# An Awareness Based Approach to Avoid Rebound Effects in ICTs

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## ABSTRACT

The full exploitation of ICTs environmental potential benefits needs to take into account a social dimension, where there is a shift of role from passive user to aware user of ICT-based services.

After a short overview of the rebound effect in ICTs, the paper will focus on the role that users, consumers or citizens can play in spreading and adopting beneficial behavior. The enabling factor of this active participative role is the collective situational awareness about environmental effects of actions. Such awareness makes a green behavior easier and can counter possible rebound effects.

An Agent Based Model approach is proposed to study individual and collective behavioral changes toward sustainability using ICT-based services and for sustainable ICTs. The use of ABM to simulate how environmental awareness spread is innovative and crosses the disciplinary borders between ICTs, energy and environment disciplines, as well as social and behavioral sciences.

## Keywords

Environmental awareness, agent based modeling, ABM, sustainable behavior, behavior changes, reduction of limited resources consumption, social influence, social norms, spread of awareness, rebound effect, socio-technical system

## 1. INTRODUCTION: ICT AND SUSTAINABILITY

There is overwhelming evidence that our current lifestyle is not sustainable. Energy consumption, carbon dioxide emission and depletion of scarce resources have to be reduced. ICTs (Information Communication Technologies) are pivotal to reach environmental sustainability. So the role and impact of ICTs on the environment are gaining more and more attention. This impact is a mix of positive and negative effects that is not only interesting to explore for ICT devices, but it is relevant for ICT-based services.

There is a general agreement about the need of an assessment methodology on the net environmental impact of ICT products, ICT services and ICT-based services. But all effects, both positive and negative, have to be taken into account. While the effects of ICTs on the environment are commonly ranked as first, second and third order effects, there is a gap in the analysis quality of first, second and third order effects of ICTs on environmental sustainability [17]. The first ones are relatively well known, complex but possible to be quantified. The second ones are difficult to exactly foresee, but can be estimated at a magnitude order level. The third ones are really hard to assess.

The third order effects are long-term environmental effects and are related to the societal changes that ICTs brings along. They include the rebound effects, i.e. the unanticipated consequences that may nullify the potential benefits of ICTs in term of sustainability.

After an overview on rebound effects in Section 2, with a focus on ICTs, the paper describes a conceptual framework to avoid negative rebound effects in Section 3, where the pivot is the concept of collective awareness about the need to reduce the consumption of limited or critical resources. The socio-psychological mechanisms behind such environmental awareness are described and introduced into a socio-technical dimension, as well as the role of social influence for the spread of awareness. The use of Agent Based Model (ABM) paradigm is discussed in Section 4, while Section 5 describes the ABM components and the related development stage. The last session gives some insights on potential applications.

## 2. THE REBOUND EFFECT

### 2.1 The rebound effect in energy economics

The term "rebound effect" originates in energy economics [2] and describes the systematic response to a measure, taken to reduce environmental impact, that offsets the effect of such measure. While the rebound effect literature is generally focused on energy consumption [33], the theory can be generalized to any natural resource or externality that is embodied in final consumption [23]. ICTs effects on the environment can be considered as externalities (negative or positive). Rebound effects are generally expressed as a ratio of the lost environmental benefit to the potential environmental benefit. The nature and magnitude of the rebound effects is the focus of long-running dispute within energy economics [32] and even the definition and the scope of rebound effects have been the subject of heated debate.

The discussion addresses both the magnitude and the mechanisms of the rebound effects. With regard to the magnitude, analysts distinguish a weak rebound effect (efficiency measures are not as effective as expected), a strong rebound effect (most of the expected savings do not materialize), and a backfire effect (the efficiency measure leads to increased demand) [16].

With regards to the economics mechanism, literature in energy economics distinguishes between different types of rebound effect [15]:

1. The substitution effect
2. The income effect
3. Secondary effects (input-output effects, indirect effects)
4. General equilibrium or economy-wide effects
5. Transformational effects

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The first two effects, sometimes also called direct rebound effects, are micro effects while the last three effects are macro effects.

Reduction of energy use and reduction of pollution are goals of energy and environmental economics, but an increase in production units may compensate the eco-efficiency improvements. These effects are often called back fire, take-back, offsetting behaviour or, as we shall call them, rebound effects [19].

