

Collegio Carlo Alberto



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

Giangiaco­mo Bravo

Elena Vallino

Alessandro K. Cerutti

Maria Beatrice Pairotti

No. 256

June 2012

Carlo Alberto Notebooks

www.carloalberto.org/research/working-papers

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

Giangiaco­mo Bravo*, Elena Vallino†, Alessandro K. Cerutti‡, Maria Beatrice Pairotti§

June 23, 2012

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).

Keywords: household consumption; carbon footprint; environmental policies; agent-based-modelling.

1 Introduction

Shaping a sustainable path of development represents a major challenge that will lead to important changes in production and consumption processes in the near future (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; Janssen and Jager 2002a). The problem is that people’s behaviour is 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

*Department of Economics and Statistics, University of Torino, and Collegio Carlo Alberto. Corresponding author: giangiaco­mo.bravo@unito.it

†Department of Economics and Statistics, University of Torino

‡Department of Agriculture, Forestry and Food Sciences, University of Torino

§Department of Commodity Science, University of Torino

towards more sustainable behaviours are significant (Diekmann and Preisendörfer 2003, 1998). Moreover, Dunlap and McCright (2008) and Schultz (2000) showed that a significant part of the western population is little sensitive to environmental informational or educational campaigns, making price-based policies more effective.

On the other hand, Jackson (2005), reviewing the effect of a large range of 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 and steady reductions in energy use would require a rise in prices by 3–5 percent 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 of 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 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 problem remains a widely recognized issue, suggesting that a raise in environmental awareness could be little effective 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 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. 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.

The remaining of the paper is organized as follows. Section 2 defines the model. Section 3 grounds the model 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 social-ecological 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). Due to their flexibility, ABMs are well adapted to model social-ecological systems (Jager and Mosler 2007; Janssen and Ostrom 2006; Poteete et al. 2010). 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. 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 (Janssen and Ostrom 2006; Gilbert 2008).

2.1 Model overview

The *CITA* model aims at estimating household consumption in Italy and the related GHG emissions under different environmental policy scenarios. *CITA* has been developed within the larger framework of the *Green Economy Research on the Mediterranean Environment* (GERME) project of the Collegio Carlo Alberto. Two complementary models stand at the core of the project. The first one is a hybrid Life Cycle-Environmental Input Output Analysis (LCA-EIOA) tool, developed by Padovan et al. (2011) 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 hybrid LCA-EIOA model has been applied to quantify the environmental requirements of specific household metabolic patterns (Kok et al. 2003), including the ones used within 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 or about changes in the environmental concern of consumers. The model is based on agents choosing between alternative “diets” depending both on their own preferences and on social influence (see below). Note that the term diets holds here the generic meaning of an *a priori* defined style of food, transport or energy consumption (see Section 3.2). 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), but are also sensible to prices and to social influence. 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 2002b). Each agent i possesses a set of preferences $P_i = \{p_{i1}, \dots, p_{im}\}$ 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 reproduces 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 take choices about three “dietary domains”: the first one relates to food choices, the second one to transportation choices and the third one to energy consumption choices (see Section 3.2). Agents have both personal and social needs, whose satisfaction is affected by their diets. Personal need satisfaction depends on the difference between the dimension d_{jk} of diet k (note that each domain j encompasses a variable number of diets) and the corresponding agent preference. Formally, the personal need satisfaction of agent i consuming diet k of

domain j is defined as

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

Note that, while diets referring to transports and energy diets possess only an environmental sustainability dimension, the one referring to food consumption has two different dimensions, namely environmental sustainability and health (see Section 3.2). In this case, the agent satisfaction is simply computed as average of the application of equation (1) over the two dimensions of the diet.

Agents are embedded in a social network. To build it, we followed a principle of homophily, i.e., agents had a higher probability to be linked with other agents having similar preferences (see Section 3.1). The underlying assumption was that agents are more likely to be influenced in their consumption choices by other agents sharing similar worldviews on environmental (or health) issues. In details, each agent created $l = 3$ undirected links with 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 (Watts 1999; Watts and Strogatz 1998) that was also used in Janssen and Jager (2002b).

