

Agent Based Modelling for Decision Making in Energy Policy

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Abstract. The paper describes a decision-making exploratory modelling approach to simulate different situations leading to a sustainable consumption of energy. An Agent Based Model (ABM) is proposed in order to study the individual and collective behavioural changes toward environmental sustainability using ICT-based services, the SAM4SN (Spread of Awareness Model for Social Norms) model. It explores the role of awareness in the consumption of a resource. Simulating how environmental awareness spreads is an interdisciplinary issue that involves ICT, energy and environmental science, as well as social and behavioural sciences. The agents of SAM4SN represent households whose consumption of energy has to be reduced. Agents influence each other. Such influence improves their awareness that, in turn, impacts on resource consumption. The social influence plays an important role in spreading awareness. The model includes the role of smart metering functions. The role of the sustainability tipping point in decision-making is introduced.

Keywords. Social Norms·Awareness Spread·Energy Efficiency·Behavioural Change·Social Influence·Tipping Point·Committed minorities·Socio-technical digital ecosystem

1 Introduction

Electrical energy consumption is an important issue. Energy reduction programs are sometimes launched by local government or by utilities companies. While traditionally such initiatives are coupled with regulatory interventions, in terms of laws or economic incentives, the current trend is to focus on behavioural changes. There has been a lot of attention to provide consumers with information and services to manage their energy use [1].

The paper starts from the idea that individuals are influenced by decisions, actions, and advice of other individuals, both consciously and unconsciously [2]. The focus of the paper is on social influence in the dynamics of energy consumption. However, we

shall consider diversity of actors, each of which may exert a different kind of influence, and may in turn be influenced differently. The notion of social diversity leads to a network of neighbours composed by different types of agents who are more or less influential on the basis of their level of environmental awareness. The rationale behind our model is to pivot on social norms - as opposed to prescriptive ones [3] - and look at the onset of collective behaviour as a turning point to reach the sustainability goals.

The proposed approach aims to explore the potential of Agent-Based Modelling (ABM) to describe (at the micro level) this influence and to observe (at the macro level) its general effects on the resource consumption. In particular the issue is how to represent awareness spread and how to assess the importance of smart metering functions to turn awareness into sustainable behaviours. The proposed model aims to explore if and how environmental awareness can drive behavioural changes toward sustainability and how the availability of smart metering functions can help households in reducing their energy consumption.

An interdisciplinary overview introduces the background linking environmental challenges and energy consumption, with individual awareness, behavioural changes and social norms. The main focus is on environmental awareness as social limiting factor to avoid overuse of a resource. We will introduce the ABM paradigm for providing a description of the awareness spread and its effect on energy consumption. SAM4SN (Spread of Awareness Model for Social Norms) model simulates social influence and its effects in achieving a given target of consumption reduction. The community modelled in SAM4SN is composed by households that can access different types of smart metering functions, allowing us to compare their consumption patterns with the ones of other consumers, as well as to dynamically re-define and share their individual reduction goals.

The concepts of tipping point as well as of committed minorities are introduced. SAM4SN is a tool for decision makers to investigate, for example, initial configurations of different types of agent leading to sustainability and the required number of committed agents to enable a social norm. Such kind of investigation is important for planning campaigns or initiatives based on social norm effects. A decision maker can pivot a policy on pilot programs to support selected groups of people to become proactive. It is possible to discover that a nucleus of strong initial commitment against an environmental goal can counter any effort to promote it.

2 Environmental challenges, awareness, behavioural changes and social norms

On October 2012, the European Union adopted the Energy Efficiency Directive (DIRECTIVE 2012/27/EU) in reaction to the fact that EU Member States were not on track to reduce primary energy consumption by 20% by 2020. The implementation of this directive, and other policies that have been adopted in more recent years, requires a change in consumer behaviour and energy consumption practices [4]. The Article 12 of the above mentioned Directive focuses on “consumer information and empowering

programs” to promote behavioural changes. Voluntary behavioural changes are usually driven by some kind of reward. As far as environmentally sustainable lifestyles are concerned, economic rewards are often not strong enough to trigger a behavioural change [5]. Individuals are influenced by the decisions, actions, and advice of others when making a wide variety of decisions, both consciously and unconsciously. However, positive effects on the environment can only happen when an entire community adopts a responsible life style. Our purpose is to explore how environmental sustainability awareness can drive people’s behaviour.