## 2.2 Rebound effect in ICTs

If rebound effects are a complex issue to deal with, their definition, identification and quantification becomes even more complex in ICTs field. When an ICT-based service is enabling an environmental benefit, the efficiency improvement in energy [4] or in other limited or critical resource, can be overcompensated by rebound effects [19]. Despite their importance and their extent, the ICT-related rebound effects are relatively unexplored because of the complexity of assessing future directions of production and consumption [8], [20].

Because rebound effects are long-term effects, their actual manifestation and related data are available only a longtime after the phenomenon that generated them. That is the reason why data about rebound effects on ICTs are difficult to acquire and, when available, are delayed of one (or more) technology generation. Cloud Computing for example is a field where new green opportunities are coupled with new environmental risks [21], [31].

Because different ICTs generations lead to different user behavioral patterns, such delay between the cause and the manifestation of these effects makes really difficult or impossible any concrete measure against negative rebound effects.

A theoretical in-depth analysis of rebound effects in general, and in particular in ICTs, is out of the reach of this article, while its research contribution is related to avoiding negative rebound effects.

Some general remarks before exploring an alternative approach have to be done.

The rebound effects are traditionally located inside the framework of the neo-classical economic principles, under the assumptions of full rationality, certainty and completeness of information, and that the agents are insatiable ("more is always preferred").

On the other side we have to remember that an overall sustainability goal is to reduce the consumption of limited or critical resources. Although the traditional vision of innovation is based on the assumption that efficiency will lead to reduction of consumption of critical or limited resource, this is in contradiction with the "more is always preferred" principle. The issue is that inside the framework of classical economics is intrinsically impossible to avoid rebound effects.

The proposed approach to deal with rebound effects is to focus on behavioral patterns relevant to sustainability and to look at rebound effects from within this framework.

Concepts as new sociological institutionalism and unintended consequences can be useful for an alternative approach, where rebound effects can be dealt with and avoided by focusing on behavioral patterns relevant to sustainability. Looking at rebound effects within this point of view, environmental sustainability awareness and its spreading inside communities became key elements.

Because the general agreement is that the negative rebound effects have to be avoided as much as possible, the paper will focus on how to avoid them in ICTs, starting from the assumption that nature and extent of rebound effects depend on behavioral changes by individuals and groups of individuals. Environmental sustainability awareness can avoid behaviors leading to negative rebound effects. Such awareness instead can lead to more sustainable lifestyles and behaviors, under the overall goal of reducing the consumption of critical or limited natural resources. In other words only a good awareness level can avoid unintended consequences, as rebound effects are. Being aware of the environmental sustainability issues means to be able to identify a critical or limited resource which consumption has to be reduced, means to be able to understand the impact of own actions on this resource and to avoid unintended consequences, as rebound effects.

Another important preliminary consideration is that to take an environmental advantage from a spread use of ICTs, humans must be engaged as active decision makers and not only as passive consumers [9]. The role that users, consumers or citizens can play in spreading and adopting beneficial behavior can be the pivot for a different approach. The enabling factor of this active participative role is the collective awareness about environmental effects of actions that enable a green behavior and can also counter possible rebound effects.

# 3. CONCEPTUAL FRAMEWORK FOR AN AWARENESS BASED APPROACH

Several research studies recommend to pay attention to understand rebound effects by including knowledge or experiments with behavioral patterns, so that circumstances can be introduced whereby beneficial impacts are promoted and the detrimental impacts are prevented as much as possible [25]. Changes in behavior toward sustainability can be fostered through a mix of social and technological intervention.

## 3.1 Environmental sustainability awareness

A basic assumption of the paper is that the awareness level drives the behavior of customers, users, and citizens. Awareness concept is very different from information concept. According to Oxford Dictionary's definition, awareness "is a concern about and well-informed interest in a particular situation or development". People can be full of information about something without being aware about it. Moreover awareness is an individual aptitude that is developed and shaped inside a social context, i.e. a social institution.

To address the issue from a new perspective of innovation theory we can look at the role that users, consumers or citizens can play in spreading and adopting beneficial behaviors, so that also rebound effects might be countered. The emerging concept of collective awareness is meant to create an extended consciousness of the environment, of the consequences of our own actions on it, and to encourage taking informed and sustainability-aware decisions. The key is in enabling access to trusted knowledge about the state of the environment, in order to allow people to understand the environmental impact of their own actions. An extended awareness can be enabled by ICTs, for instance by decentralized and federated social networks, where environmentally aware, grassroots processes and practices to share knowledge, to achieve changes in lifestyle, production and consumption patterns, will set up more participatory processes.