Following Janssen and Jager (2002b), we assumed that agents derive social satisfaction from their relations and prefer to consume the same diets as their neighbours. Social satisfaction is hence defined as the proportion of agents in the neighbourhood of i consuming the same diet 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 consuming diet k while n_i is the total number of agents in the neighbourhood.

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

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

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 dietary domain (see Section 3.2).

2.3 Agents' decisions

In each time step, agents take independent choices regarding all three dietary 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 the one of their neighbours 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 in equation (3), while uncertainty depends on the variation over time of the agent's satisfaction. It is assumed that high variability in satisfaction involves greater uncertainty for agents, since this makes difficult to forecast the consequences of the choice. More precisely, following Janssen and Jager (2002b), we defined uncertainty as

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

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 diets 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 diet as before with the one that would derive from choosing the diet that is most common in the neighbourhood. Table 1 summarizes all deliberative processes along with the conditions for their choice.

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 diet distribution in the neighbourhood and adopt the modal diet. In case of a tie, randomly select one of the most common diets.
$< \tau_n$	$\leq \tau_u$	Deliberation	Compute the expected satisfaction for each diet, then choose the one leading to the highest satisfaction. In case of a tie, randomly select one of the diets leading to the highest satisfaction.
$< \tau_n$	$> \tau_u$	Social Comparison	Check which diet is most common in the neighbourhood. In case of a tie, randomly select one of the most common diets. Compare the expected satisfaction of the selected diet with the one of your current diet and select the one leading to the highest satisfaction. In case of a tie, select one of the two diets at random.

Table 1: Summary of deliberative processes

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

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 European Common Agricultural Policy (CAP) and on the role of farmers in society, 5 questions on transportation, and 2 questions on energy consumption (see Tab. 2).

Preferences in P_i are represented as indexes bounded in the $[0, 1]$ interval. To compute them starting from survey data, we first added all answers given by a single responder and relative 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 Figure 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

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
v567		Environment citizen priority: reduce energy	{0, 1}

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

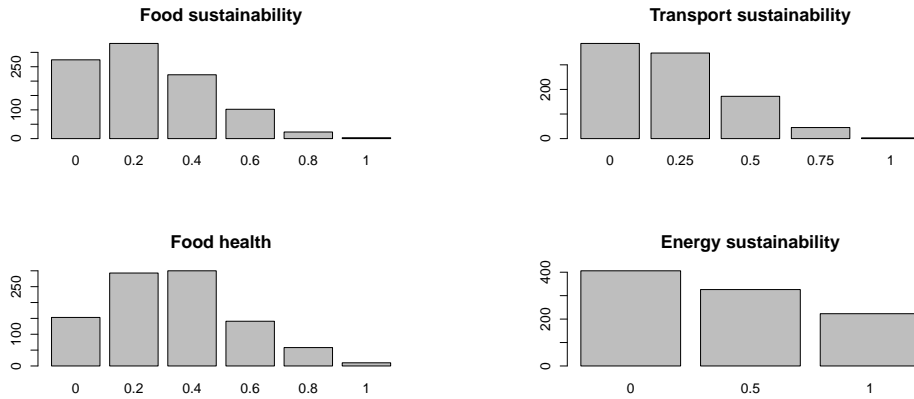


Figure 1: Distribution of agents' preferences.

across domains presents little coherence: a fact justifying our decision to model as independent the agents' choices over different domains.

3.2 Diet definition

The impacts of household consumption represent 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).

