same pattern as i

$$N_{ik}^{S} = \frac{n_i^k}{n_i} \quad (2)$$

where n_i^k is the number of agents in i neighbourhood with pattern k, while n_i is the total number of agents in the neighbourhood.

The total level of need satisfaction of agent i choosing pattern k is given by the weighted sum of personal and social satisfaction, divided by the relative price r_k of the pattern.

$$N_{ik} = \frac{\beta_i N_{ik}^{S} + (1-\beta_i) N_{ik}^{p}}{r_k} \quad (3)$$

where $\beta_i \in [0,1]$ is a randomly distributed agent parameter determining how much personal needs are weighted vs. social ones, while r_k is calculated using as reference the cost of the average Italian behaviour in each consumption domain (see Section 3.2).

2.3. Agents' decisions

In each time step, agents take independent choices regarding all three consumption domains. The cognitive process actually used depends on the agents' state. They can use rational deliberative processes, imitate the behaviour of other agents, socially compare their satisfaction level with their neighbours' one or simply repeat over time the same behaviour. Two variables are relevant to select the specific choice procedure, namely the agent's level of need satisfaction and its level of uncertainty. Need satisfaction is defined by Equation (3), while uncertainty depends on the variation over time of the agent's satisfaction. It is assumed that a high variability in satisfaction involves greater uncertainty for agents, since this makes it difficult to forecast the consequences of their choices. More precisely, following Janssen and Jager (2002), we defined uncertainty as

$$U_{it} = \sqrt{\left|N_{it} - N_{i(t-1)}\right|} \quad (4)$$

where t is the decision time for agent i. Agents with high need satisfaction and low uncertainty—i.e., with $N_i \geq \tau_n$ and $U_i \leq \tau_u$, where τ_n and τ_u are two exogenously defined thresholds for need satisfaction and uncertainty respectively—will simply repeat their previous decision. Agents with high satisfaction and high uncertainty will imitate the most common behaviour in their neighbourhood. Agents with low satisfaction and low uncertainty will use deliberation, i.e., will estimate the expected satisfaction for all possible CPs and choose the one leading to the highest result. Finally, dissatisfied and uncertain agents will enter in social comparison, i.e., they will compare the satisfaction deriving from keeping the same pattern as before with the one that would derive from choosing the pattern that is most common in the neighbourhood. Table 1 summarizes all deliberative processes along with the conditions for their application.

In each simulation step, agents first calculate their level of uncertainty and satisfaction for each CP, then choose the new CPs following one of the above procedures. The simulation goes on until the model reaches an equilibrium, i.e., agents no longer change their CPs.

Table 1
Summary of deliberative processes.

Satisfaction	Uncertainty	Deliberative process	Process details
$\geq\tau_n$	$\leq\tau_u$	Repetition	Repeat the previous choice.
$\geq\tau_n$	$>\tau_u$	Imitation	Check the CP distribution in the neighbourhood and adopt the modal CP. In case of a tie, randomly select one of the most common CPs.
$<\tau_n$	$\leq\tau_u$	Deliberation	Compute the expected satisfaction for each possible CP, then choose the one leading to the highest satisfaction. In case of a tie, randomly select one of the CPs leading to the highest satisfaction.
$<\tau_n$	$>\tau_u$	Social comparison	Check which CP is most common in the neighbourhood. In case of a tie, randomly select one of the most common CPs. Compare the expected satisfaction of the selected CP with the one of your current CP and select the one leading to the highest satisfaction. In case of a tie, select one of the two CPs at random.

3. Grounding the model into empirical data

3.1. Agents' preferences

Agents' preferences have four dimensions: food sustainability, food health, transport sustainability, and energy sustainability. To estimate them, we used EB 68.2 data, downloaded from the ZACAT-GESIS catalogue (http://zacat.gesis.org/). More specifically, we summarized in the vector P_i, having length four and determining the preferences of each agent, 12 questions on the European Common Agricultural Policy (CAP) and on the role of farmers in society, 5 questions on transportation, and 2 questions on energy consumption (see Table 2).

Preferences in P_i are represented as indexes bounded in the [0,1] interval, with 1 meaning a greater concern for the domain under consideration, namely food sustainability, food health, transport sustainability and energy sustainability. To compute the indexes, we first added all answers given by a single responder relatively to a specific domain, then we divided the result by the highest value in our dataset. Applying this strategy on EB 68.2 Italian data, we modelled 955 agents, each representing one responder. The resulting preference distribution is presented in Fig. 1.

Note that preferences are either weakly correlated or not correlated at all. More specifically, food sustainability weakly, but significantly correlates with food health ($r = 0.23$, $p < 0.001$) and energy ($r = 0.16$, $p < 0.001$), while food health correlates with energy ($r = 0.25$, $p < 0.001$). All other correlations are not significant, and even the ones above show that responders' preferences present little coherence across domains: a fact justifying our decision to model as independent the different agents' choices.