Such participatory processes are based on some psychological mechanisms like social proof or informational social influence, that are very meaningful in an ICT-based social dimension where there is a shift of role from passive user to aware and active user, like some researches [12] have shown.

Measures like setting relevant goals, gaining commitment, giving feedback, prompting behaviors, or developing new social norms, are possible steps toward "environmentally aware" behavioral changes that can be enabled by ICTs.

## 3.2 Individual behaviors and social norms

Voluntary behavioral changes are usually driven by some kind of rewards. In some cases adopting a new lifestyle has a reward in itself. For example after quit smoking or making a diet one feels better or looses weight and this effect is perceived as individual immediate positive feedback.

As far as an environmentally sustainable life style is concerned, the economic rewards sometimes are not strong enough to trigger a behavioral change, while other reward mechanisms are not at an immediate individual level. Only when a responsible life style is adopted by a collective or by a group of individuals some positive environmental effects will happen in the long run. If the adoption of a sustainable behavior is driven by awareness and such awareness shifts from an individual dimension to a shared collective one, this turns a social appraisal into the most effective reward.

The mechanisms of "motivating social environments" [1], "psychological ownership" [26] and "social proof" [6] can lead to an high enough awareness level to enable sustainable behaviors in user/consumers [11]. Such underlying societal and psychological mechanisms can be enabled by ICT-based socio-technical interventions.

### *3.2.1 Motivating social environment*

Measuring and understanding are the first steps to be able to act smart. For example personal carbon accounting is necessary for citizens to be able to understand and manage their individual carbon footprint, while smart meters with related services can reduce household energy consumption. But their success largely depends on behavioral changes by groups of individuals. As a first step it is essential to empower individuals providing feedback, goal setting, and tailored information [1].

In motivating people to change behavior for reaching the goal of reducing limited or critical resource consumption, socio-technical interventions that go beyond simple presentations of facts are necessary. They need to make use of new insights into social and behavioral psychology to motivate consumers [7]. Basic steps for building a collective environmental situational awareness are accessing real-time to easily understandable information about resource consumption, and comparing individual lifestyles against some ecological/environmental benchmark.

### *3.2.2 Psychological ownership*

Psychological ownership [26] describes a state in which a person feels closely connected to an object or idea, to the degree that it becomes part of an "extended self". As soon as people see something as their own, they value it higher and are more likely to invest time and effort in it.

In research on psychological ownership several requirements have been identified, like for example modifiable targets [11].

### *3.2.3 Social proof*

Social proof [6] describes the effect that people act a certain way because they observe others acting this way. In such situations, the fact that others choose something acts as proof that this choice is preferable.

Because consumers are driven by a mix of basic needs, personal desires and social images [10], it is important to share sustainability goals. Individuals are replacing common background or geographic proximity with a sense of well-defined purpose and the successful common pursuit of this purpose is the condensation point for human connection. Since individual and collective behaviors are leveraging on environmental awareness, a deep understanding of this socio-technical ecosystem needs suitable tools and techniques. The research contribution of this paper consists of an in-depth analysis of the spread of awareness between neighbors. Neighborhood's relationships can be topologically or socially defined or given by a mix of them.

In order to allow and improve the understanding of such mechanism, a simulation model can be a useful tool. A research corpus, in between computer science and sociological science [28], [13] shows as behavioral changes can easily be modeled according to an ABM (Agent Based Model) approach.

## 3.3 Social influence and threshold model

Before going in details in Section 4 about agents and agent based modeling approach for the above mentioned sustainability related purposes, other important concepts have to be introduced. They are taken from analytical sociology and are more and more popular in social network analysis: social influence and threshold models.

### *3.3.1 Social influence*

Individuals are influenced by the decisions, actions, and advice of others when making a wide variety of decisions, both consciously and unconsciously. Understanding how and when this "social influence" arises, and how individual decisions aggregate in the presence of such influence, should therefore be considered as central components in any theory of collective social behavior.

Social influence is thus not a singular phenomenon, or even (yet) a well-defined family of phenomena, but rather an umbrella term for a loose congregation of social, psychological, and economic mechanisms, including: identifying with, or distancing oneself, from certain social groups; avoiding sanctions; obeying authority; reducing the complexity of the decision making process; inferring otherwise inaccessible information about the world; gaining access to a particular network; or reaping the benefits of coordinated action.