Based on these data, it is clear that food, housing and transportation represents the three major source 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 behaviours (or “diets”). The different diets were set-up starting from Italian average consumption patterns, obtained by the national statistical agency (ISTAT) database, that were used as reference. In each domain (but the food one, where diets were modelled also considering some common consumption patterns in Italy), three diets were created: (i) the brown diet, which represents the consumption pattern with the heaviest environmental burden; (ii) the green diet, having the smaller environmental impact; (iii) the intermediate diet, with intermediate environmental properties. The environmental impact of all diet was evaluated using the hybrid LCA-EIOA tool. Table 3 presents an overview of all the selected diets and of their main characteristics.

Domain	Diet	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
	<i>Reference (ISTAT)</i>	<i>419.87</i>	<i>0.47</i>	<i>0.25</i>	<i>510.11</i>	<i>1.00</i>
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
	<i>Reference (ISTAT)</i>	<i>68.96</i>	<i>0.13</i>		<i>104.76</i>	<i>1.00</i>
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
	<i>Reference (ISTAT)</i>	<i>221.17</i>	<i>0.46</i>		<i>48.87</i>	<i>1.00</i>

Table 3: Overview of the diets included in the analysis and of their environmental impact. All data represent monthly averages per household. Diets based on ISTAT averages are included as reference.

In the food domain, the hybrid LCA-EIOA analysis highlighted that the most environmental friendly diet corresponded to a vegetarian consumption pattern, while the most impacting diet was the one consuming the highest quantity of animal protein (see Fiala 2008). Among the several diets showing intermediate environmental performance that were tested, we decided to include in our analysis two of them having a specific importance in guiding consumption behaviour 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/) (Tab. 3).

Diets included in the transport domain were based on the share of kilometres travelled using public transportations 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 diet, encompassing 15% of public transportation; (ii) the intermediate diet, including 25% of public transportations; and (iii) the green diet, with 30% of public transportation (Tab. 3).

Diets 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 diet, we assumed the possession and a high rate use of all appliances having statistically the highest impact on total consumption. To define the intermediate diet, 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 diet, 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 diet 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 interval of values. 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 to empirical data, we hence varied only the need satisfaction (τ_n) and uncertainty (τ_u) thresholds, testing all combinations resulting from $\tau_n \in \{0.1, 0.2, \dots, 0.9\}$ and $\tau_u \in \{0.1, 0.2, \dots, 0.9\}$. For each combination we ran 100 replications of the model, recording the equilibrium distribution of all diets. We then chose the parameter combination leading to the household average 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. Figure 2 presents an overview of calibration results.

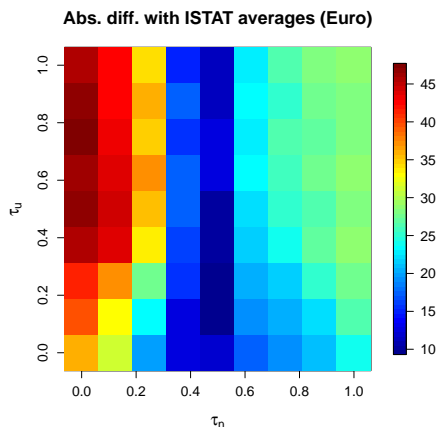


Figure 2: Overview of calibration results.

The parameter configuration that produced the best approximation of 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), 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 the best parameter configuration, in the food domain 42.9% of our agents chose the brown food diet, 23.6% the healthy one, 23.6% the Mediterranean one, and 9.8% the green one, leading to an average emission of 408.18 CO₂ equivalent kg per month. Note that, while CO₂ figures are not easily comparable to the real-world behaviour of households, the share of agents choosing the green diet is comparable, although somewhat higher, to 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 our agents chose the brown diet, 40.6% the intermediate one and 7.1% the green one, leading to an average emission of 66.79 CO₂ equivalent kg per month. Recalling that we built the three diets 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 diet, 31.2% the intermediate one and 27.7% the green one. The resulting average energy consumption was 280 kWh per month, only slightly lower than ISTAT average (285 kWh/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 diet (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 diets were risen by $(1 - d_k)\delta_1 r_k$, where $\delta_1 \in \{0.0, 0.1, \dots, 1\}$. Hence, the actual increase depended not only on the global parameter δ_1 , setting the maximum proportion of price change, but also on the environmental index of each diet, with green diet prices that remained unchanged and brown diet ones that bore the maximal increase. For each value of the δ_1 parameter, we ran 100 further simulation. Figure 3 presents an overview of the resulting diet distributions.

