SOCIO – MARKAL (SOMARKAL): First Modeling Attempts in the Nyon Residential and Commercial Sectors Taking into Account Behavioral Uncertainties

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Abstract

There is no doubt that the current century is an era of environmental awareness which will require meeting the growing demands by means of a set of generating technologies, while minimising Greenhouse Gas emissions. Provided that technologies alone could not solve the problem, we have integrated the sociological dimension, represented by the potentially powerful resource for energy conservation that exists in the ability of consumers to change their behaviour. This study aims at proposing a new MARKAL framework that would take into account consumers' technological improvements and behavioural changes minimizing carbon dioxide emissions and encouraging rational use of energy. As opposed to the traditional MARKAL framework based on technical and economic considerations, the SOMARKAL model integrates technological, economic and behavioural contributions to the environment.

Essentially, the conceptual aspects of the SOMARKAL will be presented. Based on this new MARKAL formulation, we will simulate the possible contribution of awareness campaigns in triggering energy consumption behavioural changes and possibilities of technology switch, in the residential area of the city of Nyon (Switzerland), for the period 2005-2025, using ANSWER, the IEA's platform. The main focus is on lighting technologies. Three fictitious scenarios were produced, referring to three possible penetration rates of low consumption lighting technologies.

Keywords

Energy consumption, Energy savings, Energy efficiency, Residiential lighting, Behaviour change, Sociological surveys, MARKAL

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1. Introduction

The present study addresses end-use residential energy use (space heating, domestic hot water, and electricity). It aims at assessing the joint impact of awareness campaigns and technology choice, on end-use energy consumption behaviour. Actions to achieve energy savings through the use of more energy efficient end-use technology are included.

Environmental preservation, economic growth and related topics that have an impact on Earth are becoming more and more important today. Worldwide, there's a call for a deep involvement in favour of sustainable development. Recent international studies indicate that practical sustainable development scenarios will be feasible if essentially grounded on human behavioural involvement. Pursuing sustainable development objectives needs day-by-day commitment from all the society actors: governments, industries and individuals. Among these actors, individuals play a strategic role for three main reasons. Firstly, they can have the opportunity to vote for politicians who act in favour of sustainable issues. Secondly, they can decide to purchase products and services made by sustainable industries. Thirdly, they can decide to consume natural resources more rationally (e.g., water, electricity or gasoline) so as to contribute to higher recycling rates.

To address these issues of individuals' attitudes and behaviours, we are using MARKAL, a model developed under the aegis of the International Energy Agency over the last three decades. The MARKAL model is a multi-period linear programming formulation of a reference energy system (RES). The constraints of the model describe all energy flows, production of electricity and centralized heat, industrial processes, consumption by end-use technologies and lastly energy services. The objective function in the linear programming model is the discounted sum, over the time horizon considered (usually between 30 and 45 years), of investment, operating and maintenance costs of all technologies, plus the cost of energy imports. The model also accounts for emissions of atmospheric pollutants (SO_x, NO_x, CO_2) and is currently used in many countries and regions around the world for the assessment of energy pollution abatement policies.

In this paper, we propose a new MARKAL framework that integrates the contribution of both technological improvements and behavioural changes to the reduction of CO_2 emissions. Indeed, in the classical framework of MARKAL, energy technologies are competing with each other to meet cost objectives and environmental constraints. Consequently, we propose a new MARKAL formulation that embeds both technological and behavioural contributions to the environment.

Behavioural contributions are modelled through virtual technologies built from sociological surveys, in order to capture the perception of the population in terms of attitudes and behaviours regarding energy consumption. These sociological and intangible technologies are therefore combined with traditional and tangible technologies. As a result of this combination, it will be possible to model the real behaviour of consumers as well as economically rational technology choices. To illustrate the advantages that represent such a model, i.e., the "Socio-MARKAL", here is a list of some situations which this model would allow to study: (1) Measure the resistance to change of the energy consumer; (2) Identify factors encouraging the inhabitants to change their energy consumption behaviour others than those related to the price of energy; (3) In the case of the technology changes, identify the decisive factors influencing purchasing decisions, and (4) Assess whether or not, a simple financial support could be a good enough incentive to modify consumers' technological choices.

The context of implementation for this Social MARKAL model (i.e., SOMARKAL) is the city of Nyon (a mid size city located near Geneva), Switzerland. Nyon is essentially an urbanized region with no industry. The main demand for energy is used for demand technologies in the commercial and residential sectors. We have developed a strong

collaboration with this city’s utility and government. This has enabled us to collect data relevant to different social processes arising in the residential and commercial sectors. Indeed, the analysis of a small urban area such as Nyon requires a very fine level of precision in the modelling process. We are building from our experience with MARKAL Geneva as well as from on numerous sociological surveys conducted at LEM – HEG to develop the Nyon case.
As the human attitudes and behaviours are subject to uncertainty, we also investigating how to model them through the stochastic programming version of MARKAL. In a stochastic programming implementation of MARKAL, environmental and technological choices are optimized as contingency plans which are adapted to the evolution time of the main stochastic parameters. Technically, MARKAL can be viewed as a capacity expansion model. If we introduce uncertainties in the future values of some coefficients, we may look for optimal programs with recourse. A “recourse" means that some decisions (activity levels) will be decided after the information about the true value has been obtained; however some decisions have to be taken immediately (investment decisions). These immediate decisions should be taken with a correct evaluation of the expected cost of the recourses. In our case, recourses are investment decisions to modify the behaviour of individuals, which may include marketing campaigns, training, education, and information.
This strong commitment from politicians of Nyon will be beneficial too to contribute to the effective design and implementations of environmental public policies. We intend to present to this conference the first results of a MARKAL scenario integrating comprehensive social patterns. Our analyses will be conducted on ANSWER, the MARKAL platform of the International Energy Agency (IEA). We will also be discussing reporting issues for decision makers.
This document is structured as follows: a review of the literature is presented in section two, followed by an outline of the SOMARKAL concept in section three. Section four presents the methodology. Section five describes the technical formulation of the SOMARKAL concept, particularly its adaptation to the ANSWER environment. Finally, section six presents and discusses the outcome of the simulations.

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2. Literature review

This section presents a review of the literature on energy-economy models, with a particular focus on MARKAL. It is structured as follows. The first subsection outlines the main features of energy economic models, with a focus on the MARKAL family of models, which are well known technology-explicit models. This will be followed in the second subsection by a presentation of the main limitations of such models, in particular with regard to the strong sociological dimension characterising energy consumption and the behaviour of consumers. The last and third subsection presents a number of theoretical and practical arguments justifying the relevance of a sociological approach to the existing MARKAL family of models.

2.1. Main features of an energy-economic model: MARKAL

Long-term models can provide interesting insights on future developments and deployments in the energy sector, in particular when the systems are subject to additional (external) constraints.

Among these long-term models, energy-economy models, which have been developed for different purposes, can be used as numerical tools for predicting the future, but also as a management tool for decision making. Such models are generally characterized by the following parameters (Jaccard et al, 2003): size, in terms of annual output of service or product; capital cost; non-energy operating cost (operations and maintenance costs); energy use per unit of output; emissions per unit of output; lifespan; year of market availability; current market share; linkage to other services and products, technologies and processes; special market constraints; and other information, such as an annual availability factor, etc.

Methodologies used for concrete development of energy-economy models can be found in the literature (e.g., Kleinpeter, 1995). A general overview is provided by Nakata (2004).

Many optimization models of the energy-economy system exist. Most of these models can be put into the category of technology-explicit (i.e., bottom-up or demand-oriented) models. In these model, the technologies are allocated to the energy using sectors – residential, commercial/institutional, industrial and transportation – and the energy producing and transforming sectors – energy mineral extraction, oil refining, natural gas processing and electricity generation.

