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Bounded Rationality and the SD Approach for energy modelling

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ABSTRACT

The liberalisation of energy markets provides a challenge for what is known as rational energy use, and therefore for the understanding of end-users behaviour under both government policies and traders strategies. In this environment, it is important to assess the decision making processes of energy end-users for policy and strategy intents.

The methodologies reported in the literature generally make strong assumptions with respect to the decision making processes of end-users, including: complete information, full rationality and lack of risk perception. In this paper, Simon´s bounded rationality (BR) is picked up, seeking for alternative grounds to the traditional methodologies.

System Dynamics (SD) modelling, with the help of other approaches, seems to provide a most appropriate environment for a wide number of BR applications in the energy field, as it has been claimed in the literature that this approach is well grounded on bounded rationality. However, both this claim, as well as to how SD handles uncertainty, which basically accounts for BR, needs to be clearly justified.

In this paper we undertake BR under the SD framework in two areas: modelling methodologies and applications. First by indicating, explicitly and implicitly how to incorporate uncertainty in SD and second by providing guidelines for establishing how variables are included and discarded from models.

1 FROM CENTRAL PLANNING TO OPEN ENERGY MARKETS

During the late 80s, there was a world trend of disbelief with respect to the effectiveness of state owned monopolies in charged of public services, which gave way to important reforms initially in Chile, the United Kingdom and Norway, and few years later in other European and American countries as well as in Australia.

Changes intended to:

- Introduce competition in the electric sector.
- Allow private investment and the privatisation of state owned companies.
- Eliminate vertical integration, unbundling the transmission, distribution and generation businesses.
- Focus governments actions in the area of industry regulation and in few cases also performing indicative planning for expansion.

One of the main changes introduced by these reforms was the promotion of competition at the final user's level, allowing consumers to freely procure electricity.

Against this background, some thought that these reforms were contradictory with Demand Side Management -DSM- which encompasses planning, implementation and follow up activities, with the purposes of modifying levels and patterns of electricity consumption. By means of these programmes, important benefits were achieved by both end users and power companies, especially with respect to: energy efficiency initiatives, direct load control, load interruptible and hourly pricing (EIA, 1996).

However, it was not clear that the conditions for rational energy use under a centrally planned scheme prevail when markets are liberalised.

2 EFFICIENCY AND RATIONAL ENERGY USE UNDER OPEN MARKETS

Under competition, companies can not be forced to undertake programmes of rational energy use. Government may implement indicative planning or create incentives but cannot force utilities or final users to undertake such programmes. Utilities would only offer such programmes if these are profitable, but which companies in the electric sector maybe interested in undertaking such programmes? To provide answers to this question we would try to understand the motivations of the different agents that intervene in the electric market.

Transporters would be interested in efficiency programmes, directed to reduce losses at economic levels. As regulated revenues depend on the transported energy, the business logic seems simple: transport as much as possible. Thus, they would not be interested in undertaking other programmes.

Generators may be interested in efficiency and production “optimisation”. Therefore, the regulator may incentivate highly competitive markets, forcing generators to produce at optimal levels to survive in the market place.

Traders may have incentives towards undertaking rational energy use programmes.

For established traders:

- Implementing rational use programmes to end users by means of binding contracts.
- Promoting rational use to reduce demand when prices in the wholesale market are higher than prices which have been agreed upon with end-users.
- Promoting rational use to those sectors where electricity is subsidised by law.

For new traders or those who intend to increase their market share:

- Promoting rational energy use as part of a strategy to attract clients.
- Promoting rational energy use to offer lower prices, using a similar strategy to the ESCOS –Energy Service Companies.

As has been discussed, open markets do not seem to discourage programmes of rational energy use and efficient production. It is not clear though as to when and which agents would undertake demand side management and efficiency programmes under open markets, because of possible market barriers.

Sioshansi (1995) considers that under open markets DSM programmes should operate better than under centrally planned schemes. To understand this issue better, let us revise the evolution of DSM based on Sioshansi's perspective. He identifies three periods for DSM:

1. 1973-1989 Command and control without incentives.
2. 1989-1994 Command and control with incentives.
3. 1994 - Consumer driven to achieve better efficiency.

The third wave of the DSM is marked by two events that can completely change the concept of the electricity business: competition in the trading business and free access to nets.