To check for the reliability of our indexes, we estimated logit models showing that both the food and the health indexes are significant predictors for the purchase of environmentally labelled products, while the energy one is a predictor for the purchase of local products. Moreover, both the food and the transport index are positively correlated with the *willingness* to buy environmentally friendly products, even at a slightly higher cost. The energy index is

Table 2
Summary of EB 68.2 variables used to estimate agents' preferences.

Topic	Variable name	Variable label	Values
Food sustainability	v360	CAP priorities: sustainable practices	{0,1}
	v361	CAP priorities: favour organic production	{0,1}
	v363	CAP priorities: respect for the environment	{0,1}
	v365	CAP priorities: farm animal welfare	{0,1}
	v404	Farmers in society: environment protection	{0,1}
	v409	Farmers in society: farm animal welfare	{0,1}
Food health	v361	CAP priorities: favour organic production	{0,1}
	v364	CAP priorities: healthy & safe products	{0,1}
	v366	CAP priorities: information about food	{0,1}
	v367	CAP priorities: quality production	{0,1}
	v405	Farmers in society: healthy and safe food	{0,1}
	v408	Farmers in society: diversity of quality products	{0,1}
Transportation	v491	Environmental worry: transport modes	{0,1}
	v550	Environment done for: travelling	{0,1}
	v557	Environment done for: less car use	{0,1}
	v562	Environment citizen priority: public transports	{0,1}
	v563	Environment citizen priority: energy efficient cars	{0,1}
Energy	v554	Environment done for: energy consumption	{0,1}
	v567	Environment citizen priority: reduce energy	{0,1}

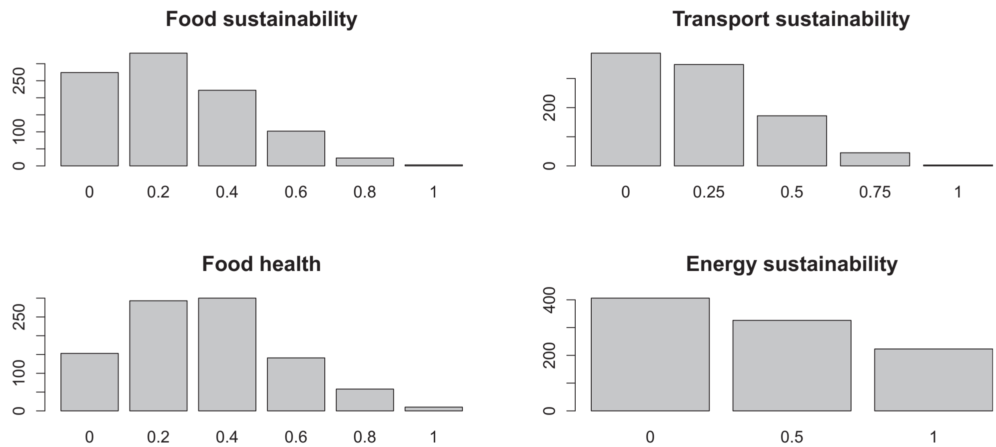

Fig. 1. Distribution of agents' preferences.

weakly, but negatively, correlated with the same variable.[2] Overall, these statistics suggest that our indexes can significantly capture at least some important drivers of environmental behaviour within the sample given by the Italian responders to the EB 68.2 survey.

3.2. Definition of consumption patterns

Household consumption represents an important driver of the total pressure on natural systems. According to a recent literature review, housing accounts for 35–53% of the total energy use, mobility (including fuel use, vehicle purchase and public transportation) for 15–31%, food for 11–19%, recreational activities for 4–10%, clothing for 3–5%, and health for 1–5% (Hertwich, 2011). Moreover, a comprehensive research across Europe found that 31% of GHG emissions depend on food, beverage, tobacco and narcotics, 2% on clothing and footwear, 24% on housing, furniture, equipment and utility use, 2% on health, 19% on transports, 2% on communication, 6% on education, 9% on restaurants and hotels, and 5% on other goods and services (Tukker et al., 2006).

Overall, these data show that food, housing and transportation represent the three major sources of environmental impact related to household consumption. We hence decided to focus on these three domains, creating for each of them different alternative situations based on specific consumption patterns. The different CPs where set-up starting from Italian average data obtained by the national statistical agency (ISTAT) database, which were used as reference (ISTAT, 2009). In each domain (but the food one, where CPs were modelled taking into account some common consumption patterns in Italy), three CPs were created: (i) the brown CP, which represents the consumption pattern with the heaviest environmental burden; (ii) the green CP, having the smaller environmental impact; (iii) the intermediate CP, with intermediate environmental properties. The environmental impact of all CPs was evaluated using the *LCA–EIOA* tool. Table 3 presents an overview of all the selected CPs and of their main characteristics.

Consistently with previous research (e.g., Fiala, 2008), the *LCA–EIOA* analysis highlighted that the most environmental friendly CP in the food domain corresponds to a vegetarian diet, while the most impacting one is the pattern including the highest quantity of animal protein (Cerutti et al., 2012). Among the several CPs showing intermediate environmental performance that were tested, we decided to include in the analysis two patterns that are especially relevant in Italy: the healthy diet, as defined by the Italian Society of Human Nutrition (www.sinu.it/index.asp), and the Mediterranean one, as defined by the National Research Institute of Nutrition (www.inran.it/) (Table 3).