Mainly social network research is studying how the properties of the corresponding influence network - that is, the network of "who influences whom" - can impact the dynamics of collective decisions, determining, for example, the likelihood that large "cascades" of influence can originate from small initial seeds, the ability of prominent individuals to trigger such cascades, and the importance of group structure in triggering and propagating large cascades.

Models of social influence, moreover, tend to assume (often implicitly) that all actors involved are of the same kind, whereas in reality, individuals may be influenced by a variety of actors - for example, peers, role models, media organizations, and high profile individuals, each of which may exert a different kind of influence, and may in turn be influenced differently.

The consequences of a particular class of heuristics - the threshold rules - for collective decision-making processes are an open research question [38].

### 3.3.2 Threshold models

A research area of growing importance inside social network analysis is now focusing on a special case of influence response functions - namely, deterministic threshold functions, according to which individuals adopt a new *state* based on the perceived fraction of others who have already adopted the same state.

Threshold models are already understood in certain limiting cases, like in particular, the all-to-all approximation [14], in which all individuals are influenced equally by the states of all others. Other studies [36], [37] proceed systematically up the chain of complexity, reviewing the dynamics of *cascades* of influence on random networks. More recently [38] models of networks that advance on the random network model by including some notions of group structure have been introduced and have been considered how these changes affect the likelihood of cascades for different seeding strategies.

The notion of threshold is fundamental for the present paper. If for its purpose it is acceptable the informal reasoning that a threshold rule is a plausible rule of thumb for an individual to follow, the attention has to be focused on the influence network - that is, "who pays attention to whom" and to how strong is such influence.

The classical above mentioned Granovetter's threshold model [14] has been adapted [38] in research works to a network framework where in contrast to the all-to-all assumption, individuals are assumed to be influenced directly only by a small subset of immediate "neighbors" - a more realistic assumption. One of the assumptions of this paper is that mainly an "immediate neighbor" influences individuals. As described below, in the proposed social contagion model the notion of social diversity [35] is introduced, in order to simulate a network of neighbors composed by different types of agents, which are more or less influential on the basis of their level of environmental awareness.

# 4. THE ABM APPROACH

In an overall sustainability framework some small, achievable changes at an individual scale allow to achieve great benefits at a community scale, and the social influence drives such mechanism.

Agent-based simulation is a modeling approach enabling to build models where individual entities - so called agents - and their interactions are directly represented [27]. An Agent Based Model is particularly suitable when the emergence of a collective behavior, impossible to foresee at an individual level, is an important consideration. Modelers can represent in a natural way multiple scales of analysis, the emergence of structures at the macro or societal level from individual action, and various kinds of adaptation, none of which is easy to implement with other modeling approaches [5]. As an important tool to investigate socio-ecological processes, ABM use is driven by increasing demand from decision makers [3] to provide support for understanding the potential implications of decisions in complex situations, as, for example technology adoption processes [24].

A crucial feature of agent-based models is that the agents can interact, that is, they can pass informational messages to each other and act on the basis of what they learn from the messages. The messages may represent spoken dialogue between people or more indirect means of information flow, such as the observation of another agent or the detection of the effects of another agent's actions. The possibility of modeling such agent-to-agent interactions is the main way in which agent-based modeling differs from other types of computational models.

Within this conceptual framework is born the idea to simulate how a sustainable behavior can emerge in a system composed by several aware agents. Such behavioral mechanism can lead to avoid (or mitigate) the rebound effects, according to the awareness levels, both at individual and collective level. Awareness is not only a precondition for sustainable behaviors, but also a trigger for an active engagement.

# 5. THE MODEL

The proposed model describes how behaviors can avoid rebound effects in the adoption of ICTs products or services, leveraging on the awareness level of the agents. The core model is an ABM, describing the spread of environmental sustainability awareness between agents. Agents are individuals, like households, or simple users of ICT-products or ICT-based services. The key feature of each agent is its awareness, and such awareness can be modified by interaction with neighbors. The interaction embeds the notion of threshold. A collective behavior can emerge, leading (or not) to the reduction of critical resource consumption. The goal of reducing a resource consumption represents a kind of "limiting factor" to avoid rebound effects.