Sioshansi argues that under market schemes DSM can be more effective than ever before, however the literature has already reported some difficulties. Several researchers have noticed that substantial differences exist among the current levels of energy efficiency and those that should exist if they had undertaken the appropriate decisions under a rational approach. This problem is referred to in the literature as the energy efficiency gap (Jaffe y Stavins, 1994), which will be discussed next.

The effectiveness of market mechanisms to reach socially desirable levels of energy efficiency had generated a debate among specialist and policy makers. The neoclassical assumptions of perfectly informed markets and rational individuals that consider all costs, when deciding what appliances to buy, seem insufficient for understanding DSM.

When observing electricity consumption, agents seem to implicitly use discount rates above 89%, which is much higher than those rates applied to other common investments (Howart and Andersson, 1993; Hausman, 1979; and Gately, 1980).

Some authors claim that consumers use such high discount rates due to uncertainties related to the operation and penetration of new technologies. Other authors argue that these high rates maybe explained by the consumers' low revenues and their difficulty for investment in new technologies. This phenomenon reveals that consumers expect to recover investments in very short periods. These two problems may be solved by: a) providing guarantees or b) subsidising low revenues customers. To this respect, a critical issue is establishing the size of the energy gap and the definition of the optimal level of energy efficiency (five independent notions of optimality have been identified; Jaffe and Stavins, 1994).

This section has been focusing on issues related to failures in electricity markets. Apparently some of these failures are due to market uncertainties and other aspects related to the decision making processes of final users: cultural barriers, aesthetic parameters, habits, asymmetric information or knowledge and high risks.

The above discussion suggests that the problem of demand side management and efficiency should incorporate the perspective of rational energy use under some sort of bounded conditions as suggested by Simon (1978) – this could be referred as rationally bounded energy use.

3 DECISIONS MAKING

A simple way to explain an action, is to consider it as depending on two successive filtering operations (Elster, 1990). The initial step begins enquiring about all possible actions that the individual can undertake. The first filter comprises all the physical, economic, legal and psychological restrictions that the decision maker faces. We are left after the first filtering with an opportunity group. The second filtering operation determines which actions are included in the opportunity group, figure 1A.

We can observe that due to the first filtering operation, the election may not be carried out to the second filtering operation. That is to say, the opportunity group decreases in the first step.

Opportunities are more basic than desires in one aspect: they are easier to observe. The military strategist states that his plan should be based on the enemy's capacity (Verifiable) rather than on his intentions (unverifiable) (Sun Tzu, 500 BC). This means, getting ready for the worst case, in which the enemy will harm us as much as he can possibly do.

It is important to realise that it is usually easier to change people's opportunities than their way of thinking. Desires and opportunities can be influenced each other and they can both be influenced to produce an action, as illustrated in figures 1 B,C.

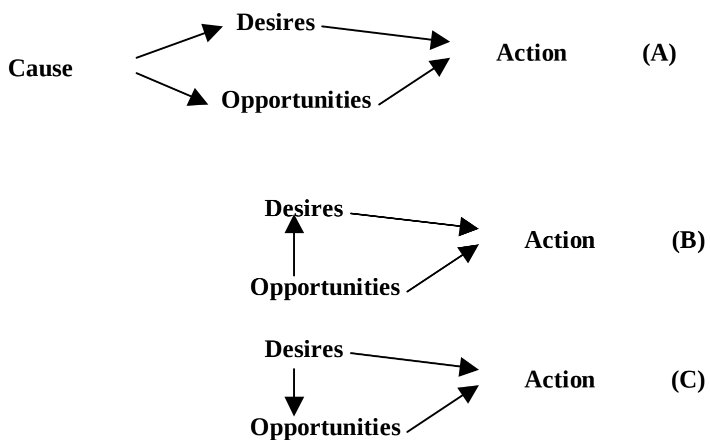


Figure 1. Desires and Opportunities

When facing a decision, people usually do what they believe is best on his behave. This sentence, deceivingly simple, summarises the theory of the rational election (Elster, 1990a).

For an action to be rational should be the result of three optimal decisions (Elster, 1990a). First, it should be the best means to carry out one person’s desire according to his beliefs. Second, these beliefs should be optimal given the evidence that the person has. Finally, the person should gather a good amount of evidences, neither too much nor too little. The correct amount depends on his desires, the importance assigned to the decision and his beliefs about costs and benefits. Figure 2 (Elster, 1990b) shows the process.