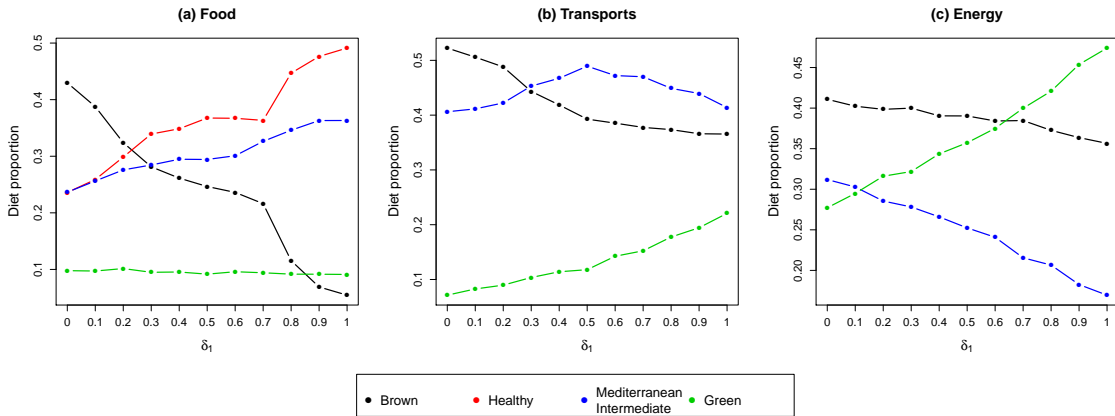


Figure 3: Price change scenarios for food (a), transport (b) and energy (c) diets.

In the food domain, increasing prices led to a significant reduction in the adoption of the brown diet, with a large increase of the share of agents choosing the healthy and the Mediterranean diets

but only a small improvement of the most sustainable behaviour (Fig. 3a). On average, monthly emissions decreased up to 17% for $\delta_1 = 1$. Emissions 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 diet significantly increased for high δ_1 values. The significant increase of the share of the green diet 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 diet (Fig. 3b,c). Over the three domains, setting $\delta_1 = 1$, which caused a doubling of the brown diet price and smaller increases for the other ones, led to a reduction of 84.79 CO₂ 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 because the agents' higher sensitivity to environmental topic 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} (note that p_{i2} , representing the health preference, was left unchanged). The parameter $\delta_2 = \{0.0, 0.1, \dots, 1\}$ represents the policy intensity. For each value of δ_2 , we ran 100 further simulations. Figure 4 presents the resulting diet distribution for each δ_2 level.

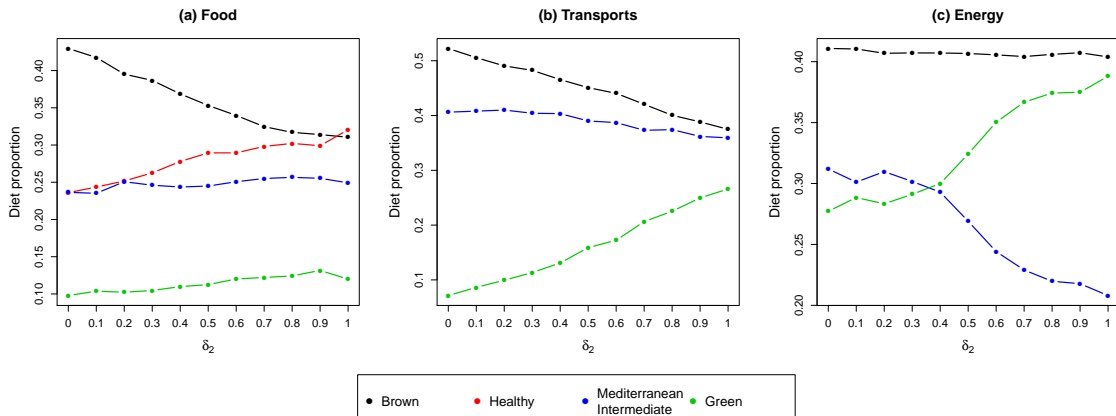


Figure 4: First set of preference change scenarios for food (a), transport (b) and energy (c) diets.