Awareness is a numerical quantity and according to its value, different types of agents are defined. Each agent belongs to one and only one of these types of agents. An agent can improve his awareness level on the basis of the influence of neighbors. When the awareness level exceeds given threshold the agent shifts from one type to another. Thresholds for the switch are different type by type, and the threshold to reach the highest level (corresponding to became an "evangelist") is the highest one.

The threshold idea in social influence is not directly related to make a choice, as for example in "all-to-all" model [14], but to apply the dynamic of social influence between different types of neighbors. The interaction leads to change the awareness level, which in turn allows an agent to shift from a given set of agent to another. Trigger events (external environmental factors, like environmental programs) allow an easier reach of the switch thresholds.

Because, as we see below, different types of agent can perform different actions, their impact on the overall status of the system (the limited resource consumption) is different.

## 5.1 The ABM and its components

The core of the proposed model is an Agent Based Model of the awareness diffusion.

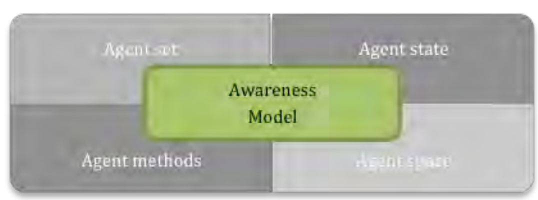


**Figure 1. The model components**

The ABM, as described in Figure 1, is composed by sets of agents, their state, methods and space.

### 5.1.1 The agents

In the core model an agent is the consumer of a critical or limited resource. There are five types of agent: blind, indifferent, spectator, active, and evangelist. All agents have as fundamental attribute the awareness, increasing from the bottom (blind agent i.e. the less aware type of agent) to the top (evangelist agent, i.e. the more aware type of agent), as described in Figure 2. An intuitive color code, from red to green, is used for visualize the agent typing and its dynamics.

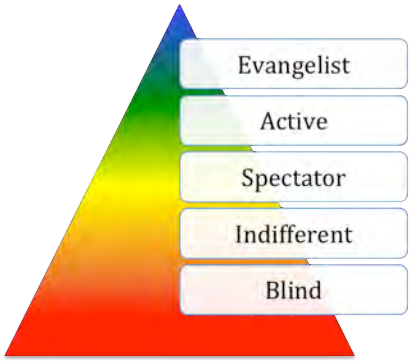


**Figure 2. Types of agent and awareness levels**

The bottom level is not environmentally aware, while the top level is the most aware. Such attribute value typifies five sets of agents (implemented as NetLogo agentset, as described in 5.3) and this value is a condition for an agent to belong to a specific set of agents. Each agent can shift from a type to another when its awareness level reaches a given value.

An "awareness level", increasing as the agent acquires knowledge and sensibility about environmental issues in general and in particular on the effect of its own behavior on the specific case, quantifies awareness. The awareness level can change by interaction with neighbors and such change happens under different conditions (depending on other agents and on the system condition in general). All awareness levels, that typify an agent as indifferent, spectator, activist, or evangelist, can increase (rarely decrease) by interaction with neighbors. The threshold to change the status is different from one level to another and is different in ascending or descending score. The threshold to shift from activist to evangelist is higher than other thresholds. Another feature of an agent that can influence its awareness level is the aptitude to a social behavior. Items with an impact on the awareness level come also from other global state variables.

### *5.1.2 Agent methods*

Agents are active. According to the conceptual framework below described the agents can perform different methods (Fig. 3). Actions are related to reduce the limited (or critical) resource consumption. Agent awareness level corresponds to the ability of an agent to perform different kind of action.


**Figure 3. Different actions for different types of agent**

For example an agent belonging to the *indifferent agentset* can *identify* which physical quantity to take into consideration.

An agent belonging to the *spectator agentset* can *measure* his own consumption of this quantity, while an agent belonging to the *active agentset* can *compare* with friends/colleagues/neighbors his own consumption, to *share* a target level on consumption to achieve within the social network.

Actions like *to show* own consumption or *to share* it with social network neighbors are reserved to agents belonging to the types with a high awareness level. Only the more aware type of agent, the evangelist, is able to *act to promote* the collective target, by attempting to convert other agents to achieve the overall sustainability goal.

Figure 3 shows how some action can be performed only by a small numbers of very aware agents.

### *5.1.3 Agent state*

The agent state can change continuously by the interaction with other agents. A change of state corresponds to a change of awareness level and of other state variables.

Actions are different for agent types. For example the agent with an awareness level of spectator will take into consideration the environmental quantity to be reduced, for example energy or material [29] and his own consumption.