A general overview and classification of such energy-economy models is provided by Nakata (2003: 423). Examples include the following: MARKAL models, DEECO, SIMS (Jaccard et al, 2003), NEMS (US, DOE, 1994), MODEST (Henning, 1999; Henning & Trygg, 2008), IKARUS (Martinsen et al, 2004), GENIE (Mattsson & Wene, 1997), MESSAGE (Messmer, 1997), EFOM (1989), POLES (Kouvaritakis et al, 2000a,b), ERIS (Barretos & Kypreos, 2004), and various integrated energy models linking both commercial and renewable energy sources (Jebaraj & Iriyan, 2006).

The main focus of this project is on MARKAL, a well known optimization model of the energy-economy system, which may be put into the category of technology-explicit models. Similar models, with specific regional coverage have been developed. MARKAL is a widely applied bottom-up-technology-based dynamic linear programming (LP) model developed by the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency (IEA). It is used to describe the characteristics of energy technologies in detail, and so can be used to evaluate individual energy technologies within an entire energy system. MARKAL is optimized for satisfying energy demand, meaning that the demand is set as useful energy demand consumed by energy demand technologies.

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2.2. Background on the existing MARKAL models and their limitations

The *MARKAL family of models* includes the MARKAL-MACRO, MARKAL-MICRO and MARKAL-ED, which have a partial equilibrium model that does not represent the rest of the economic system, but allows demands to be reduced in response to higher energy prices (Hamilton et al, 1992 ; …).

In its standard form, *MARKAL* identifies the least-cost combinations of technological processes and improvement options that satisfy a specified level of demand for goods and services under certain policy constraints. Notably, the achievement of certain specified GHG reduction objectives must be met, in a way that the overall system costs are minimised over all time periods simultaneously. This is done for a part of the economy, whereby certain parameters have to be provided from outside the model.

The standard MARKAL-LP model has provisions to model material flows within the energy system and to include uncertainties by a stochastic programming approach (Fragnière and Haurie, 1996; Fragnière et al, 1999). It generally comprises the whole energy chain, from supply resources (by import, domestic extraction, stock changes and export) through conversion and transformation (refineries, power plants, heat plants, and so on), distribution to end use (by processes, end users, etc) (e.g., see Seebregts et al, 2001, for a concise recent overview).

MARKAL-MACRO is a single sector model that features a detailed description of the energy sector, taking into account the interactions that exist between the energy sector and the economy. However, the model is only able to roughly capture many changes in energy demand resulting from changes in exogenous variables

Markal-ED is an extension the standard/technology Markal with elastic demands, i.e., energy demands responsive to price[1]. It is therefore possible to handle different elasticities for different demand categories (Loulou and Lavigne, 1996)

The recent global attention on global warming has raised a number of challenges to the world, including those challenges related to issues as to how to target and set our goals toward the future regarding energy use. As a consequence, the concept of sustainability is being adopted by policy and decision makers, whose interest in clean combustion technologies and rational use of energy is increasing. Particular interest is focused on reducing costs and CO2 emissions, as well as on securing energy supply (Fragnière et al, 2000; Turton & Barreto, 2006).

The concept of sustainability[2] requires balanced conditions among energy, the economy, and the environment and social aspects as well. In addition to environmentally sound technologies, there are several other concepts of sustainability : Zero emission (Suzuki, 2002), Industrial ecology (Allenby, 1999 ; Ayres, 1996), 'Factor Four' and 'Factor Ten' theories (von Weizsacker et al, 1997), and CO2-related concepts which include CO2-sequestration and CO2-disposal (Klara et al, 2003).

The most important goal of energy decision makers is to design feasible scenarios for the future. As far as technologies are concerned, most energy models aim mainly at energy conversion technologies as in industrial sector, commercial sector, residential sector, transportation sector, and electricity sector. Therefore, future energy systems need optimised solutions among the following three elements: emissions, supply security and the market

[1] Own price for elasticity of demands

[2] As a point of departure for our definition of *sustainability* as opposed *to sustainable development,* we use the Brundland definition (WCED, 1987) of sustainable development. Sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". This definition is considered the key to sustainability.

economy. Based on the Brundland definition of sustainable development, these elements can be considered as the three pillars of energy sustainability.

As the existing literature shows, the MARKAL family of models and similar energy optimization models to a certain extent are appropriate to answer questions such as: how do technologies and policies affect environmental impacts of energy use (i.e., GHG and emissions of other pollutants)? What is the effect of market based instruments? How do demand-side actions affect the supply-side and vice versa? How to model the dynamics of technology?

However, among the existing MARKAL models, the social/sociological aspect of energy sustainability, which plays a paramount role in today's debate, is not taken into account. In particular, none of these models takes into account the contribution of end use consumers' behavioural change as a reliable resource for energy efficiency, energy savings, and emissions reductions.

In the next subsection, we will present elements of the literature that justify the relevance of a socio-economic approach to the existing MARKAL family of models.

2.3. Theoretical justification for the development of the Social MARKAL

Energy conservation can be defined as the *behavioural changes* resulting in the use of less energy, whether purchased from utility companies or from other energy distributors (Rice & Paisley, 1981). Previous studies have shown that the means to promote energy conservation such as environmental learning tools are falling short of: (1) giving people the ability to accurately monitor their energy use (2) providing them with meaningful feedback and guidance for altering their energy use (Botrill, 2007). Some of these studies even show evidence of limitations of household and personal energy conservation programs (e.g., through energy billing, display devices and awareness campaigns) (Wilhite & Ling, 1995; Brandon & Lewis, 1999; Wood & Newborough, 2003; and Darby, 2006). Moreover, installing a low-carbon energy technology can positively influence people's behaviour toward energy and the environment (Hondo & Baba, 2009). Likewise, Hondo and Baba noted among many findings that, an increase in communication about environmental behaviour in a family tends to go hand-in-hand with the increase in environmental behaviour. This suggests that the installation of energy saving technologies can potentially influence people's behaviour, i.e., can affect people's concern, views and norms about energy and the environment.

According to a recent report from the United Nations Environment Programme (UNEP, 2008) Sustainable Construction and Building Initiative (SBCI), significant gains can be made in efforts to combat global warming by reducing energy use and improving energy efficiency in buildings. The above mentioned report recognises that more than 80% of the total energy consumption takes place during the use of buildings, through heating, cooling, lighting, cooking, ventilation and so on. In addition to the traditional advice that pushes for a greater use of existing technologies like thermal insulation, solar shading and more efficient lighting and electrical appliances, the SBCI stresses the importance of changing energy consumers' behaviour through education and awareness campaigns. To this end, it would be paramount to promote flexible solutions and provide appropriate information to energy consumers paramount. This could include appropriate government policies on building codes, energy pricing and financial incentives that encourage reductions in energy consumption. In developed countries the main challenge is to reduce harmful emissions among mostly existing buildings. This can largely be achieved by reducing the use of energy within these buildings

(EC, 2008a,b). In 2006, the European Union took the commitment to cut its annual consumption of primary energy by 20% by 2020. To this end, it is mobilizing public opinion, decision-makers and market operators and is setting minimum energy efficiency standards and rules on labeling for products, services and infrastructure (EC, 2006).

Moreover, there is broad agreement that, integrating behaviour change, choice and human action into energy efficiency policy and programs, is a key strategy to affecting climate change. What do we know about behaviour to see it as a reliable resource? Can such a strategy result in persistent savings? Is it reasonable to assume that behaviour and techno-economic approaches should be integrated? What could be the barriers to such strategies?