Consumption patterns included in the transport domain were based on the share of kilometres travelled using public transportation on the total of number of kilometres travelled by the population of the selected country. According to the ODYSSEE database (www.odyssee-indicators.org), the Italian share of public transportation was 18.2% in 2009. We used this figure as reference to set up the transportation expenditures for an Italian family under three different situations: (i) the brown CP, encompassing 15% of public transportation; (ii) the intermediate CP, including 25% of public transportations; and (iii) the green CP, with 30% of public transportation (Table 3).

Consumption patterns included in the energy domain also derived from ISTAT 2009 data. The benchmark was the Italian average of household electricity consumption and appliance distribution. The approach of conditional demand (see Caves et al., 1987; Parti and Parti, 1980) allowed to decompose the total domestic expenses for electricity as a function of the possession of various appliances. To construct the brown CP, we assumed the possession and a high rate use of all appliances having statistically the highest impact on total consumption. To define the intermediate CP, we assumed that the utilization of the main appliances was halved with respect to their average utilization and that some minor appliances were absent. In the green CP, only the appliances forming the household constant quota of consumption were included, together with computer and television. Moreover, lighting consumption was reduced by one third with respect to average data. For each pattern we calculated the total consumption in kWh and the corresponding monetary expense, referring for that to the 2009 figures given by the Italian energy authority (AEEG, see www.autorita.energia.it/it/dati/ees5_09.htm).

4. Results

4.1. Model calibration

Preliminary analyses showed that the model is little sensitive to variations in the network parameters, at least under a reasonable

[2] This last correlation may be explained by the phrasing of the question in the EB 68.2 questionnaire, which mentioned the purchasing of "environmentally friendly products" without any reference to energy saving actions. This negative correlation can be contrasted with the positive relation that the same variable holds with the purchasing of local products, which is often thought as a way of reducing GHG emissions by reducing transport requirements.

Table 3
Overview of the consumption patterns and of their environmental impact. All data represent monthly averages per household. Consumption patterns based on ISTAT averages are included as reference.

Domain	Consumption pattern	Emissions (CO_2 eq. kg)	Environmental index	Health index	Abs. cost (Euro)	Relative cost
Food	Brown	519.95	0.00	0.00	632.97	1.24
	Healthy	335.99	0.86	1.00	440.00	0.86
	Mediterranean	319.80	0.93	0.50	416.89	0.82
	Green	305.07	1.00	0.50	394.53	0.77
	Reference (ISTAT)	*419.87*	*0.47*	*0.25*	*510.11*	*1.00*
Transportation	Brown	70.86	0.00		107.42	1.03
	Intermediate	63.36	0.52		96.94	0.93
	Green	56.49	1.00		87.43	0.83
	Reference (ISTAT)	*68.96*	*0.13*		*104.76*	*1.00*
Energy	Brown	275.11	0.00		60.10	1.23
	Intermediate	194.80	0.68		43.39	0.89
	Green	157.37	1.00		35.10	0.72
	Reference (ISTAT)	*221.17*	*0.46*		*48.87*	*1.00*

interval of values.[3] We hence kept them fixed at the value of $l = 3$ and $p = 0.05$. A similar finding concerned the distribution of the β_i parameter, that was kept uniform in the [0,1] range in all simulations.

To calibrate the model against empirical data, we used the average monthly expenditures of Italian households derived from the ISTAT 2009 tables. The two parameters used in the calibration process are the need satisfaction (τ_n) and uncertainty (τ_u) thresholds. We tested all combinations resulting from $\tau_n \in \{0.1,0.2,\ldots,0.9\}$ and $\tau_u \in \{0.1,0.2,\ldots,0.9\}$, running 100 replications of the model for each combination of the two parameters and recording the resulting CP equilibrium distributions. We then chose the parameter combination leading to the overall household expenditure closest to the empirical one. We did this by summing the absolute differences between the average results for food, transportation and energy and the corresponding ISTAT figures and by choosing the parameter combination minimizing this value. Fig. 2 presents an overview of the calibration results.

The parameter configuration that led to the best reproduction of the empirical data was $\tau_n = 0.5$ and $\tau_u = 0.2$. Note that correcting our data by weighting them to take into account the different amount spent by households in the different domains led to the selection of the same parameter values. Overall, our best estimations led to an average monthly expenditure of 513.01 Euro for food, 101.74 Euro for transports, and 47.96 Euro for energy. In all three domains, the error is less than 3% (more specifically, 0.6% for food, 2.9% for transports and 2.0% for energy), while the overall error is only 0.16%, which represents a satisfying test of the capacity of our model to correctly approximate the real data. Moreover, being simultaneously able to fit real choices in different domains represents a form of pattern-oriented modelling (Grimm et al., 2005) that further increased our confidence in these results.