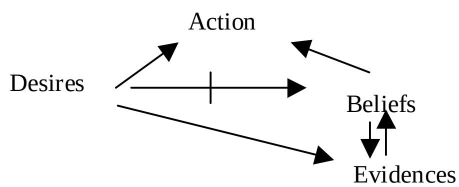


Figure 2. Optimisation process in rational decision making.

When making a decision, we confront risk for acting too soon with little information or for delaying the process of information gathering, until it is too late.

Decisions making is necessary limited because of the processing capacities of human beings and the failure of rationality as a consequence of physiologic or sociological problems.

The logic is to establish a set of rules to progress from an unknown condition to one which is known (León, 1994). The problem is to define what is true in a series of situations and to established their limits. For example, the expression "the water is hot" becomes true under certain circumstances in a specific environment. Also, this logic does not establishes what is true or false, but rather provides a great number of combinations between both, such as it is done in fuzzy logic.

Human intelligence does not work as this logic prescribes. According to Simon (1978), human beings are fundamentally adaptive to the environment. An environment of high complexity would paralyse a totally logical system, forcing the decision maker to discard a large amount of information. In highly complex environments, calculations should be made by procedures that allow us to reach the objectives on time, although not always providing the best or optimal solutions.

Against this background, two important characteristics of the problem solving process are: a) that mental representations are supported in work memory with finite capacity only, and b) that human decisions differ from computationally logical systems, since they are affected by the environment. While formal system disregard context, humans seem to integrated it better in its decision making process. Is it correct then to attribute full rationality to man and to model it under these assumptions?

In organisations, although man does not behave totally rational, he intends to - this is denominated rationally bounded behaviour. The importance of bounded rationality resides in better understanding the decision making process for better policy modelling.

4 MODELLING

Modelling is centred in the problem of understanding decisions for most effective policy making, specifically for understanding the decisions of the agents that intervene in the energy market. Problems have been detected at three levels:

Producers: These agents produce electricity for sale in the wholesale market, by way of contracts or directly in the pool. Their clients are traders and other generators. They do not have direct contact with final users.

Traders: These are agents that, by means of purchases and sales, provide electricity to final users. These agents also carry out covering operations, selling electricity to generators and other traders. Sales to final users are carried out by way of contracts, in the case of large consumers, and through tariffs determined by the regulator, in the case of regulated users.

Final Users: There are two types of final users. Those who can freely negotiate prices with a trader, and those that have fixed tariffs. The first ones are denominated not regulated users and the second ones regulated users.

In this research we will focus on the limitations of agents from point of view of both final users and traders, investigating what effects these produce on other agents in the electricity market. These two types of agents were chosen since they are the most important ones from the point of view of demand. Policies evaluated in this paper are geared towards overcoming the barriers of final users for the adoption of certain type of energy technologies. This research may also support traders strategy intents.

The methodologies for bounded rationality should be able to overcome some of the deficiencies exhibited in the classical approaches, specifically with respect to efficiency, rational energy use and DSM, as these usually assume full rationality. It has been argued that the classic approaches are ineffective (Bunn and Dyner,1996), as they are:

- **NORMATIVE**
- **DETERMINISTIC**
- **LINEAL**
- **NON-SYSTEMIC**
- **MECHANISTIC**
- **STATIONARY**

These feature become modelling requirements for a new methodologies. To improve our understanding about demand evolution and the interactions between traders and final users, alternative approaches also need to support simulation capabilities for policy assessment. With this research we expect to improve our vision on technology diffusion, rational use of energy, efficiency, substitution, losses, cultural aspects and externalities such as environmental contamination, all these under a deregulated environment and strong competition between traders.

The precedent section identified that desires and opportunities are relevant aspects in the decisions making process. It was also observed that man's limitations in decision making maybe explained by bounded rationality arguments. A framework is now proposed for the understanding of decision making for energy investment from the point of view of end users. This framework uses the inherent sociological and psychological limitations of mankind.

In general terms the decisions making framework is represented in the figure 3. This system evolves according to the actions of participants. These actions consider desires and opportunities, and policies induce changes in desires and the opportunities.