The literature on behavioural studies shows that environmental, personal and behavioural factors can be considered as the main explanatory parameters of behavioural change, with each factor affecting the others (Bandura, 1988; McKenzie-Mohr, 1994; McKenzie-Mohr et al, 1995).

Stern (2000: 408) defines environmentally significant behaviour as follows: (1) the behaviour that "changes the availability of materials or energy from the environment or alters the structure and dynamics of ecosystems or the biosphere itself"; (2) the "behaviour that is undertaken with the intention to change (normally to benefit) the environment". Most consumption behaviour falls into the first category.

Rydin et al (2007) and Nye & Burgess (2008) conducted an in-depth exploration and analysis of programs aimed at promoting sustainability and durability in consumption behaviour. For these authors, in order to create generalised and durable behavioural change, it is necessary to engage with both the root practice (s) and the overarching context (lifestyle) in which practices occur.

The aggregate impact on the environment is a function of both lifestyles and specific practices, because lifestyles are bundles of social practices (Giddens, 1991), while systems of provision develop around and sustain lifestyles (Spaargaren & VanVliet, 2000). Provided that energy consumption can be considered as a social practice (Shove and Pantzer, 2005)[3], the behaviour of end-use energy consumers can be used as a reliable resource for energy efficiency, as well as for both energy consumption and emissions reductions. Lutzenhiser & Gossard (2000) have established and illustrated the relationship between lifestyles and social practices. A generalisation of this relationship is outlined in Figure 1. As an illustration, these authors used data on consumer culture, purchasing patterns and energy use. One of their findings is that the concept of lifestyle in energy research is appropriate, especially in energy efficiency, including the behavioural aspects related to energy use.

[3] Consumption is defined by Shove and Pantzer (2005) as a flow of objects, products and associated skills, images and information. For these authors, this flow only has value when integrated into a social framework.

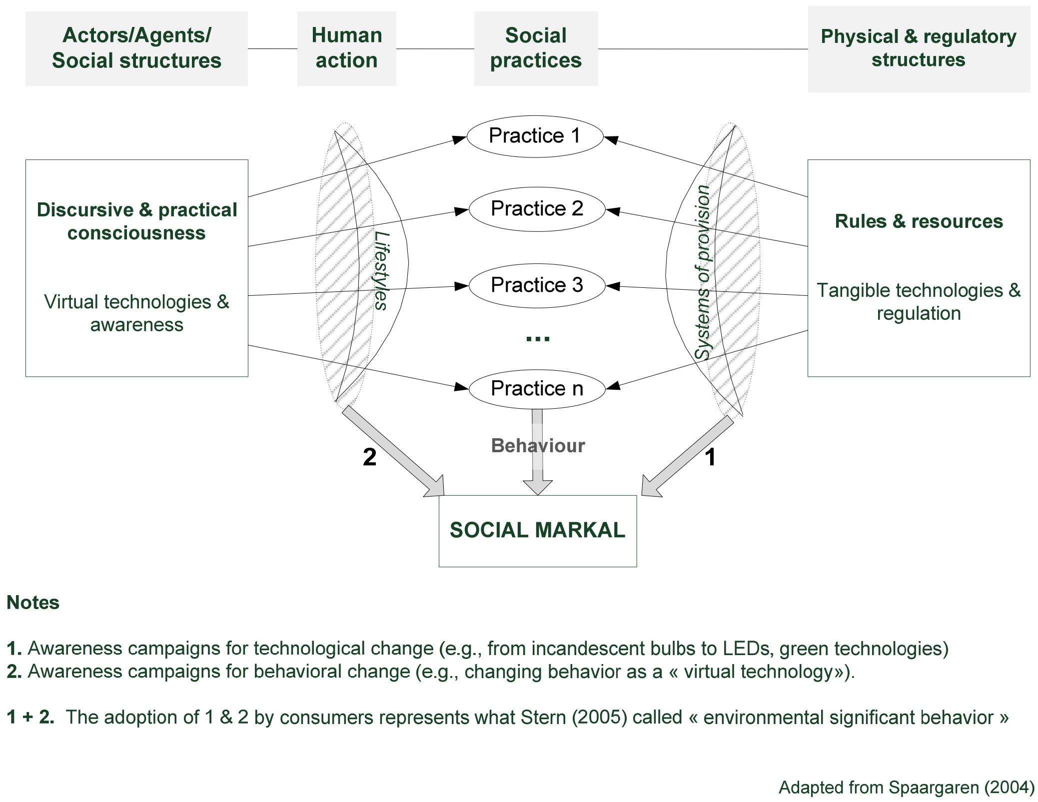


Figure 1. Technical and sociological parameters in energy consumption: interrelations and interdependence

Nye (2008) and Rydin et al (2007) have focused on the qualitative evaluation of the drivers for long term behaviour. They found evidence of behaviour change across a variety of practices related to energy use, transport, waste, and recycling behaviour. For Nye, it is necessary to engage with both the root practice(s) and the overarching context (lifestyle) in which practices occur, in order to create generalised and durable behaviour. Therefore, to achieve a durable behavioural change, a re-materialisation of waste production and energy use through direct experience is necessary (Giddens, 1991; Nye, 2008); meaning that social support must be developed through interactions, which may lead to lifestyle change (Hobson, 2002). However, there is a need to examine more closely, how strongly overall lifestyles are affected. Is this a radical shift, or do energy consumers simply become greener and more rational?

Policy outputs generally remain focused on changing specific actions. In this context, *social Marketing*, which aims at developing a context-specific cure for a specific behaviour, recognises the importance of behavioural contexts and aims at overcoming barriers to change in those contexts (McKenzie-Mohr and Smith, 1999; Räthzel and Uzzell, 2009; Scarpa and Willis, 2009).

Gyberg and Palm (2009) examined the discourse that the idea of efficiency is built upon according to different actors trying to influence households' energy behaviour. The reasons given for changing one's behaviour are motivated both by lower energy costs and a reduced impact on the environment. Common advice for energy reduction is to change to a more energy-efficient apparatus. In this sense efficiency is a way of *not* changing lifestyle but instead changing technical equipment and user routines. Additionally, Gyberg and Palm highlighted the possibility to improve existing artefacts, pointing out to the need to change our lifestyle.

For Ouyang and Hokao (2009), occupants' behaviour is one of the most important issues with respect to energy efficiency in households. These authors discussed the relationship between electricity consumption and household lifestyle and evaluated the energy-saving potential by improving occupants' behaviour in domestic life through energy-saving education. To this end, they conducted a series of surveys between 2007 and 2008, targeting 124 households in three residential buildings in Hangzhou (China). The main findings are as follows. Firstly, there is a correlation between electricity consumption and people's living standard and more dependency on electric appliances. Secondly, improving the energy consumption behaviour can save up to 10% energy use. Finally, they suggest shifting energy savings efforts from technological measures so as to improve energy consumers' behaviour.

Räthzel and Uzzell (2009) examined the changing relations in global environmental change, by comparing people's environmental concerns and their perceptions of the causes and solutions in Sweden and the UK. They conducted an extended study that included series of surveys. In the open-ended part of the survey, individual behaviour is seen as the most important cause of environmental degradation. In particular, from the respondents' everyday experiences, countries' governments and industry policies promoting economic growth are the main causes of environmental degradation.

2.4. The way forward

The above review of the literature shows that individual energy-use behaviours are influenced not just by the larger culture but also by the norms of the smaller groups of which we are part, i.e. socio economic aspects. Likewise, education and information can accelerate citizen awareness and empower people to act[4].