Using this parameter configuration, in the food domain 42.9% of the agents chose the brown CP, 23.6% the healthy one, 23.6% the Mediterranean one, and 9.8% the green one, leading to an average emission of 408.18 CO_2 equivalent kg per month. Note that, while CO_2 figures are not easily comparable to the real-world behaviour of households, the share of agents choosing the green pattern is comparable, although somewhat higher, to the number of Italian vegetarians, that a recent survey estimated to be close to 7% of the total population (Eurispes, 2011).

In the transportation domain, 52.2% of the agents selected the brown CP, 40.6% the intermediate one and 7.1% the green one, leading to an average emission of 66.79 CO_2 equivalent kg per month. Recalling that we built the three CPs taking into account a share of public transportation of 15%, 25% and 30% respectively, this leads to a 20.1% average of public transportation use, somewhat but not substantially higher than the 18.2% share estimated in Italy for 2009 (see www.odyssee-indicators.org).

Finally, 41.1% of our agents chose the brown energy CP, 31.2% the intermediate one and 27.7% the green one. The resulting average energy consumption was 280 kW h per month, only slightly lower than the Italian actual average of 285 kW h/month.

4.2. Policy scenarios

Keeping fixed τ_n and τ_u at the values above, we separately explored the effect of an increase in prices proportional to the environmental impact of each CP (e.g., via carbon taxes) and of changes in the agents' preferences (e.g., because of educational campaigns).

4.2.1. Price change scenarios

In the price change scenarios, the prices of all CPs were risen by $(1 - d_k)\delta_1 r_k$, where $\delta_1 \in \{0.0,0.1,\ldots,1\}$. The actual increase hence

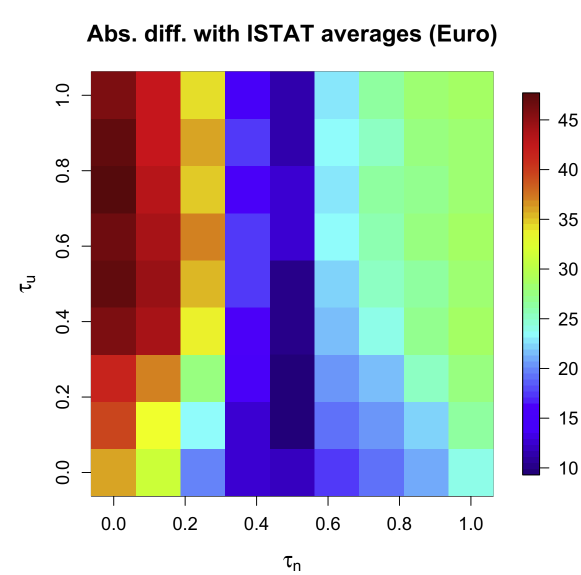

Fig. 2. Overview of the calibration results.

[3] We also tried alternative network structures, e.g., the Hamill and Gilbert (2009) "social circles" one, that only led to minor differences in our outcomes.

depended not only on the global parameter δ_1, setting the maximum proportion of price change, but also on the environmental index of each CP, with green CP prices that remained unchanged and brown CP ones that bore the maximal increase. For each value of the δ_1 parameter, we ran 100 further simulation. Fig. 3 presents an overview of the resulting pattern distributions.

In the food domain, increasing prices led to a significant reduction in the adoption of the brown pattern, with a large increase of the share of agents choosing the healthy and the Mediterranean ones but only a small improvement of the most sustainable behaviour (Fig. 3a). On average, monthly emissions decreased up to 17% for $\delta_1 = 1$. Emission gains in transports and energy were more limited, around 3% and 5% respectively. The transports domain showed limited changes, even if the adoption of the green CP significantly increased for high δ_1 values. The significant increase of the share of the green CP in the energy domain occurred mainly at the expense of the intermediate one, with only a small reduction of the number of agents adopting the brown CP (Fig. 3b,c). Over the three domains, setting $\delta_1 = 1$, which caused a doubling of the brown CP price and smaller increases for the other ones, led to a reduction of 84.79 CO_2 equivalent kg per household per month, i.e., 12% of households' GHG emissions.

4.2.2. Preference change scenarios

Besides price changes, we designed two different sets of preference change scenarios. The first one simulated information campaigns having no specific population target. We assumed that, everything else being equal, these will have more influence on agents with already developed environmental preferences. This is because the agents' higher sensitivity to environmental issues makes them more receptive to the campaign contents. Formally, this assumption was implemented by adding $\delta_2 p_{ik}$ to p_{i1}, p_{i3} and p_{i4}, while p_{i2} (health preference) was not changed. The parameter $\delta_2 = \{0.0, 0.1, \ldots, 1\}$ represents the policy intensity. For each value of δ_2, we ran 100 further simulations. Fig. 4 presents the resulting CP distribution for each δ_2 level.

Preference changes led to results that are similar to the ones obtained with price changes, although less pronounced. The maximum emission decline was 5% in the food domain, 4% in the transport domain and 2% in the energy domain. In all cases this occurred for $\delta_2 = 1$. The overall gain in emissions was only of 29.98 CO_2 equivalent kg per household per month, i.e., about 4% of overall household emissions.