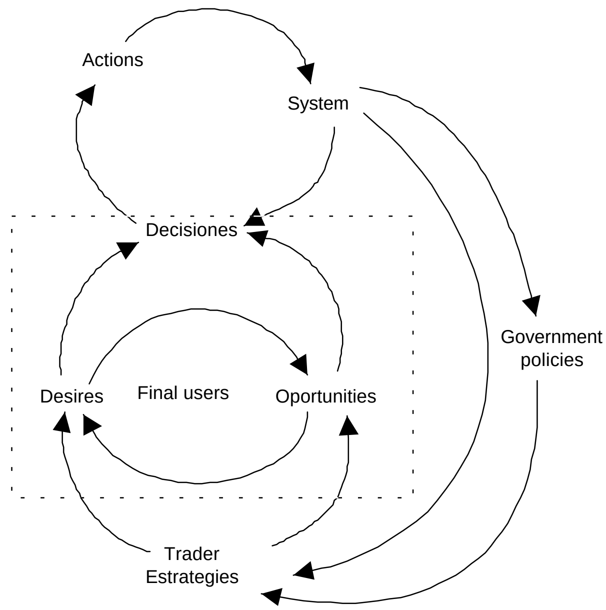


Figure 3. General scheme of the system.

In general, for the problem of technology choice, decisions making operates as shown in figure 4, where there exists filters for desires and the opportunities.

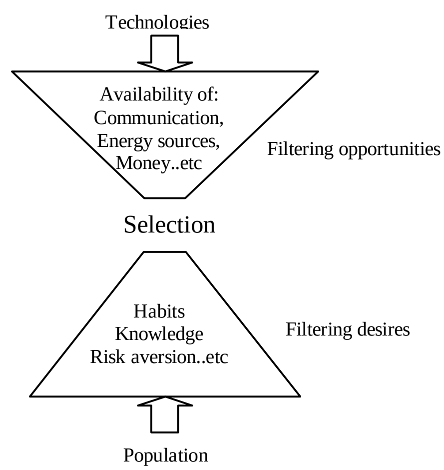


Figure 4. Double filtering of desires and opportunities.

To develop a methodology that allows incorporating the concepts of bounded rationality is necessary to find a tool capable of supporting the implicit limitations of the decisions making in energy systems. We discuss next our modelling approach using systems dynamics. This modelling approach focuses on the representation of end user's decision making.

When evaluating several tools for the representation of energy systems, the literature provides foundations to carry it out using systems dynamics. In the first place Bunn and Dyner (1996) state that systems dynamics may be a sensible option, especially if one works with changing systems or with recently restructured markets. On the other hand Morecroft (1983) argues that systems dynamics implicitly uses bounded rationality in its formulations.

The Carnegie School states that the behaviour of complex organisations can only be understood taking into account the knowledge of individuals and their psychological limitations (Morecroft, 1983). This point of view focuses on the flows of information within complex systems, the quantity and quality of the information that is manageable in the decision making processes and the decision rules used.

It is at the level of information flows and decision making where most of the fundamental ideas of the Carnegie School coincide with systems dynamics, but it is also at this level where Carnegie School radically brakes apart from the point of view of economics and the operational research – specifically with respect to desires and opportunities in the selection of efficient technologies and with respect to electricity planning.

In relation to problem solving by way of simulation, systems dynamics and the Carnegie School share the belief that simulation is a powerful way of gaining understanding of the decision making process.

There are three important ideas of the Carnegie School that could positively influence systems dynamics (Morecroft, 1983):

Improve communication with other disciplines: The Carnegie School offers an alternative methodology in which feedback structures can be explained in terms of flows of information and the processing of this information in the decisions making process.

Conceptualisation focusing in the organisation: Models conceptualisation can be improved if those who builds the models clearly recognise that they are building models of human organisations and that they are governed by the principle of bounded rationality. This does not mean that we would construct models for better decisions, but rather models that are more adjusted to reality.

Analysis of behaviour, making use of intentional rationality: Systems dynamics models are of two types: partial and total models. The partial ones represent a portion of a process and will be possible to observe intentional rationality, this means that parts of the organisation could behave slightly more rationally if they were allowed to behave freely. When several groups interacts, policies based on intentional rationality can fail. This is probably why policies that succeed in small environments, fail when facing more complex environments.

Systems dynamics can add more elements to the process of model formulation and a new dimensions to the analysis of behavioural models than the Carnegie School Approach (Morecroft, 1983).

The construction of any systems dynamics model may begin by establishing the main variables that have an impact on the system under consideration and the elaboration of chains of causation among variables. In a later phase, a stocks and flows diagram is built. Finally mathematical relationships among model variables are constructed and the values of the parameters and the initial conditions of the level variables are determined.