Unfortunately, such sociological components – which are critical elements of any public program to reduce such things as energy use, waste and greenhouse gas emissions. – are not explicitly taken into consideration by the current MARKAL family of models. These components must be considered as a continuum (CCC, 2008), rather than a single element of a system. At one end of such a continuum, there are people who "may not realize their actions contribute to a problem and who may be ill inclined to voluntarily change that behaviour." At the other end are highly-motivated people seeking or using available and detailed information on, say, what needs to be done to use energy more rationally.

Specific issues have been reviewed regarding some of the main practices that can encourage changes in energy consumption. But if change occurs, how can we ensure that it will be sustained? On the one hand, e*nergy efficiency*, is considered as one of the optimal and quickest options to meet *environmental goals* in general (including the Kyoto target), and in promoting *renewable energy* production (EC, 2005; Nilsson, 2007). On the other hand, e*nergy saving* is an important option for preventing emissions of greenhouse gases. Furthermore, "it can reduce the spatial and temporal density of energy consumption, providing support to a rising market share of renewable energy sources" (Perrels et al., 2006: 121).

With this in mind, it must be stressed that, meeting environmental goals through the above mentioned options, i.e., energy efficiency and energy saving measures, can be counter-productive. Once put in place, (e.g., the replacement of an inefficient energy conversion technology by a cleaner and more efficient technology), these measures are can lead to a reduction in energy service prices, provided that they are supposed to reduce energy costs (i.e., energy savings). The resulting rebound effect may be translated into either a price or an

[4] The dissemination that follows EU-funded programs (Examples), are in fact evidence of campaigns aiming at educating as well as informing people and governments.

income effect (Dubin et al, 1986; Binswanger, 2001; Chalkley, 2001; Matthew et al, 2009). The *price effect* may be considered as an increased consumption of the services (e.g., household appliance) if the appliance becomes more efficient. In addition, the cost of using the appliance decreases, which may to some extent counterbalance the initial energy-saving potential. The *income effect* implies that real income will increase as a result of reduced costs for energy services (Brännlung et al, 2007; Scarpa and Willis, 2009).

The above mentioned aspects of the rebound effect will also be explored and integrated into the model.

3. Social MARKAL (SOMARKAL): outline of the concept

The current era of environmental awareness requires energy resources to satisfy the world's energy demands. We can use current energy use scenarios to help us understand how energy systems could change. Unfortunately, these scenarios have always had a strong technology component, leaving the behavioural aspect aside.

The MARKAL model was originally designed for the evaluation of the possible impacts of new energy technologies on national or regional systems. In fact, this model is a multi-period linear programming formulation of the reference energy system (RES). The RES is subject to constraints that describe the basic properties of the model. This description include all energy flows, production of both centralised and distributed power and/or heat, industrial or commercial processes, consumption by end-use technologies and energy services.

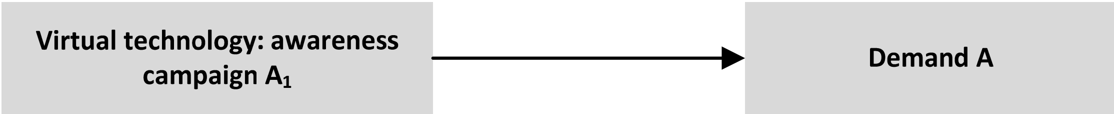
The objective function in the linear program is the discounted sum over a time horizon (30 to 45 years) of investment, operating and maintenance costs of all technologies, plus the cost of energy imports. Additionally, emissions of atmospheric pollutants are taken into account, as is currently the case in many countries around the world.

Based on the theoretical and practical arguments presented on the previous section, the current project aims at proposing a MARKAL approach well adapted to the current challenges that nations have to face in their fight against climate change. Having found that technologies alone could not solve the problem, we had the idea of integrating the sociological dimension. This dimension is represented by the potentially powerful resource for energy conservation that exists in the ability of consumers to change their behaviour. On the basis of these considerations, we propose the SOMARKAL, a new MARKAL framework that would take into account technological improvements as well as behavioural changes in order to minimize carbon dioxide emissions. This new MARKAL formulation therefore integrates both technological and behavioural contributions to the environment.

The SOMARKAL concept is based upon the introduction of a virtual technology built from sociological surveys. The purpose of such a concept is to assess the perception of consumers regarding their energy consumption, with a strong focus on their attitudes and behaviours. To this end, the virtual, i.e., "sociological" technologies are associated with tangible technologies, allowing planners or analysts to model, analyse and assess the actual behaviour of consumers as well as technology choices which are economically rational.

Two cases illustrating the features of the SOMARKAL are presented below. These cases are basically aimed at explicitly showing how the concept could fit to the traditional MARKAL family of models.

The case presented in Box 1 outlines an awareness campaign A1 set to affect one sector of the energy demand.



Parameters

- Investment cost [CHF/capacity unit]: IC
- Fixed annual cost [CHF/capacity unit]: VC
- Lifetime [years]: T
- Demand upper bound [capacity units]: D_{max}

Notes on the parameters

The *investment cost* is the amount of money invested in the awareness campaign A_1, which is expected to lead to a reduction of demand A by 1 unit.
The awareness campaign is expected to induce a change in the bahaviour of end-use energy consumers. Consequently, it has been modelled as a fictitious energy -saving technology A_1 characterized by its capacity to affect (i.e., reduce) energy demand A.

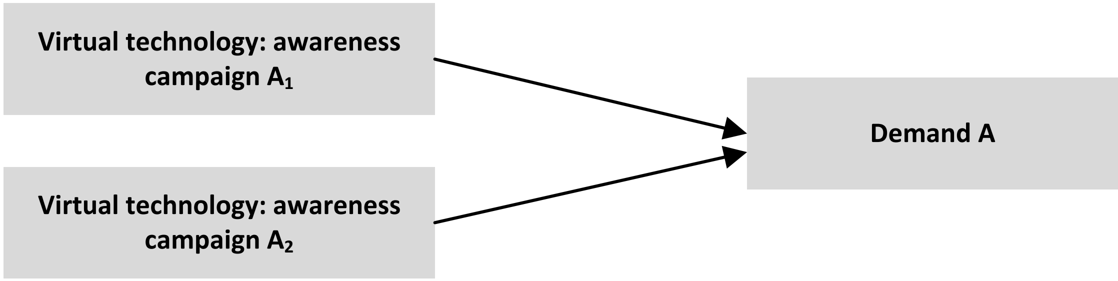
The *fixed annual cost* is the yearly money spending required to sustain the awareness campaign over the years.
Depending on the case, one could assume *decreasing fixed annual costs* specifically if we consider a gradual behavioural change over the years. As a result, the annual costs of campaign A_1 after 15 years would be lower than in the beginning of the campaign.

Lifetime defines the time horizon over which the awareness campaign would remain efficient. Setting this paratemeter to the infinite leads to the following and reasonable assumption: once a change in behaviour has occured, the new or changed behaviour would be permanantly held.

The *demand upper bound* is the maximum number of demand units that can be reduced thanks to the fictitious technology A_1.

Box 1. Illustration of the SOMARKAL concept: one technology, one demand sector.

Box 2 outlines the case of two awareness campaigns, A1 and A2, set to affect the same energy demand. The main idea is to introduce the second awareness campaign as a complement of the first (Box 1). The SOMARKAL model will therefore be subject to a particular constraint: it will choose A1 first and then A2. Consequently, the consistency of the cost structure must be guaranteed and based on a merit order ranking: the first awareness campaign, A1 must be cheaper than the second one, A2.