In the second set of preference change scenarios, we assumed programmes specifically targeted to agents having low environmental preferences. While this population group is the one most difficult to reach by any pro-environment initiative, it is also the one in which the potential effect of any successful action is greater. We hence designed a condition where the lower the environmental attitude of the agent the higher the preference change. Formally, we added to p_{i1}, p_{i3} and p_{i4} the amount $(1 - p_{ik})\delta_3$, where $\delta_3 = \{0.0, 0.1, \ldots, 1\}$ represents the policy intensity. Note that the formula above implies that, for $\delta_3 = 1$, all agents will have fully green environmental preferences. For each value of δ_3, we ran 100 further simulation runs. Fig. 5 presents the resulting CP distributions.

Policies targeting agents having low environmental concern led to significant behavioural changes. In the food domain, emission reduction reached 20% for $\delta_3 = 0.9$. Note that, the improvement was slightly less pronounced for $\delta_3 = 1$ due to a sudden rise of the healthy CP at the expense of both the Mediterranean and the green ones (Fig. 5a). This somewhat unrealistic feature of the model depends on the fact that, for $\delta_3 = 1$, all p_{ik} but p_{i2} (health preferences) become equal to one, irrespectively of the actual preferences expressed in the EB 68.2 survey. As a consequence, p_{i2} remains the only factor affecting the shape of the agents' network. This strongly reinforces the behaviour of health concerned agents, now closely linked, that spreads from this cluster to the remaining of the population. This interpretation is confirmed by the fact that, applying the $\delta_3 = 1$ change also to p_{i2}, the sudden increase in the adoption of the healthy CP no longer occurs.

Emissions in the transport domain declined by 15% for $\delta_3 = 1$, and the reduction was even more pronounced in the energy domain (24%). It is also interesting to note that, in all domains, the brown CP almost disappeared for value of δ_3 greater than 0.5 (Fig. 5). Overall, this set of scenarios led to a 17% emission reduction already for $\delta_3 = 0.5$, and to a 20% reduction for $\delta_3 = 1$, corresponding, respectively, to 120.54 and 137.86 CO_2 equivalent kg per household per month.

5. Discussion

In the *CITA* model, virtual households choose among alternative consumption patterns presenting different degrees of environmental impact (GHG emissions). Agents' behavioural routines derive from Janssen and Jager (2002) model, while agents'

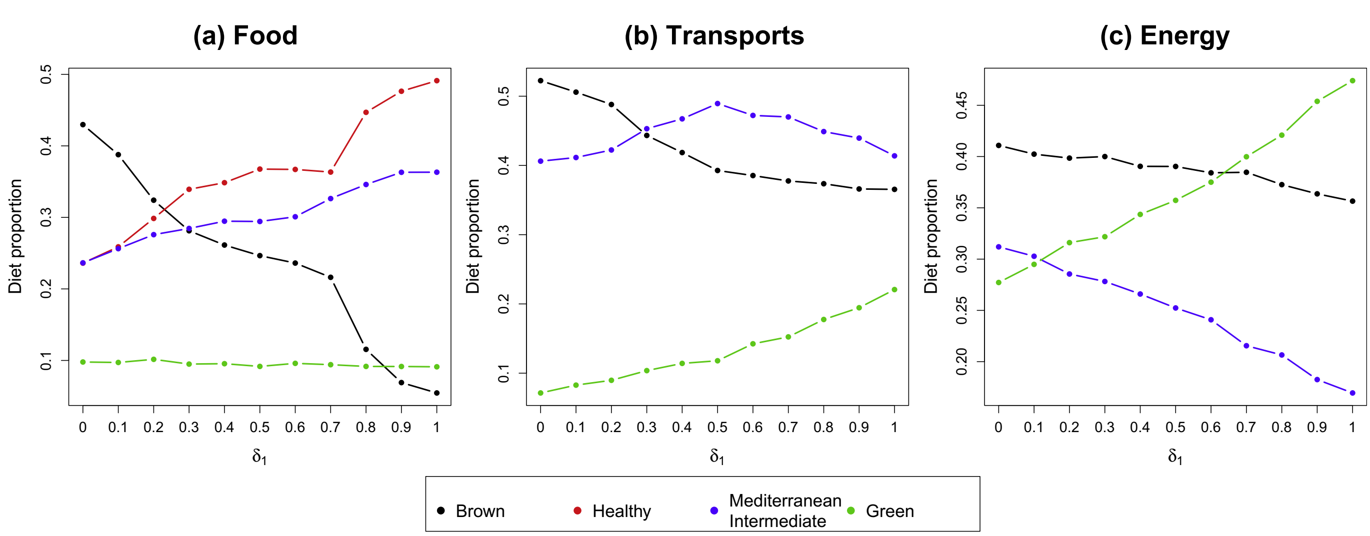

Fig. 3. Price change scenarios for food (a), transport (b) and energy (c) consumption patterns.