According to the Oxford Dictionary, awareness is defined as “a concern about and well-informed interest in a particular situation or development”. Awareness does not coincide with information: people may have plenty of information about something without being aware of it. Rather, awareness is an individual aptitude that is developed and shaped inside a social context. Understanding how and when this awareness arises should therefore be considered as a central issue in any theory of collective social behaviour [6]. Some researchers [7] have argued that participatory processes are based on psychological mechanisms like social proof or social influence. We claim that such mechanisms are amplified in an ICT-based social dimension, where technology enables users to progress from a passive role to an active one.

Previous research has identified two essential factors for encouraging people to act: providing them with feedback on their situation and assisting them in setting their goals [8]. Such factors can be enhanced by ICT-based tools, able to motivate people to modify their behaviour [9]. These factors can be readily adapted to the encouragement of environmentally aware lifestyles. The first factor can be stated as providing individuals with real-time access to information about their personal resource consumption, while the second is providing them with a way to compare their lifestyles with some environmentally aware benchmark.

The mechanisms of psychological ownership, social proof and social influence are basic concepts to approach behavioural changes in resource consumption. Psychological ownership [10] describes a state in which a person feels closely connected to an object or idea, to the degree that it becomes part of her "extended self".

To be correctly used, instruments have to be appropriated by users [11], i.e. contextualized in their daily routine. A way to extend a social norm is to use rewards for “socially acceptable behaviour” like incentives, although not necessarily monetary ones. As soon as people consider something as “their own”, its perceived value increases and they are more likely to invest time and effort in preserving it [12,13]. Social proof [7], [9] describes how people act in a certain way because they see others acting that way. In such situations, the fact that others make a choice acts as a proof that this choice is preferable. While a mix of needs, personal desires and social images drives consumers, individuals are known to replace common background or geographic proximity with a sense of well-defined purpose and successful common pursuit of this purpose [14]. Social influence is an umbrella term for a loose congregation of social, psychological, and economic mechanisms.

The influence network – the network of “who influences whom” – impacts the dynamics of collective decisions [15], determining, for example, the likelihood that “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 tend to assume (often implicitly) that all actors involved are of the same type, 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. A research area of growing importance inside social network analysis is now focusing on a special case of influence response - namely threshold rules, according to which individuals adopt a new state based on the perceived fraction of their peers who have already adopted the same state.

Threshold models are well understood in certain special cases, like all-to-all approximation where all individuals are influenced equally by the states of all others. Other studies [16] moved systematically up the complexity chain, reviewing the dynamics of cascades of influence on random networks. Other [17] models of networks progressed with respect to the random network model by including some notion of topology. For example, neighbourhood relationships defined topologically or socially are giving rise to threshold models that are more and more popular in social network analysis. The classical Granovetter's threshold model [18] has evolved into a network setting where (as opposed to the conventional "all-on-all" influence assumption), individuals are influenced directly only by a small subset of their immediate "neighbours" according to some notion of distance. In this context, a notion of social diversity [19] is needed in order to simulate a network of neighbours who are more or less influential on the basis of their level of environmental awareness.

As above mentioned, economic rewards alone are not strong enough to trigger a behavioural change. Other kind of reward can be more effective. When a community adopts a responsible life style some positive environmental effects will happen in the long run. When the adoption of a sustainable behaviour is driven by awareness and such awareness shifts from an individual dimension to a shared collective one, this generates the most effective reward: social appraisal. Such a mechanism is the trigger for a social norm. If environmentally friendly behaviour becomes a social norm it will be carried on without any need for controls, fines or law enforcement: "Effective policies are ones that induce both short-term changes in behaviour and longer-term changes in social norm" [3]. Social norms are persistent and, once adopted, are followed even after the state intervention ceases. Making collaborative behaviours convenient may strengthen both personal and social norms. Making all behaviours more visible shows people what others are doing. ICT-based systems, as smart metering advanced functions, can be pivotal.

3 An Agent Based Modelling approach

Axelrod [20] considers simulation as a third way of undertaking scientific research, after induction - i.e. the discovery of patterns in empirical data - and deduction - that involves specifying a set of axioms and proving consequences that can be derived from them. Namely, Axelrod remarks: "starting with a set of explicit assumptions,

simulation does not prove theorems but instead generates data that can be analysed inductively, as a way of conducting thought experiments” [7]. Some questions can however be answered with simulation experiments [21]. According to Marks [22] “... a simulation might attempt to explain a phenomenon; it might attempt to predict the outcome of a phenomenon; or it might be used to explore a phenomenon, to play, in order to understand the interactions of elements of the structure that produces the phenomenon”. There are important classes of problems for which writing down equations is not a useful activity. In such circumstances, resort to agent-based computational models may be the only way available to explore such processes systematically, and constitute a third distinct usage of such models [23]. We present an exploratory model that might be used to play and explore different situations, in order to understand the interactions of elements of the structure that produces the phenomenon.