Example

<u>Virtual technology</u> A_1
IC (A_1) = 100 CHF/capacity unit
VC (A_1) = 10 CHF/capacity unit.year
T (A_1) = infinite
D_{max} (A_1) = 5 capacity units

<u>Virtual technology</u> A_2
IC (A_2) = 200 CHF/capacity unit
VC (A_2) = 20 CHF/capacity unit.year
T (A_2) = infinite
D_{max} (A_2) = 10 capacity units

Box 2. Illustration of the SOMARKAL concept: two technologies, one demand sector

Finally, Box 3 and Box 4 in the appendix present two additional configurations, slightly more complex than the previous ones. These configurations represent the case of two awareness campaigns designed to affect two demand sectors.

4. Protocol for the SOMARKAL: methodology, data collection and framework.

This section presents the set of steps and rules that must be followed for an appropriate use of the SOMARKAL. These are described in the following subsections, and essentially comprise the protocol, which include the methodology and the data collection.
A comprehensive basis for the protocol could be based on the following four steps:

- *Identify* the barriers and benefits for reducing energy use into a demand category (e.g., residential lighting)
- *Develop a strategy*, putting forward issues shown to be effective in affecting and driving the perception and attention of energy consumers on the importance of changing their behaviour
- *Pilot* the strategy/ *launch* the campaign
- *Evaluate* the strategy once it's been implemented throughout the target population (i.e., residential consumers), and *analyse* the results.

Each step should involve several actions. Identifying barriers and benefits, for example, requires a literature review, focus groups and a survey of a random sample of residents. "It's a rigorous process, which makes it much more likely that a program is going to work" says Doug McKenzie-Mohr, who has helped pioneer this approach in Canada. "It identifies which behaviours to go after and it helps systematically remove as many barriers as possible." (Winter and McKenzie-Mohr, 1993).
Of course, this method requires considerable expertise, resources, and time. The good news is that, the public is increasingly receptive to the message that “green”/”energy efficiency” campaigners/governments are trying to get across. The success of “green campaigns” around the world shows that people are willing to do something about air quality and will respond to peer pressure when attitudes start to change.
"I think the marketplace is ready for these types of messages," says Antonuk. "It's not just high energy costs that people are responding to now. More and more, it's the social good and environmental benefits that motivate them."[5]

4.1. The SOMARKAL protocol

These days, environmental/behavioural campaigns are becoming increasingly sophisticated, going far beyond standard information-only programs. Consequently, it is essential to define a clear and systematic protocol for socio-technological evaluations based on the SOMARKAL concept.

This subsection presents a method for collecting social data in the context of the SOMARKAL project.

1) *Hypothesis generation*: qualitative research to identify potentials of behavioural change regarding energy consumption, handled through qualitative methods (semi structured interviews, observations, social experiments). The energy-saving benefits (without a reduction in performance) as well as the essential character of behavioural change must be clearly explained. If the interviewees or respondents express interest

[5] http://www.climatechangecentral.com/publications/c3-views/january-2008/campaigns-stimulate-behaviour-change-conserve-energy

in the campaigns, the awareness program must be designed so as to remove all the barriers – e.g., lack of information and motivation, cost of changing the technology, as well as its installation.

2) *Hypothesis testing*: survey research to test and measure hypotheses generated during the first phase (questionnaire, rank and sample statistical analyses)

3) *Behavioural change scenario process*: construction of long-term scenarios including behavioural change, in particular expert-built scenarios from the collected data

4) *Design*: transformation of the SOMARKAL data and scenarios to feed the MARKAL data base.

4.2. Methodology

The methodology is structured as follows (see Figure 2).

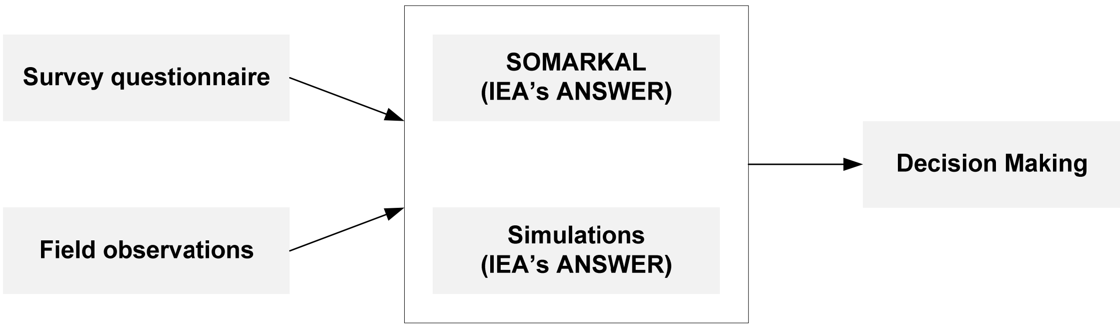


Figure 2. Outline of the methodology

The *survey questionnaire* will be elaborated with the express purpose of assessing the potential contribution of behavioural change in end-use energy consumption pattern, and thereby in climate change mitigation. This questionnaire will target the general adult population of a limited number of households in the middle-sized Swiss city of Nyon. We will use the STEEP framework in order to evaluate and analyse the key issues arising from this study. STEEP is an acronym for Social, Technological, Economic, and Environmental and Political domains. The "Social" aspect together with "Economic" is taken into consideration. "Technological", because the new approach (i.e., SOMARKAL) that is being presented builds from the traditional MARKAL which is a model for technological choice. This choice is generally made by decision makers based on technical, economic and environmental constraints/variables. Finally, "Political" justifies the involvement of politicians in the decision-making process.

The questionnaire can be constructed based on the consideration that climate change is due to greater energy use by humans. In line with this, two approaches apparently inclusive can be used (Rudin, 2000): (1) improving the efficiency of end-uses of energy and (2) not using or conserving energy. For Rudin, the proponents of the first approach seem to denigrate the overall notion of sufficient and limited energy use.

Even if it may be difficult in practice to convince large number of consumers to change their ingrained habits, financing and organizing (environmental) campaigns[6] may persuade many people to reduce their energy consumption. Ongoing works are focused on data gathering in the area of Nyon.

Field observations involve a number of observational procedures aimed at validating the behavioural pattern obtained from the answers of the respondents who participated in the questionnaire.

The SOMARKAL model, which is materialised by the optimization model, must be viewed as an aggregator. The associated mathematical model will integrate data from both the questionnaire and field observations. The IEA platform, ANSWER, will be used to simulate the RES in order to evaluate the potential impact of behavioural change (i.e., through awareness campaigns), on energy consumption in residential areas. Our first evaluation will target lighting in the residential sector. In forthcoming projects, it will cover other sectors of energy demand in residential areas, i.e., heating, motive power and so on.

4.3. Data collection

Collecting energy-related consumer behaviour information in the real world can be difficult, provided the trade-off that may exist between the means and the end. In fact, as pointed by Leach et al (2006), there is generally a dynamic tension between the information that researchers and practitioners want to gather, and what can be effectively collected. This tension may even be increased when participants are non-technical respondents.

Green & Skumatz (2000), and Middleton et al (2000) remarked that tools such as advertising, education and strategies to change markets and behaviours can potentially be better and more successful than evaluating measures or hardware programs, as mentioned by Bottrill (2007) and many authors Wilhite & Ling, 1995; Brandon & Lewis, 1999; Wood & Newborough, 2003; and Darby, 2006).

One of the lessons that we learned on our previous projects, is that providing information, on its own, is usually insufficient to prompt changes in behaviour. However, face to face assessments (questionnaires) combined with or without (financial) incentives can be successful. This was the case in a first assessment that we conducted jointly with the utility services of the city of Nyon, regarding lighting technologies (Cubizolle, 2008). Moreover, series of ongoing studies are currently conducted at the HEG by graduate students on data collection focused on various subjects, including energy and the environment (Cubizolle, 2008; De Sousa, 2008; Morales, 2008; Wieland, 2009).