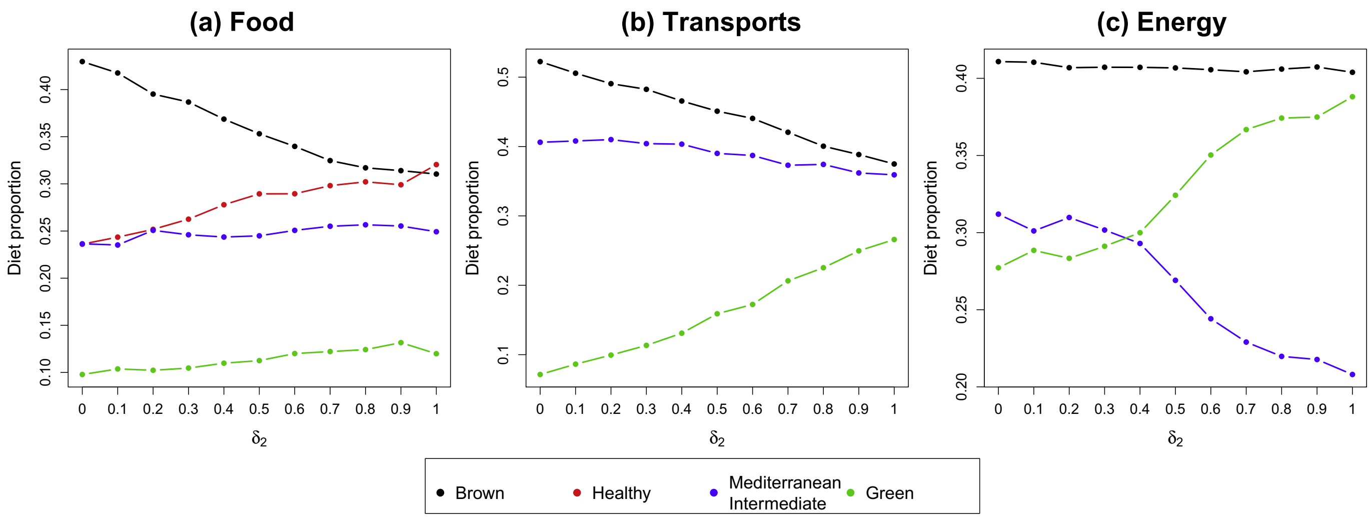

Fig. 4. First set of preference change scenarios for food (a), transport (b) and energy (c) consumption patterns.

preferences are based on Eurobarometer data. Overall, the model succeeded in reproducing Italian household expenditures in different consumption domains—namely food, transportation and energy—and allowed to estimate CO_2 emissions under various policy assumption. Fig. 6 summarizes the emission gains resulting from all the explored scenarios.

The first group of scenarios considered price changes. These led to an important reduction in GHGs, even if relatively high levels of price increase for "brown" goods—up to their doubling—are required to obtain a significant effect. Moreover, most of the gains pertained to the food domain, while transports and energy showed more limited variations. Nevertheless, taking into account that, according to ISTAT, Italian households were over 24 millions in 2008, the forecasted reduction of 85 CO_2 equivalent kg per household per month means almost 25 billions CO_2 equivalent kg of avoided emissions per year at the country level. This represents about 6% of total Italian CO_2 emissions, which exceeded 445 billions kg in 2008.[4]

Note that, while in the transport and energy domains the share of green CPs significantly increased with δ_1, the same did not occur in the food one. Here the reduction in the number of agents choosing the brown pattern mainly translated into a larger adoption of the healthy and intermediate patterns. This implies that part of the potential emission gain in this domain does not occur even with the imposition of high prices. We consider this feature of the model quite realistic since, while it makes sense that an extra cost on high environmental impact items, like meat, will reduce their consumption, it is unlikely that price-based policies will convince people to become fully vegetarian: a choice that usually depends on deep personal values and motivations.

The preference change scenarios led to mixed results. Generic informational policies produced only limited gains, even for high levels of policy intensity: at best around 4% of total household emissions. This mainly happened because preferences expressed in the EB 68.2 survey were far from the ones needed to adopt the greenest patterns. As a consequence, even relatively high levels δ_2 were not able to drastically alter agents' choices. Moreover, adding $\delta_2 p_{ik}$ to the original preference of agents could not produce any large change in the less environmentally concerned agents (i.e., the ones with $p_{ik} \approx 0$) who represent a significant share of our virtual population.

This could be seen an unrealistic feature of the model deriving from exceedingly restrictive assumptions. Nevertheless, even if the assumption that a significant part of the agents has little sensitivity to generic information campaigns may appear severe, we consider it justified on the light of research showing that this specific population group is little responsive to most of what is usually done (Dunlap and McCright, 2008; Jackson, 2005; Schultz, 2000). It is also worth noting that our results are consistent with the findings presented in Diekmann and Preisendörfer (1998, 2003) who argued that economic incentives and structural arrangements are more effective than factors such as environmental consciousness or ecological knowledge to reduce environmental impact, at least in situations where the costs linked with the transition towards more sustainable behaviours are significant. As a consequence, our finding that generic environmental education actions have little effect on agents' behaviour is, at least, compatible with real-world-based knowledge and not just an arbitrary feature of the model.