When building a system dynamics model that represents decision making, it is also necessary to consider: desires, opportunities and the decisions making mechanism itself, this is represented next.

Determination of Opportunities

Modelling begins by establishing the set of all opportunities, that is determining all possible decisions that the individual can make. This group may be reduced because of the technologies that are available in the local market. In turn this group of technologies is limited by the technologies that the decision maker considers.

The set of real opportunities is finally reduced by the economic limitations of end users. The general diagram of the opportunities can be appreciated in figure 5.

With this vision, modelling opportunities can be approached by reducing values gradually, before reaching a decision.

Determination of Desires

Modelling desires consists on determining the portion of population that will not be shifting away from former energy technologies because they have no knowledge about alternatives, or because they are reluctant to change (and they not even consider the possibility of change), or even because they are risk averse. All these inhibit the entrance of technology alternatives.

There are some problems related to modelling. Perhaps the main one is that related to modelling habits, which seems to be an important factor against technological changes. The general diagram that describes the filtering processes of desires and opportunities can be appreciated in figure 5.

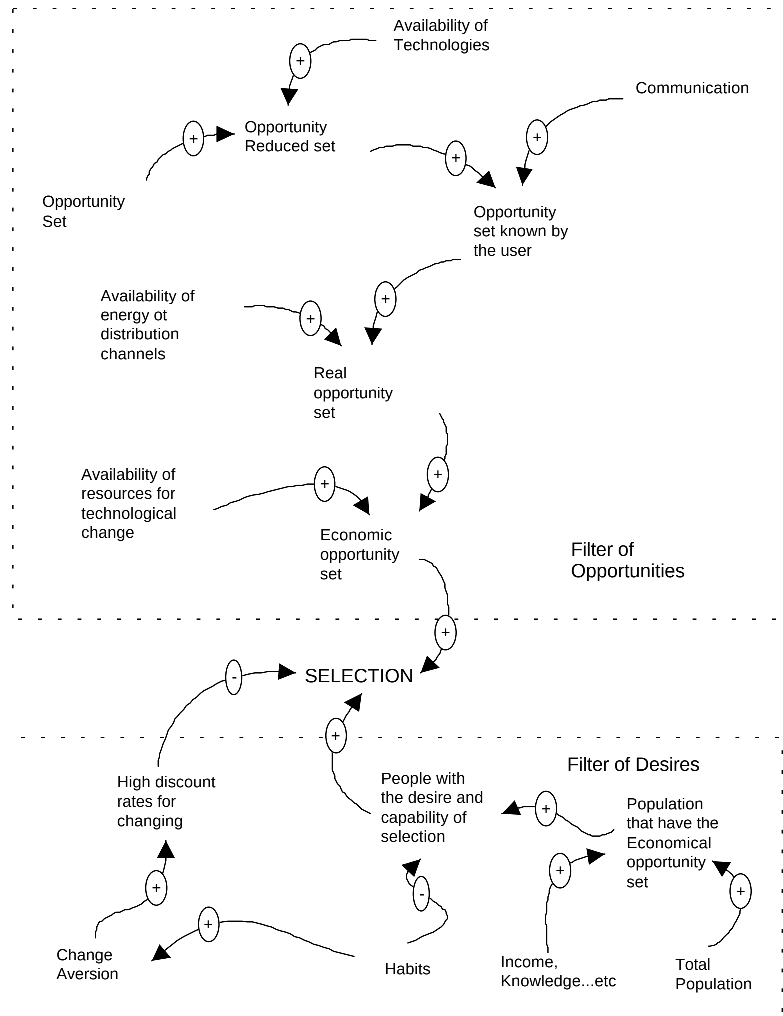


Figure 5. Double filter in technology choice.

Establishing limits for decisions making

When individuals confront decision making with no limitations, a reasonable assumption is that they intend optimality. This would be a rational decision since limitations have already been filtered. These decisions could be modelled by means of the logit model using an infinite gamma (see ahead), or simply assuming that the decision maker take the best option, under the information available to him.

For the evaluation of investment decisions, it is necessary to restate the concepts of annual equivalent costs, net present value, monthly equivalent cost, operational costs, and investment costs, among others.

A model that considers limited rationality has the advantage that it allows to focus on policies directed to both desires and opportunities.