The analysis of an early survey on energy services in the same area, seem to indicate that end-use consumers perceive they can change their consumption behaviour, and are therefore willing to spend more money to acquire more energy efficient end-use technologies (e.g., incandescent light bulbs vs. compact fluorescent lamps/LED lamps).

Hypotheses taken into consideration in this fictitious case are as follows. Firstly, we consider that levels of technical knowledge about how to conserve energy are low among the consumers. Secondly, we will assume that the perceived decreases in rising energy bills may be an important motivation for energy conserving behaviour. Thirdly, we consider that, based on the theory of reasoned action (Sheppard et al, 1988), persons may be more willing to engage in energy conservation if they perceive that others are doing the same. This theory assumes that individuals consider behaviour’s consequences before performing the particular behaviour. Fourthly and finally, it is expected that the concept presented in this paper and its use in the Nyon area will also help improving the social responsibility of energy consumers towards the environment.

[6] Campaigns may include website postings, brochures and newsletters, phone lines and public talks, workshops and trade shows.

The conclusions drawn from one of our previous studies (Weber et al., 2009) show that the sociological/behavioural approach, i.e., data collection through surveys and sociological experiments are powerful tools that can help people understand their (personal) energy use and for motivating their actions to reduce carbon emissions. This means that awareness campaigns can stimulate behaviour change to conserve energy.
Consequently, *both technological and behavioural contributions can be integrated into a single strategy*. *In turn, this is enough to justify an extension of the current MARKAL family of models, through the integration of data collected through surveys and/or awareness campaigns.*

5. SOMARKAL in action

This section aims at presenting the case study, specifically the changes that were achieved in practice, to move from the traditional MARKAL framework to the SOMARKAL, using ANSWER, the IEA platform (Seebregts et al, 2001; Goldstein et al, 2003; Goldstein et al, 2007; Tosato, 2007). The context of implementation is the city of Nyon (a mid-sized city located near Geneva), Switzerland. Nyon is essentially an urbanized region with no industry, which does not produce process or convert energy. Only energy imports are used to meet the commercial and residential demands.

The next subsection will firstly present the reference energy system. This will be followed by an outline of the common features of the contextualisation of our model to the behavioural aspects related to lighting technologies at the residential level. The second subsection will present the main scenarios, followed in the third subsection by the presentation and discussion of the main results.

5.1. Energy reference system and representative parameters of the SOMARKAL

The block chart for the energy reference system proposed in this study, using structures defined by MARKAL, can be seen in Figure 3.

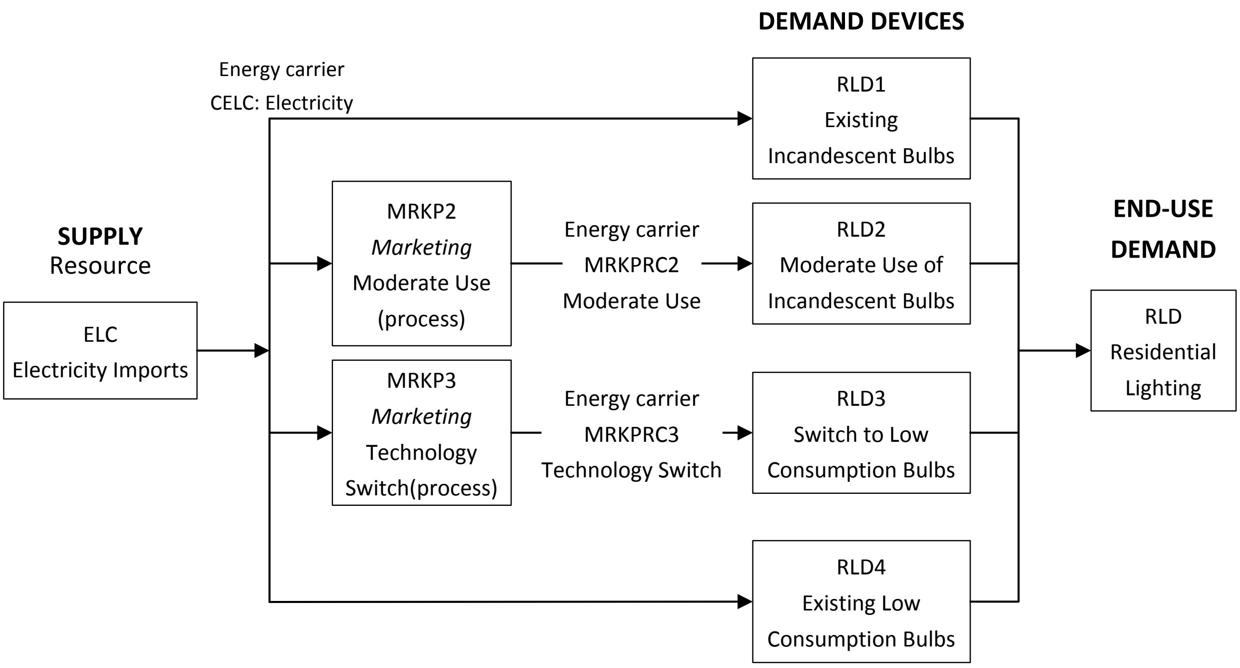


Figure 3. Structure of the energy reference system.

Representative parameters of the technologies in the SOMARKAL

The representative parameters of the SOMARKAL have been designed so as to keep the traditional MARKAL formalism. This will ease the use of MARKAL platforms such as ANSWER.

As mentioned on the previous sections, energy conservation may require the introduction/adoption of measures aimed at promoting rational use of energy. These measures include: (1) a better use and management of existing equipments or technologies and/or (2) technology switch. In this study, we assume that people/consumers who are willing to adopt one or more of these measures are driven by the desire to change their energy consumption behaviour. This willingness could be explained by many factors, such as their sensitivity to marketing/awareness campaigns, training, their education, the quality of information they have been receiving, as opposed to the assumption of perfect economic rationality generally used in the traditional MARKAL family of models

Behavioural change in SOMARKAL requires introducing virtual technologies, whose purpose is to trigger behavioural change among energy consumers. To have a clear understanding of the SOMARKAL, it was necessary to define the terms appearing in Figure 3. These terms are defined Table 1.

Parameters	Value	Units	Type
ELC	Energy imports	TJ	Resource
CELC	Energy carrier	TJ	Resource
MRKP2	Awareness campaign “Moderate use of incandescent light bulbs”	CHF/capacity unit	Process technology
MRKP3	Awareness campaign “Technology switch towards low consumption bulbs”	CHF/capacity unit	Process technology
MRKPRC2	Energy carrier MRKP2	TJ	Process
MRKPRC3	Energy carrier MRKP3	TJ	Process
RLD1	Existing Incandescent Bulbs	Hundreds of light bulbs	Demand device
RLD2	Moderate Use of Existing Incandescent Bulbs	Hundreds of light bulbs	Virtual demand device
RLD3	Technology Switch toward Low Consumption Bulbs	Hundreds of light bulbs	Virtual demand device
RLD4	Existing Low Consumption Bulbs (a mix of new technologies)	Hundreds of light bulbs	Demand device
RLD	End use residential lighting	Hundreds of light bulbs	Demand

Table 1. Technologies and their description

Parameters RLD1 and RLD4 represent the real and tangible lighting technologies, receiving electric power as input, and generating residential lighting.

Parameters RLD2 and RLD3 represent the virtual technologies. As opposed to the real technologies, virtual technologies receive inputs that are intangible, leading to energy savings or technology switch.