4 The SAM4SN Model

The SAM4SN allows defining a set of scenarios to study the emergence of collective phenomena that are impossible to foresee at individual level. Of course, there will be scenarios that lead to overuse of the resource, and scenarios where this does not happen because the social mechanism has a positive effect, i.e. sustainable behaviour emerges. The goal is to observe at a macro-level how awareness can spread in the community, how the dynamics of awareness impact on individual reduction goals, and how the availability of different smart metering functions impact on such mechanisms. “Green” people, i.e. people with high environmental awareness, can decide to limit the privacy of their own consumption information and share with the community their own consumption data. Such voluntary mechanism of “privacy versus reputation” is an emerging trend in some communities, where becoming a green opinion leader is perceived as a social recognition.

SAM4SN is a certified model, fully available at OpenABM [24], where a full description of SAM4SN is supplied, according the ODD (Overview, Design concepts, Detail) protocol [25]. Further details are supplied in G. Sissa, 2015 [26].

The agents represent people involved in the consumption of a limited or critical resource. Each agent models a household. Agents can be supplied or not by smart functions of metering.

We have five entity types: blind agents, indifferent agents, spectators, actives, and evangelists.

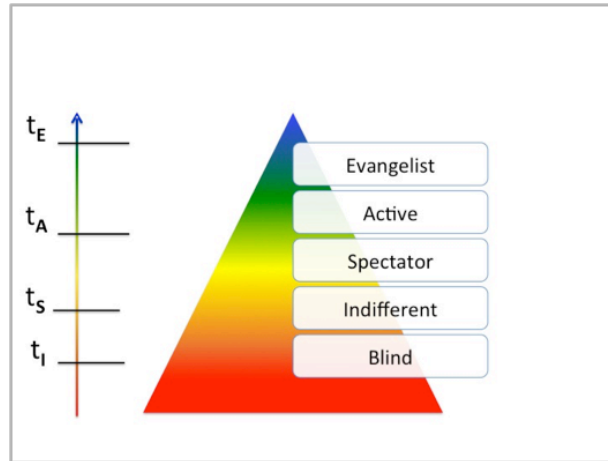


Fig. 1. Agents and awareness thresholds

- Blind agents exhibit dysfunctional behaviour with respect to the goal. As detractors of the need to prevent an overuse of the resource, their consumption pattern is only driven by their individual needs; furthermore, they mock other behaviours and have negative influence on neighbours.
- Indifferent agents, the largest group, are neutral about the environmental sustainability goal. Their consumption is constant.
- Spectator agents are quite neutral in their behaviour, but are open to listening and keen to observe their neighbours' behaviour.
- Active agents are “green” people, strongly committed to the reduction of resource consumption. They allow other people to inspect their consumption data in order to share their reduction achievements with others.
- Evangelist agents are active agents that, in addition, are able to contribute to the resource supply. They are energy prosumers.

Agents belong to one and only one type at time. A state variable of agents is their awareness, expressed as a cardinal numerical quantity (Fig. 1). Different types of agent have different awareness; such awareness is a continue variable. Other agent variables are: the agent's resource consumption rate, its own resource reduction goal, and its own resource production.

The space of agents is bi-dimensional and represents a set of households on a given geographical area.

SAM4SN agents interact by proximity and change their awareness according to the number and the type of their neighbours. Once an agent's awareness reaches a threshold, the agent joins a different type (Fig 1). The awareness diffusion mechanism is a core point of our model. It is driven by the assumption that the most influential neighbours are those lying at the two extremes of the awareness scale: evangelist at the top and blind agents at the bottom (Fig. 2).