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 CO₂ 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 lowest the environmental attitude of the agent the highest the preference change. Formally, we added to p_{i1} , p_{i3} and p_{i4} the amount $(1 - p_{ik})\delta_3$, where $\delta_3 = \{0.0, 0.1, \dots, 1\}$ 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. Figure 5 presents the

resulting diet distributions.

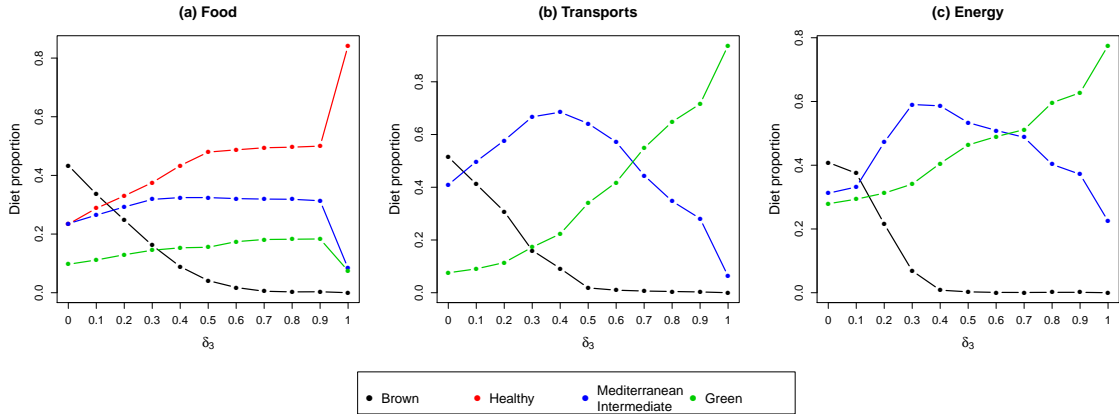


Figure 5: Second set of preference change scenarios for food food (a), transport (b) and energy (c) diets.

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 diet at the expense of both the Mediterranean and the green ones (Fig. 5a). This unrealistic feature of the model depended on the fact that, for $\delta_3 = 1$, all p_{ik} but p_{i2} (health preferences) became equal to one irrespectively of the actual preferences expressed in the EB 68.2 survey. As a consequence, p_{i2} became the only factor affecting the shape of the agents' network. This strongly reinforced the behaviour of health concerned agents, now closely linked, that spread from this cluster to the remaining of the simulated population. This interpretation was confirmed by the fact that, applying the $\delta_3 = 1$ change also to p_{i2} , the sudden increase in the adoption of the healthy diet no longer occurred.

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 diets 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 CO₂ equivalent kg per household per month.

5 Discussion

In the *CITA* model, virtual households choose among alternative diets presenting different degrees of environmental impact (GHG emissions). Agents' behavioural routines derive from Janssen and Jager (2002b) model, while agents' 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 CO₂ emissions under various policy assumption. Figure 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, were needed 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 CO₂ equivalent kg per household per month means almost 25 billions CO₂ equivalent