Policies intending to stimulate opportunities:
Policies intending to stimulate opportunities are easy to detect and implement as stated by Elster (1990): "Opportunities are external to individuals, while desires depend on him". It is

easier to change people's opportunities than transforming their way of thinking. Policies intend to increase opportunities, attacking the causes that restrict them. The different policies that can increase the elements included in the opportunity sets are now listed:

- Set of reduced opportunities: Research and development of new technologies.
- Set of opportunities known to user: Popularisation or marketing.
- Set of real opportunity: Improvement of distribution channels of technologies.
- Set of economic opportunity: financing, soft credits.

Policies intending to stimulate desires:
There is no use for an extensive opportunity group if people have limited desires. To focus on policies to stimulate desires it is necessary to consider people's habits, then trying to modify them. This could be accomplished by means of education or by demonstration (pilots plans). Changing habits may be achieved by children education.

5 SD MODELLING AND OTHER MODELLING APPROACHES

To show how methodologies differ we will show alternative representations for decision making under both bounded rationality and full rationality, using: The Logit Model and Financial schemes. The problem under consideration is market split between incandescent and fluorescent compact bulbs.

A systems dynamics model was constructed (figure 6) and different decision making mechanisms were investigated for comparison purposes. Next we describe in brief the mechanisms under examination.

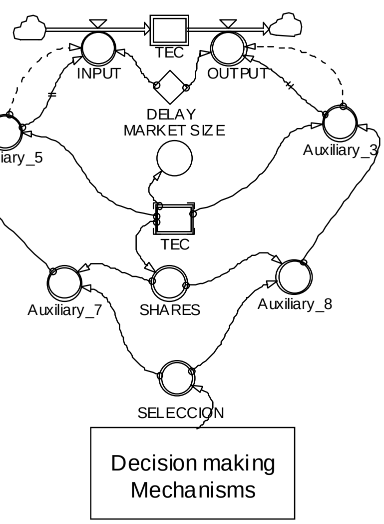


Figure 6. Model diagram.

Optimisation: If optimisation is used compact fluorescent bulbs would immediately take the whole market, as they have lower annual equivalent costs. This result is obviously impossible because of production, technological and cultural barriers.

Logit Model: The Logit model is used for decisions making analysis when the annual equivalent cost of an alternatives is evaluated as a percentage of the annual equivalent cost of other technologies. The model diagram is shown in the figure 7 and is represented as follows:

$$PE_i = \frac{CAE_i^{-\gamma}}{\sum_j CAE_j^{-\gamma}} \qquad i = 1,2,...,k\ ; \quad J = 1,2,...,k.$$

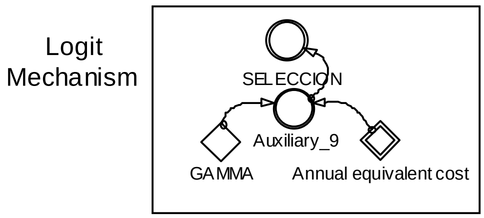


Figure 7. Model's diagram using logit for decision making

The results obtained with the Logit model can be appreciated in figure 8. The market share of compact fluorescent bulbs is larger than the one of incandescent bulbs, but do not penetrate the whole market.