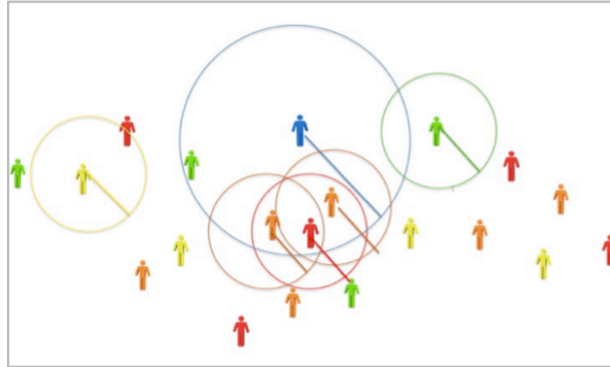


Fig. 2. Influence radius of agents

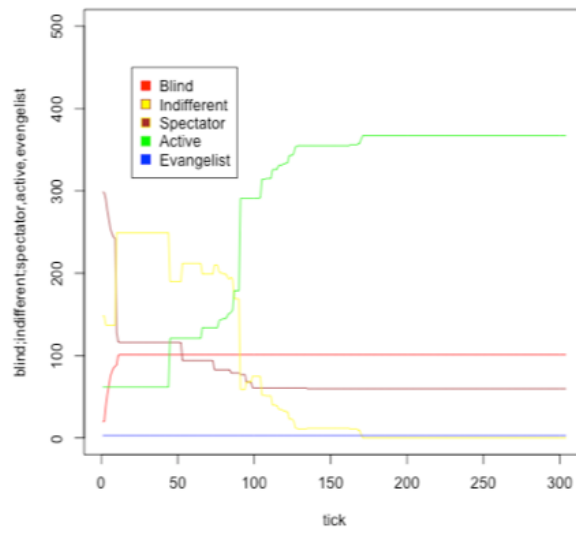


Fig. 3. Dynamics of agent types

At each process iteration, the awareness of the agents is updated (Fig. 3). A basic design principle of this mechanism is context-dependence: the influence of neighbours depends on their type. Also, the rate of awareness change and thresholds are different for each type.

Another important design principle is saturation: the “greener” the agents, the higher the threshold they have to reach for moving to a new type. A third principle is hysteresis: once agents become “green” (i.e. join the active or evangelist types), their awareness never decreases. Finally, transitivity of influence supports a kind of cascade effect, limited by the influence sphere of the agents.

Each agent has a reduction goal concerning the limited resource and progresses toward its goal at a given rate. At each run the number of agents belonging to a type

can change, while total number of agents is constant. Main global variables include the cardinality of each type of agents, the current resource consumption and an overall reduction goal.

The model evolution stops when the global consumption reduction goal is achieved. At each iteration, agents look around to verify how many neighbours they have and of what type. According to its neighbourhood, each agent then changes its awareness level. The rules to update awareness are different for each agent type. Blind agents can change their awareness only if they have completely green neighbourhoods and even then their awareness increases very slowly. After the upgrade of awareness of each agent, if the agent's awareness rises beyond a given threshold the system updates the agent state, i.e. sets the membership of the agent to a new type.

Each type of agent has a different consumption and such consumption is updated according to an individual reduction goal. The overall consumption is evaluated on the basis of the individual consumption and also on resource production on the part of evangelists.

Each agent's individual resource consumption depends on an overall reduction goal. For each agent type, the goal is computed as the difference between the previous resource consumption and the individual reduction goal that has to be reached with a given rate. The individual reduction goal varies according to agent type.

SAM4SN relates awareness change to the availability of specific functions of a smart metering system. The availability of smart metering functions can impact on such mechanisms by empowering agents.

Four classes of smart functions are identified:

- In home metering;
- Individual feedback about own consumption of the limited or critical resource;
- Information about green leaders and their low consumption profile that are taken as reference;
- Personalized advice for consumption reduction.

Availability of smart metering functions enables the agent to know its own consumption of the resource and to identify an individual reduction goal. For blind agents, it is independent from the availability of any facilitating conditions, because blind agents want to increase their consumption despite any evidence of the need to reduce it. When the function of comparison with neighbours is available, agents know the consumption of other agents and can set their own reduction goal on the basis of the minimum consumption of other agents.

The reduction goal depends on the minimum known consumption and is given by the difference between the previous consumption of the agent and the reference consumption of another agent that has the minimal consumption. Such difference is multiplied by a green-competition index.

4.1 Social reinforcement

In SAM4SN model, awareness is also modified by the mechanism of social reinforcement. A comparison takes place between the individual agent's consumption

trend and the global trend of resource use. When their behaviour trends are concordant with the general consumption trend, the agents can *reinforce* their beliefs and this social reinforcement, in turn, changes their awareness. Positive reinforcement happens when both individual and global consumption trends are of reductions; negative reinforcement happens when both individual and global consumption trends are increasing.