The strongest rebound effect happens when all agents have zero awareness level, i.e. all agents are blind. When the awareness increases in some agents, the rebound effect decreases.

### *5.1.4 Agent space*

The agent space (topology) will be the neighbors network, where the neighborhood can be topological or social or a mix of both. Local information is obtained from interactions with an agent's neighbors (and maybe in some way with all agents) and from its localized environment (and from the entire environment). Agents acquire also a global overview of the whole state of the system.

## 5.2 ABM application field

The present ABM of environmental sustainability awareness spread is the core part of a broader research activity to foster behavioral changes in ICTs towards reduction of limited or critical resource consumption.

Such core model of awareness-based behavior is aimed to allow a better understanding of the underlying socio psychological mechanisms and their role in the consumption reduction of different limited resources. The idea is that basic mechanism is the same into all behavioral changes toward limited resource consumption reduction. The ABM of such core mechanism can be applied to different cases of consumption reduction of a limited resource. In particular, as below described, the model validation will be done in non-ICT case studies.

The final use is oriented to reach this goal in ICTs field and mainly oriented in avoiding or reducing rebound effects. In such domain the limited or critical resource to be reduced can be energy or materials.

## 5.3 ABM development stage

The system implementation is still at an early stage. The first prototype is under development in NetLogo, a very popular development environment to build Agent Based Model. NetLogo is an agent-based programming language and integrated modeling environment. It is a cross platform, free and open source under a GPL license, [39] and it supplies also simple and effective tools for an easy visualization of ABM output. It allows programmers to save models as Java applets, permitting seamless publication of simulations from NetLogo built-in integrated development environment to a Web page. Such features allow the target users (i.e. the policy makers) an easy interaction and use of the ABM, by changing parameters, visualizing results etc.

The ABM is developed according to the ODD (Overview, Design, Details) protocol for ABM development [27].

Further phases of verification and validation of the model are foreseen.

### 5.3.1 *Model verification*

Amazon Mechanical Turk is becoming more and more popular in conducting behavioral research [22]. For the model verification its use is under consideration.

### 5.3.2 *Model validation*

A validation phase has been planned. Using Input data, coming from a totally independent experiment about limited resources consumption reduction, will allow a basic validation of the awareness mechanism model. The original real data have been made available from an academic research institution engaged into water consumption reduction programs. The validation datasets are totally independent from the present research and they refer to experiments made before the start of the present research. That's why the validation of the model, if successful, will be a proof about the validity of the awareness driven behavioral changes model.

### 5.3.3 *Proof of concepts in ICTs*

The ABM can be used in ICTs field to reduce or avoid rebound effects. Proof of concepts can be, for example, related to the potential gain of energy coming from a more efficient PC, which is instead overcompensated by stronger and less careful use of the energy. In this case the physical quantity to be reduced is energy. A strong environmental awareness can lead to switch off the PC when not in use or to take other measures against rebound effects.

Another example related to ICTs can be the potential environmental gain rising from the adoption of flat screens. The potential gain in energy is overcompensated by the fact that very often the old devices are kept in service and the new ones don't substitute them. The awareness level can totally (or partially) avoid this rebound, using a new efficient screen to substitute an inefficient one, instead of adding it to other equipment.

The feasibility of such proof of concepts depends on data availability.

## 6. AIMS OF THE ABM AND FOLLOW UP

The expected result consists of a better understanding about the spreading of the awareness mechanisms. The ABM is a descriptive model and it can help to find, if any, an emergent collective phenomenon. An ABM to describe how aware behaviors can avoid rebound effects in the adoption of ICTs new products or services is an innovative tool to support policy maker in taking decision about environmental sustainability and limited resource consumption reduction. In particular in ICTs field this can enable to avoid or reduce rebound effects.

Therefore one policy response could be to make agents conscious or aware of rebound effects occurring within their own realm [34]. For this purpose policy makers need suitable, powerful, and friendly tools to help them in decision-making [30]. Such a need leads to design new Agent Based Models to study how rebound effects can be avoided or mitigated by raised awareness levels, both at individual and collective level.

Policy makers, mainly at a local level, can foster sustainable behaviors by supporting behavioral change programs to reduce the consumption of limited resources. An ABM approach suggests further research on societal aspects for better addressing the ICTs sustainability issues and for better exploiting the potentials of ICTs for sustainability.

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