As outlined in Figure 3, these intangible inputs (i.e., MRKRP2 and MRKRP3) are marketing/awareness campaigns which have the effect of changing the behaviour of energy consumers. MRKRP2 and MRKRP3 both stand for "Process Marketing Campaign” are process technologies. The first is a process supposed to trigger the “Moderate use of incandescent light bulbs”, while the second (i.e., MRKRP3) aims at triggering behaviour towards low consumption bulbs, i.e. “Technology Switch towards low consumption bulbs”.

Despite their intangible nature, MRKRP2 and MRKRP3 are actually processes having electric energy as input, and the intangible “marketing product” as output. This output is an enabler for the presence of the virtual technologies (i.e., RLD2 and RLD3).

Based on this short description, we can therefore construct a minimalist MARKAL model with the following characteristics: no electricity production (i.e., imports only), electricity as energy carrier, demand devices RLD1 through RLD4, an energy demand (i.e., residential lighting) that must be met, and two process technologies MRKP2 and MRKP3.

Modelling bounds (the important part of the trick)

In order to prevent the so-called bang-bang[7] effect from occurring, bounds on capacity should be set to the respective technologies described above. This is a standard MARKAL way to proceed.

These bounds are subjective and dependent on the modeller's judgement and erudition. In our case, bounds are set for parameters RLD1 and RLD4.

One of the main contributions of this paper is to determine the values of the above mentioned bounds by means of our sociological survey. In addition, we introduce specific SOMARKAL bounds, whose values should also come from our sociological surveys. These surveys are currently conducted and will be presented in subsequent papers. Here, our goal is just to prove that the SOMARKAL concept is feasible.

The first bound characterizes the *penetration of a moderate use behaviour pattern resulting from a marketing/awareness campaign*. The second bound represents the *willingness to invest in technology switch, also as the result of a marketing/awareness campaign*.

As a result, we will prevent an unbound MARKAL behaviour resulting in bang-bang effect.

5.2. Illustration

In this section, we will assess the SOMARKAL model with an illustration based on three fictitious scenarios. In this illustration, we consider an evaluation over a span of 20 years (i.e., from 2005 to 2025) spread over 4 periods of 5 years.

Assumptions

A number of assumptions outlined in Table 2, have been introduced, specifically regarding both the demand investments for residential lighting technologies.

The overall *demand* for light bulbs is expected to grow by about 50% over the evaluation period, i.e., from 1654 hundreds units (165'400 bulbs) in 2005 to 2500 hundreds units (250'000 bulbs) in 2025. Residual capacity is split between RLD1 and RLD4, respectively for 80% and 20%.

*Investment cost*s for RLD1 are expected to rise by 40% over the evaluation period, i.e., from 1 CHF/bulb in 2005 to 1.40 CHF/bulb in 2025. However, for low consumption bulbs (RLD4), we assume decreasing costs at a variable rate over the time periods (see Table 2 below), of respectively 10%, 33%, 17%, and 0% during the last period.

The *lifetime* of new light bulbs is set to 1 year for incandescent bulbs (RLD1) and 10 years for low consumption bulbs (RLD4).

The e*nergy carrier input, (i.e.* MA (ENT) in ANSWER), remains constant over the evaluation period. For RLD1 and RLD4, it is set to 0.0328 TJ/unit and 0.0065 TJ/unit respectively.

	2005	2010	2015	2020	2025
DM for light bulbs [x 100 units]	1654	→	+ 50%	→	2500
IC for RLD1 [CHF/bulb]	1	→	+ 40%	→	1.4
IC for RLD4 [CHF/bulb]	20 – 10% →	18 – 33% →	12 – 17% →	10 — 0% →	10

Notes
DM: represents the total demand for all types of bulbs (i.e., RLD1 to RLD4) IC: investment costs

Table 2. Summary of the main assumptions made on demand devices and investment costs

[7] It consists of important changes of output in response to very small changes of input.

Scenarios and results

We consider three fictitious scenarios.

Scenario 1: the first scenario (see Figure 4) is based on an unconstrained MARKAL model. One can observe as outlined in Figure 4, that after 2005, there is no investment in incandescent bulbs (i.e., RLD1), while all investments go to low consumption bulbs (i.e., RLD4).

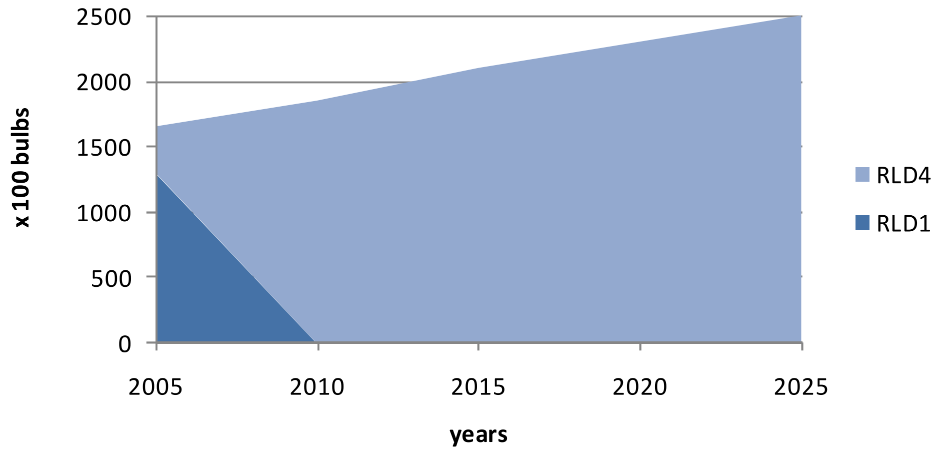


Figure 4. Outcome of scenario 1, "unconstrained MARKAL model"

Scenario 2: the second scenario (Figure 5) is based on the use of a modelling approach in which the modeller sets reasonable bounds. These bounds are more or less subjective, and therefore depend on the modeller's appreciation and erudition. Furthermore, the growing demand will be met in priority through low consumption bulbs (i.e. RLD4), because bounds are set for the minimum capacity of incandescent light bulbs (i.e., RLD1), so as to keep them in the optimal solution. Their penetration will be kept at the bound level.

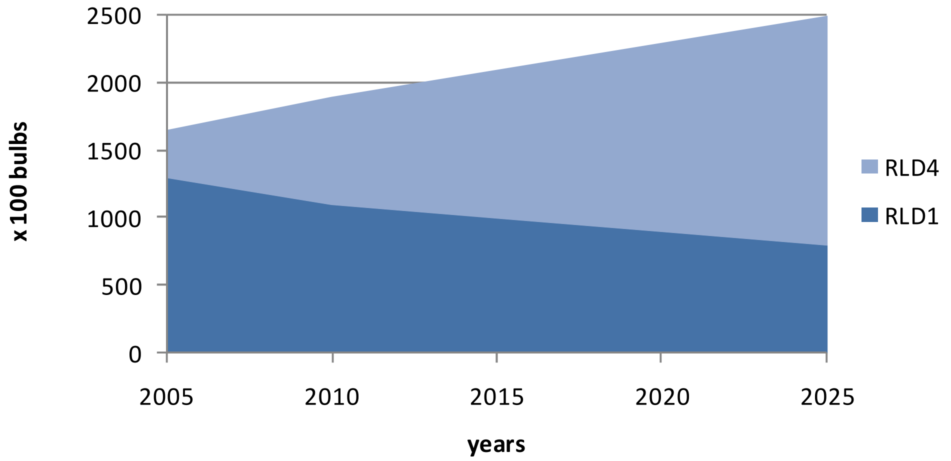


Figure 5. Outcome of scenario 2, "Markal model with bounds"

Scenario 3: the third scenario (Figure 6) introduces the SOMARKAL approach.