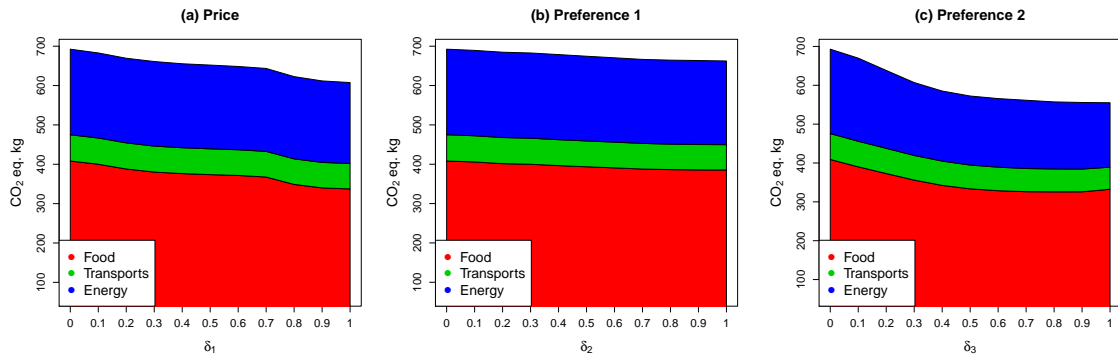


Figure 6: Total emissions in the price scenarios (a) and the two preference scenario sets (b and c respectively).

kg of avoided emissions per year at the country level. This represents about 6% of total Italian CO₂ emissions, which exceeded 445 billions kg in 2008.¹

Note that, while in the transport and energy domains the share of the green diet 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 diet mainly translated into a larger adoption of the healthy and intermediate diets. 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 diets. 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 as an unrealistic feature of the model deriving from exceedingly restrictive assumptions. Nevertheless, even if the assumption that a significant part of the agents is little sensitive to standard 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 were 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 relevant. As a consequence, our finding that generic environmental education actions had 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 environmentally concerned agents led to much stronger changes. The 20% emission reduction recorded for $\delta_3 = 1$ corresponds to almost 40 billions CO₂ equivalent kg per year at the national level, i.e., 9% of total Italian 2008 GHG emissions. Moreover, unlike the other scenarios where

¹Source, The World Bank Data Catalog, <<http://data.worldbank.org/data-catalog>>.

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 CO₂ equivalent kg per year or almost 8% of Italian emissions. Unfortunately, the model offers no information about the actual tools that could be used to successfully convince the less environmental concerned citizens to change their mind (but see Jackson 2005). Nevertheless, it nicely highlighted the large potential gain of such policies if successfully carried on.

Finally, note that preference and price changes jointly 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 this figures were quite large, it is worth noting that they were less than what could be potentially obtained by separately summing the effects of these two policies. This is in contrast 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 was simply a feature of our model or corresponded 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.

Although in line with the European 20% reduction target for 2020, the reduction in GHG emissions resulting from our model 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). Further 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 a different country is straightforward, given the existence of appropriate statistical data and of emissions calculation tools. 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.

References

- Allen, M. R., Frame, D. J., Huntingford, C., Jones, C. D., Lowe, J. A., Meinshausen, M., and Meinshausen, N. (2009). Warming caused by cumulative carbon emissions towards the trillionth tonne. *Nature*, 458:1163–1166.
- Balbi, S. and Giupponi, C. (2009). Reviewing agent-based modeling of socio-ecosystems: a methodology for the analysis of climate change adaptation and sustainability. Working Paper 15, Department of Economics, Ca' Foscari University of Venice.
- Bowles, S. (2008). Policies designed for self-interested citizens may undermine "the moral sentiments": Evidence from economic experiments. *Science*, 320:1605–1609.
- Caves, D. W., Herriges, J. A., Train, K. E., and Windle, R. J. (1987). A bayesian approach to combining conditional demand and engineering models of electricity usage. *The Review of Economics and Statistics*, 69(3):438–448.
- DEFRA (2006). Sustainable consumption and production: Encouraging sustainable consumption. Department for Environment Food and Rural Affairs, London, UK.
- Diekmann, A. and Preisendörfer, P. (1998). Environmental behavior: Discrepancies between aspirations and reality. *Rationality and Society*, 10(1):79–102.
- Diekmann, A. and Preisendörfer, P. (2003). Green and greenback: The behavioral effects of environmental attitudes in low-cost and high-cost situations. *Rationality and Society*, 15(4):441–472.