While generic educational policies had little effect, policies specifically targeted to the less environmental concerned agents led to much stronger changes. The 20% emission reduction recorded for $\delta_3 = 1$ corresponds to almost 40 billions CO_2 equivalent kg per year at the national level, i.e., 9% of Italian 2008 GHG emissions. Moreover, unlike the other scenarios, where extremely high policy intensities were needed to significantly change the agents' behaviour, here the reduction was already large for $\delta_3 = 0.5$, namely 35 billions CO_2 equivalent kg per year or almost 8% of Italian emissions.

The simultaneously application of preference and price changes led to an overall 19% emission reduction for $\delta_1 = 0.5$ and $\delta_3 = 0.5$, and to a 20% reduction for $\delta_1 = 1$ and $\delta_3 = 0.5$. Although these figures are quite large, it is worth noting that they are less than what could be potentially obtained by separately summing the effects of these two policies. This finding contrasts with Jackson's conclusion that a combination of different policy instruments could be more effective than simple policies based on a single motivational driver (Jackson, 2005). It is difficult to say whether the observed "displacement" between price and informational policies is simply a feature of our model or corresponds to a real trade-off between economic and normative incentives. Supporting the latter idea, some studies have suggested that monetary incentives or fines can undermine intrinsic pro-social motivations and hence produce unintentional effects on people's willingness to cooperate to achieve collective goals (see Bowles, 2008; Frey and Jegen, 2001): an argument that nicely fits with our findings.

[4] Source, The World Bank Data Catalog, <http://data.worldbank.org/data-catalog>.

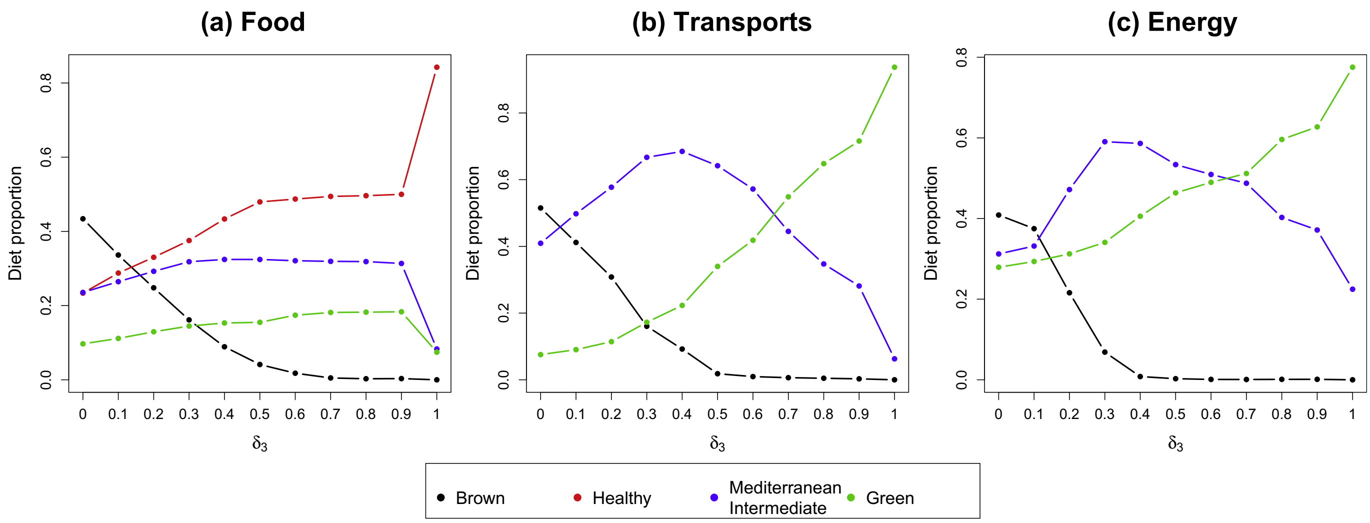

Fig. 5. Second set of preference change scenarios for food (a), transport (b) and energy (c) consumption patterns.

It is worth comparing our model with a similar one where only the deliberation procedure is used to select the different CPs, i.e., with agents following the rationality assumption of much environmental policy (Jackson, 2005). In *CITA*, this corresponds to a situation where agents only derive their satisfaction from the fulfilment of their personal needs with no influence from their neighbours and always select the deliberation procedure. The calibration of the "rational" model on ISTAT data, following a procedure similar to the one presented in Section 4.1, led to average household monthly expenditures of 527.67 Euro for food, 100.71 Euro for transports, and 48.56 Euro for energy. These figures correspond to an overall 2% error, which is much greater than the one for the *CITA* model (0.16%).

Applying the price scenario to the rational model led to lower emissions gains, with a 12% decrease for $\delta_1 = 1$. This reduction is mainly due to the lack of the multiplying effect promoted by social influence (i.e., the imitation and social comparison procedures) in *CITA*. Considering preference changes, $\delta_2 = 1$ led to a 5.4% emission reduction, while $\delta_3 = 0.5$ and $\delta_3 = 1$ led to a 17.5% and 22.2% reduction respectively. These improvement are somewhat greater that the corresponding *CITA* cases because preference changes now directly translate into behavioural ones, without the lock-in effects that are common in the real world (e.g., due to habits), which instead emerged in *CITA*.