We introduced the notions of commitment and “quasi-commitment” as useful notions when linked to the concept of social reinforcement. Once a committed (evangelist) or quasi-committed agent (a blind or an active) is reinforced in his belief, this reinforcement is persistent and the agent remains reinforced as it was (positively or negatively), while not committed agents (spectators and indifferents) are responsive to positive or negative reinforcements.

In our model, committed agents coincide with evangelists, i.e. the most influential ones, while blind or active agents are “quasi-committed”. In our model awareness is affected by social reinforcement, because the reinforcement value is added to the awareness level.

4.2 The tipping point and social norms

According to some studies [3], as soon as enough people with high social influence [27] adopt a social norm, a tipping point [28, 29] is reached. The idea of a tipping point for environmental sustainability is used by Kinzig and colleagues [3] and derives from theoretical works [30] about the role that committed agents have in reaching consensus. In particular the value of 10% of committed agents - as a critical value for opinion diffusion - has been introduced by Xie and colleagues [30].

The tipping point is the critical point in an evolving situation that leads to a new and irreversible development. It takes place, making the norm widely shared and the corresponding behaviours pervasive. In our system the agents that are “consistent and inflexible” in their beliefs” are the active ones and the evangelists, i.e. the green agents, but also the blinds. In SAM4SN this notion is specialized and the sustainability tipping point (STP) is defined.

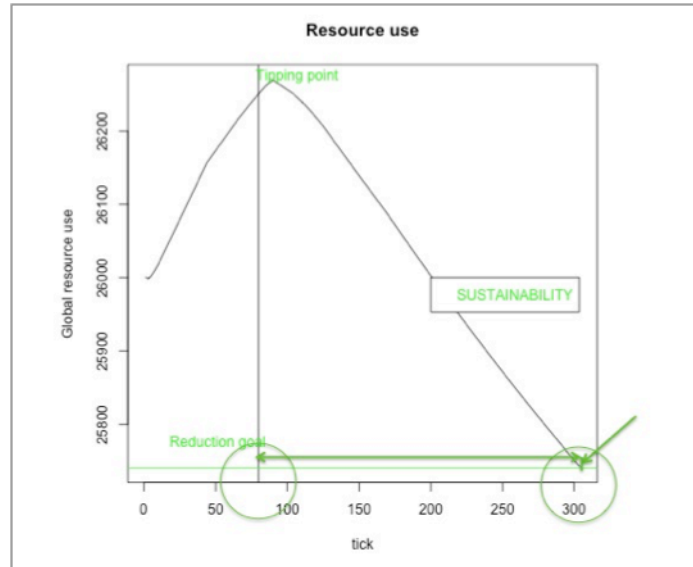


Fig. 4. Sustainability Tipping Point is reached before the reduction goal

Looking at situations evolving toward sustainability, we can observe, as the sustainability tipping point is reached much earlier than the overall reduction, as showed in Fig. 4. If we can consider the reaching of the reduction goal as a long-term effect of a sustainability social norm, STP could be seen as an “early warning” signal, able to anticipate the reaching of sustainability. STP can be a sustainability indicator. In our case it corresponds to know “how early” the STP becomes true before the system reaches the sustainability (i.e. the reduction goal).

5 Conclusions

The STP could help in estimating “if and how long after” a given target will be reached. STP can help decision makers to establish the initial configuration of different types of agent leading to sustainability. To consider the initial commitment of agents as a constraint to reach an overall objective can be an approach for several kind of campaigns or initiative based on social norm effects.

A decision maker can pivot on that idea, for example, in pilot programs to support group of people to become more proactive and committed on a given cause. On the opposite he can evaluate that a strong initial commitment against such cause will counter any effort toward it. In policy-making it can be useful to better distribute effort and resources in environmental sustainability programs, while for a utility company the STP can be valuable to predict trends of decrease in resource consumption.

STP can be an useful tool for policy makers to better understand, for example, the areas of a political intervention where to allocate more resources or less resources.

The sustainability tipping point can give decision makers a support to understand if a sustainability social norm is emerging in a given area.

SAM4SN can be used as a virtual laboratory where to perform experiments on such mechanisms and concepts. For utility companies, it could be a useful tool to explore how and when to invest on smart metering functions development.

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