- Dietz, T., Stern, P. C., and Guagnano, G. A. (1998). Social structural and social psychological bases of environmental concern. *Environment and Behavior*, 30(4):450–471.
- Dobson, A. (2007). Environmental citizenship: Towards sustainable development. *Sustainable Development*, 15(5):276–285.
- Dunlap, R. E. and McCright, A. M. (2008). A widening gap: Republican and Democratic views on climate change. *Environment*, 50:26–35.
- ECMT and OECD (1995). Urban travel and sustainable development. Organization for Economic Co-operation and Development, Paris, France.
- Eurispes (2011). *Rapporto Italia 2011. L'Italia: una terapia della scelta*. Eurispes, Roma.
- Eurobarometer (2008). Attitudes of european citizens towards the environment. Special Eurobarometer 295 / Wave 68.2.
- Ferber, J. (1999). *Multi-agent systems: an introduction to distributed artificial intelligence*. Addison Wesley, Longman.
- Fiala, N. (2008). Meeting the demand: An estimation of potential future greenhouse gas emissions from meat production. *Ecological Economics*, 67:412–419.
- Frey, B. and Jegen, R. (2001). Motivation crowding theory. *Journal of Economic Surveys*, 15:589–611.
- Gilbert, N. (2008). *Agent-Based Models*. Sage, London.
- Grimm, V. (1999). Ten years of individual-based modeling in ecology: what have we learned and what could we learn in the future? *Ecological Modeling*, 115(2–3):129–148.
- Grimm, V., Revilla, E., Berger, U., Jeltsch, F., Mooij, W. M., Railsback, S. F., Thulke, H.-H., Weiner, J., Wiegand, T., and DeAngelis, D. L. (2005). Pattern-oriented modeling of agent-based complex systems: Lessons from ecology. *Science*, 310:987–991.
- Hare, M. and Deadman, P. (2004). Further towards a taxonomy of agent-based simulation models in environmental management. *Mathematics and Computers in Simulation.*, 64(1):25–40.
- Hertwich, E. G. (2011). The life cycle environmental impacts of consumption. *Economic Systems Research*, 23(1):27–47.
- IPCC (2007). Climate change 2007: Synthesis report. Intergovernmental Panel on Climate Change — Fourth Assessment Report.
- Jackson, T. (2005). Motivating sustainable consumption: a review of evidence on consumer behaviour and behavioural change. Report to DEFRA, Sustainable Development Research Network .
- Jackson, T. (2009). *Prosperity Without Growth? Economics for a Finite Planet*. Earthscan, London.
- Jackson, T. and Michaelis, L. (2003). Policies for sustainable consumption. a report to the sustainable development commission. Sustainable Development Commission, UK.
- Jager, W. (2000). *Modelling consumer behaviour*. Universal Press, Groningen.
- Jager, W. and Mosler, H. J. (2007). Simulating human behavior for understanding and managing environmental resource use. *Journal of Social Issues*, 63(1):97–116.
- Janssen, M. and Jager, W. (2002a). Stimulating diffusion of green products. co-evolution between firms and consumers. *Journal of Evolutionary Economics*, 12:283–306.
- Janssen, M. A. and Jager, W. (2002b). Stimulating diffusion of green products. *Journal of Evolutionary Economics*, 12:283–306.
- Janssen, M. A. and Ostrom, E. (2006). Empirically based, agent-based models. *Ecology and Society*, 11(2):37.
- Kok, R., Falkena, H. J., Benders, R. M. J., Moll, H. C., and Noorman, K. J. (2003). Household metabolism in European countries and cities. IVEM Report.
- Matthews, R. B., Gilbert, N., Roach, A., Polhill, J. G., and Gotts, N. M. (2007). Agent-based land-use models: a review of applications. *Landscape Ecology*, 22(10):1447–1459.
- Meinshausen, M., Meinshausen, N., William Hare and, S. C. B. R., Frieler, K., Knutti, R., Frame, D. J., and Allen, M. R. (2009). Greenhouse-gas emission targets for limiting global warming to 2°C. *Nature*, 458:1158–1163.
- Michaelis, L. (1997). Special issues in carbon/energy taxation: carbon charges on aviation fuels. Working Paper 12, series Policies and Measures for Common Action Under the UN FCCC. Organization for Economic Co-operation and Development, Paris, France.
- Pacala, S. and Socolow, R. (2004). Stabilization wedges: Solving the climate problem for the next 50 years with current technologies. *Science*, 305:968–972.
- Padovan, D., Martini, F., and Cerutti, A. K. (2011). Methodologies and early results in the application of the Energy Analysis Program to the Italian context. Presented at the International Conference of