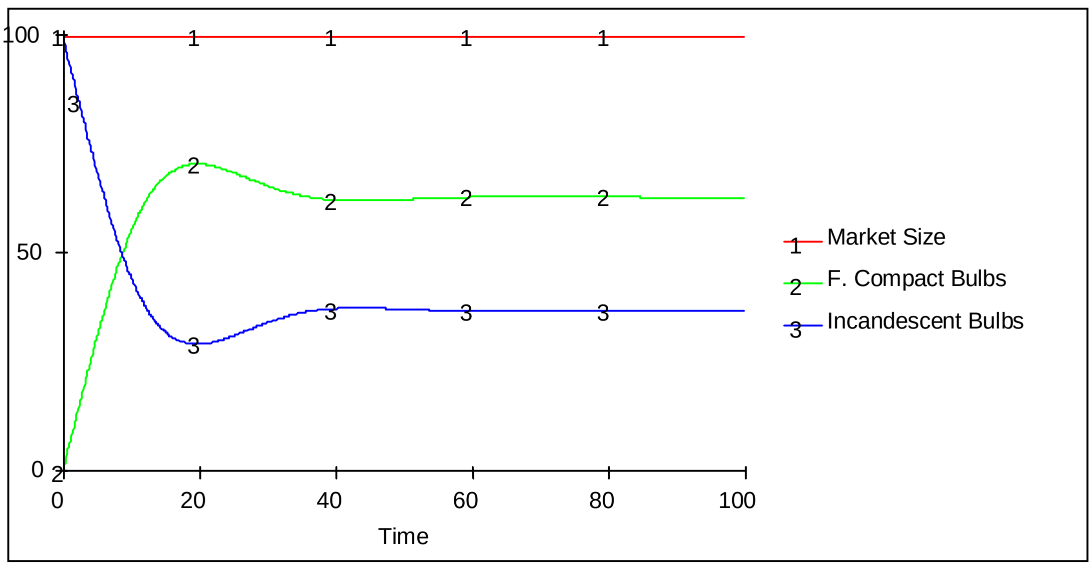


Figure 8. Technology propagation of light bulbs using the logit model

Financial decisions: When modelling financial decisions, such as net present value, one could determine the discount rates at which compact fluorescent bulbs would be most attractive. The developed model uses the same principle as the logit model, however net present value is used instead of the annual equivalent cost, to incorporate the concept of risk, via discount rates (see figure 9).

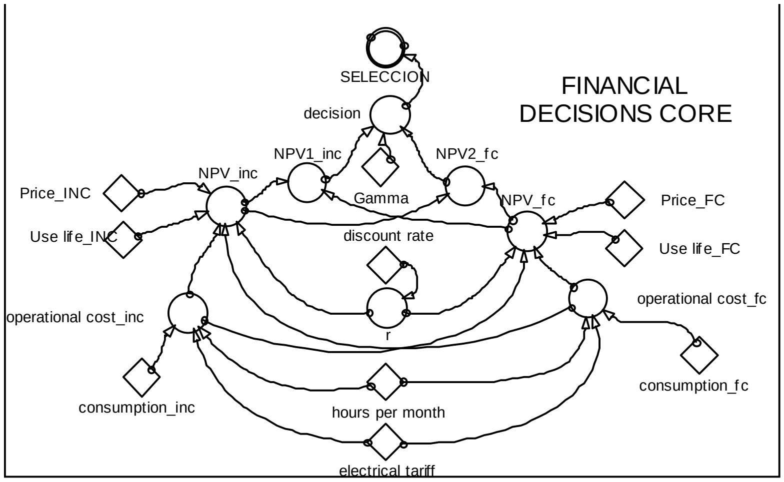
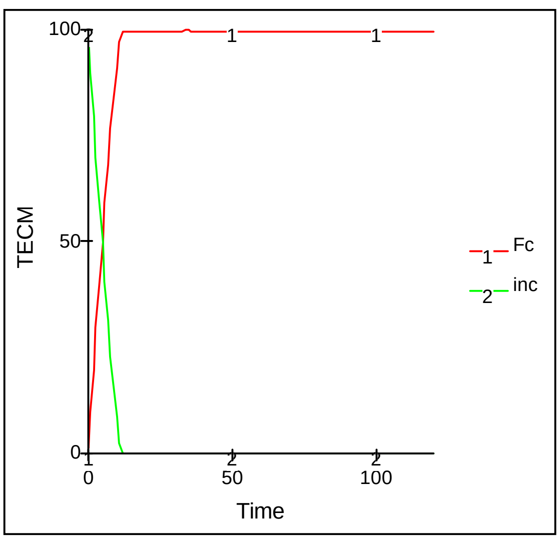


Figure 9. Financial Decisions mechanism

Figure 10 shows model results when financial decisions are used, for discount rates of 30% and 200% respectively. Results are as expected: to lower discount rates, larger penetration of the corresponding technology. These discount rates could be modify by means of educational programmes.