Overall, the comparison between an idealistic model (the rational one) and one trying to incorporate some of the social and psychological factors affecting human behaviour (*CITA*) suggests that policies based on a rationality assumption may under-estimate the effect of price-based actions while over-estimating the effect of preference-based ones. From this point of view, our research appears to be more in line with some findings of the environmental social sciences (e.g., Dunlap and McCright, 2008; Schultz, 2000) than with environmental economics ones (e.g., Jackson, 2005).

In the light of the findings of both *CITA* and the rational model, it is worth noting that the current economic downturn led to greener behaviours only in the transport and energy domains. Between 2008 and 2011, Italian households increased their consumptions of high environmental-impact food items (meat, fish and dairy products) while they spent less for fuel and electricity (ISTAT, 2012). However, recently released data showed that, during 2012, meat and fish consumption declined as well (see www.istat.it).

A significant remark regards the role of social influence. On the one hand, this force favours lock-in effects, making small variations in prices or preferences have little effect. This is confirmed by a recent research on carbon tax early adopters that highlighted a weak or insignificant effect of relatively small taxes (often with several exemption possibilities) on CO_2 emissions (Lin and Li, 2011). On the other hand, social influence can act as a multiplier under

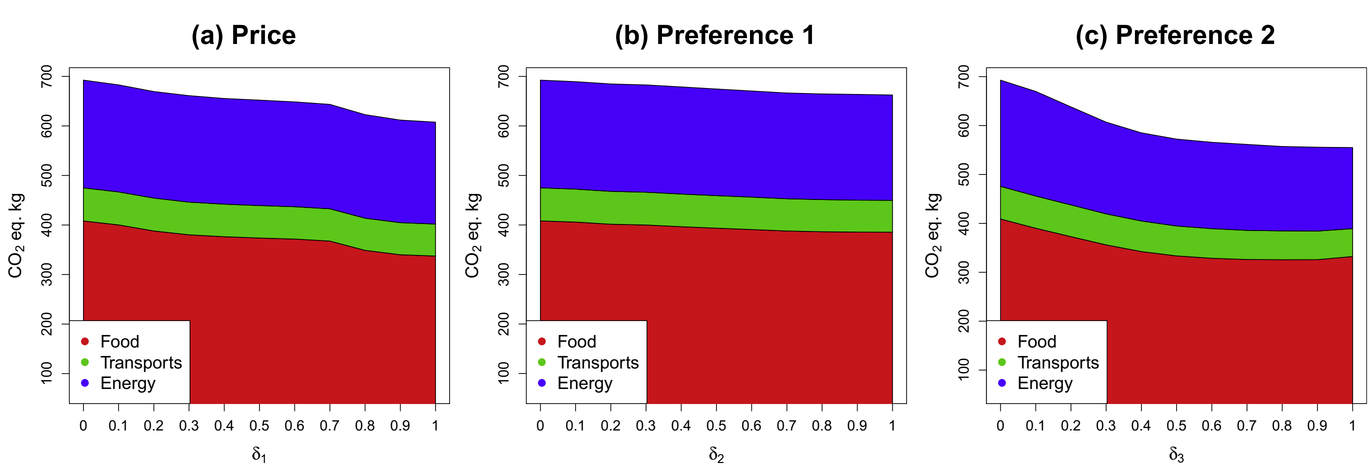

Fig. 6. Total emissions in the price scenarios (a) and the two preference scenario sets (b and c respectively).

higher policy intensities, even if this may happen only above a threshold that is often difficult to reach. Experimental research highlighted the role of information provided by peers, family and friends—i.e., by the closest nodes in a homophily-structured network—on sustainable consumption (Salazar et al., 2012). Together with our finding that educational campaign should target the less environmental friendly agents to be effective, this result suggest that sustainable behaviour could spread at the condition that it breaks the invisible border between green and non-green agents. How policies could do that in practice is a matter of debate. Different options may be valuable, including community-based actions or policies based on role-models (Bell et al., 2005; Jackson, 2005). From this point of view, our model remains agnostic regarding the specific policies to be adopted. However, it shows the need of going beyond generic educational campaign if serious targets of emission reductions should be reached and, more generally, it nicely highlights the large potential gain of preference-based policies if appropriately carried on.

A final note regards the fact that, although in line with the European 20% target for 2020, the reduction in GHG emissions resulting *CITA* even under significant policy changes remained small compared to the one required to avoid the worst consequences of climate change (Allen et al., 2009; IPCC, 2007; Meinshausen et al., 2009). Future developments will hence concentrate on exploring the effects of the interplay of the factors analysed with other policy mechanisms like, for instance, the effect of a reduction in uncertainty or of campaigns specifically targeted to exploit social influence in fostering positive behaviours (see Jackson, 2005; Jager, 2000). Overall, our model proved to be powerful and flexible enough to support such changes. Moreover, its extension to other countries is straightforward, given the existence of appropriate statistical data. Creating scenarios of alternative policy approaches can hence develop both in a significant contribution to our understanding of the drivers of environmental behaviour and in the construction of practical tools able to help the selection of the best policy options to improve our common environment.

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