- Social Aspects of Energetic Issues, Sustainable Development, Social Organization and Acceptance of Alternative Sources. Chieti (Italy), May 26–27, 2011.
- Parti, M. and Parti, C. (1980). The total and appliance-specific conditional demand for electricity in the household sector. *The Bell Journal of Economics*, 11(1):309–321.
- Patrinos, A. A. N. and Bradley, R. A. (2009). Energy and technology policies for managing carbon risk. *Science*, 325:949–950.
- Poteete, A. R., Janssen, M. A., and Ostrom, E. (2010). *Working together: collective action, the commons, and multiple methods in practice*. Princeton University Press, Princeton, NJ.
- Rockström, J., Steffen, W., Noone, K., Åsa Persson, Chapin, F. S., Lambin, E. F., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H. J., Nykvist, B., de Wit, C. A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R. W., Fabry, V. J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., and Foley, J. A. (2009). A safe operating space for humanity. *Nature*, 461:472–475.
- Schultz, P. (2000). Empathizing with nature: The effects of perspective taking on concern for environmental issues. *Journal of Social Issues*, 56(3):391–406.
- Sheth, J., Newman, B., and Gross, B. (1991). Why we buy what we buy: a theory of consumption values. *Journal of Business Research*, 22:159–170.
- Stern, D. J., Common, M. S., and Barbier, E. B. (1996). Economic growth, trade and the environment: Implications for the environmental Kuznets curve. *World Development*, 24:1151–1160.
- Stern, N. (2007). *The Economics of Climate Change*. Cambridge University Press, Cambridge.
- Sutcliffe, M., Hooper, P., and Howell, R. (2008). Can eco-footprinting analysis be used successfully to encourage more sustainable behaviour at the household level? *Sustainable Development*., 16:1–16.
- Tukker, A., Huppes, G., Gunee, J., Heijungs, R., de Koning, A., van Oers, L., Suh, S., Geerken, T., van Holderbeke, M., Jansen, B., Nielsen, P., Eder, P., and Delgado, L. (2006). Environmental impact of products (eipro). EUR22284EN. Seville, EC Joint Research Centre – IPTS.
- Volk, T. (2008). *CO₂ Rising: The World Greatest Environmental Challenge*. The MIT Press, Cambridge, MA.
- Watts, D. J. (1999). Networks, dynamics and the small-world phenomenon. *American Journal of Sociology*, 105(2):493–526.
- Watts, D. J. and Strogatz, S. H. (1998). Collective dynamics of ‘small-world’ networks. *Nature*, 393:440–442.
- Wiedmann, T. (2009). Carbon footprint and input-output analysis — an introduction. *Economic Systems Research*, 21(3):175–186.
- Wilting, H. (1996). An energy perspective on economic activities. PhD. Thesis, Centre for Energy and Environmental Studies, University of Groningen.
- Young, W., Hwang, K., McDonald, S., and Oates, C. (2010). Sustainable consumption: green consumer behaviour when purchasing products. *Sustainable Development*., 18:20–31.