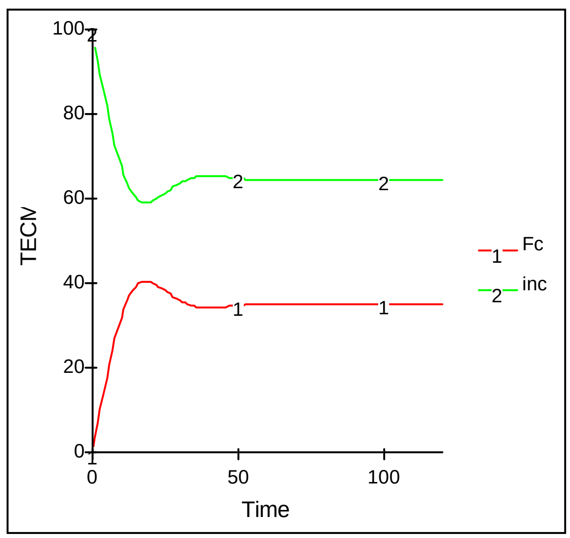


Figure 10. Results of the financial model for a rate of discount of 30% and of 200%, respectively.

When considering technology diffusion mechanisms (on top of financial decision), where individuals are just followers, and never take their own decisions, we have the model of Figure 11.

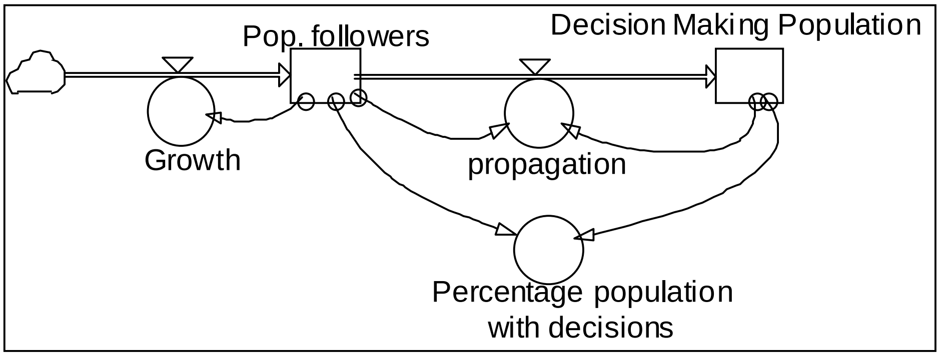


Figure 11. Decision propagation model

Model results can be appreciated in the figure 12. These results contrast the findings exhibit in figure 10. This is due to the fact that only a small percentage of the population is capable of making decisions because of their lack of knowledge or fear of change. However, we expect to experiment a propagation process that will help defeat the incumbent technology.

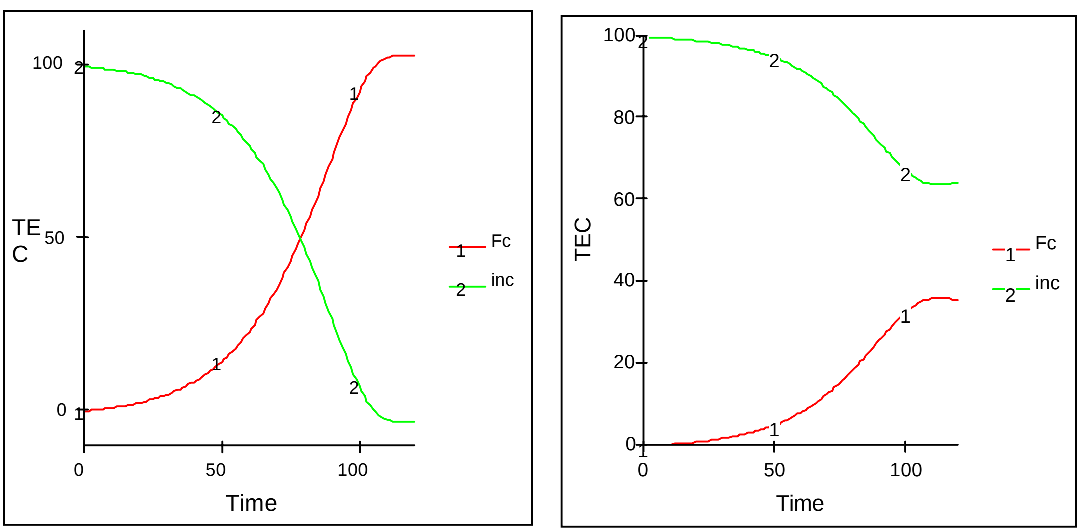


Figure 12. Technology propagation when 5% of the population's considers changing, using discount rates of 30% and 200%.

6 Conclusions

By way of conclusion one can say that results are encouraging and that further work may contribute to help changing the vision of policy making with respect to demand side management. This investigation may reveal the importance of using models at the final user's level, rather than some large aggregate models that are often used for policy assessment nowadays.

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