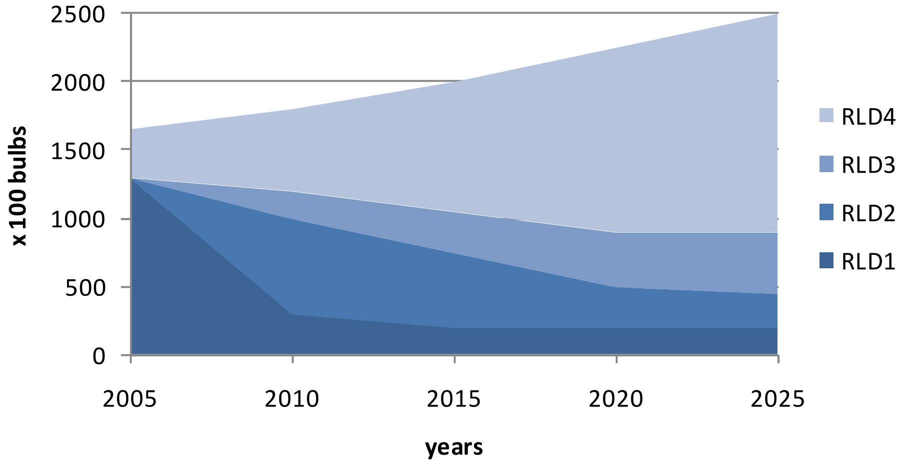


Figure 6. Outcome of scenario 3, "the SOMARKAL model"

As discussed in the previous sections, this approach aims at introducing virtual process technologies as well as determining the values of bounds. Virtual process technologies represent awareness campaigns both for energy savings and technology switch. These process technologies act as enablers for demand devices RLD2 (i.e., moderate use of incandescent bulbs) and RLD3 (i.e. technology switch to low consumption bulbs). This approach allows us to keep the MARKAL formulation and introduce behavioural parameters.

6. Conclusion

We have proposed a new MARKAL framework integrating technological improvements and behavioural changes, provided that these aspects can contribute both to CO_2 emissions reduction and energy savings. This new framework, SOMARKAL, aims at integrating the above mentioned aspects.

Basically, in the traditional MARKAL framework, energy technologies are in competition to meet a number of costs and environmentally-related objectives. SOMARKAL rather combines the contribution of technologies and, individuals' attitudes and behaviours to the environment. So far, such an approach has not been specifically integrated in any of the existing MARKAL formulations.

This new formulation has enabled us to propose a model and simulate the possible contribution of awareness campaigns in triggering energy consumption behavioural changes and possibilities of technology switch, in the residential area of the city of Nyon (Switzerland), for the period 2005-2025, using the MARKAL tool. The main focus was on lighting technologies. Three fictitious scenarios were produced, referring to three possible penetration rates of low consumption lighting technologies.

It is important to note that the main objective of this study was to validate the conceptual approach presented above. Using a limited number of three fictitious scenarios, we have been able to show that it was possible to introduce behavioural aspects of energy consumption into the traditional MARKAL, and most importantly, combine them with tangible technologies. These behavioural aspects are taken into account using the concept of virtual technology (e.g., marketing campaign and see Box 1 to 4).

Subsequent papers will deal with the conceptual model in more detail. Sociological surveys are currently conducted in order to feed the SOMARKAL model with relevant data.

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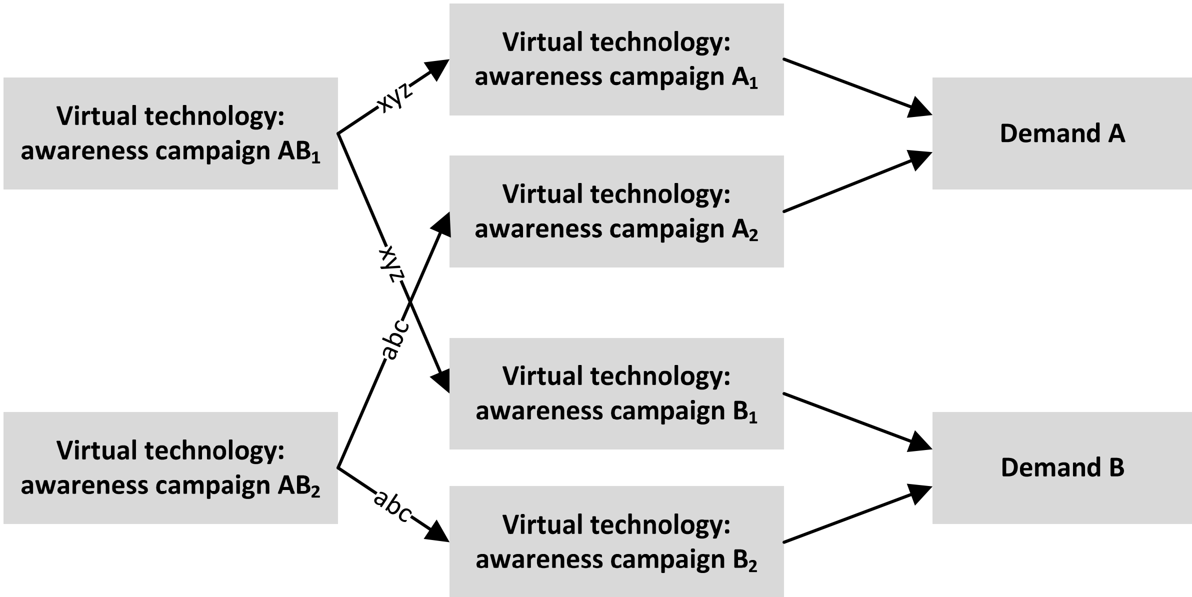
8. Appendices



Example

<u>Virtual technologies</u> AB_1 and AB_2

IC (AB_1) = 500 CHF/capacity unit

VC (AB_1) = 50 CHF/capacity unit.year

T (AB_1) = infinite

D_{max} (AB_1) = 15 capacity units
(e.g. 5 for technology A, and 10 for B)

IC (AB_2) = 850 CHF/capacity unit

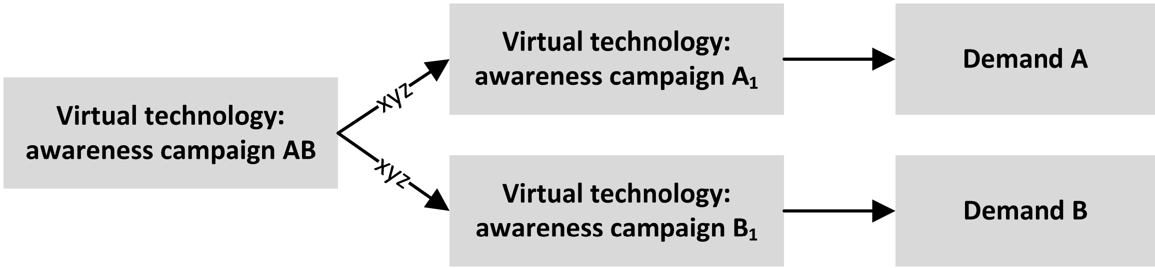
VC (AB_1) = 100 CHF/capacity unit.year

T (AB_2) = infinite

D_{max} (AB_2) = 35 capacity units
(e.g. 15 for technology A, and 20 for B)

xyz and abc are parameters defining the allocation respectively between A_1 & B_1 and A_2 & B_2

Box 3. Illustration of the SOMARKAL concept: two technologies, four sub technologies, and two demand sectors



Example

Virtual technology AB
IC (AB) = 500 CHF/capacity unit
VC (AB) = 50 CHF/capacity unit.year
T (A_1) = infinite
D_{max} (AB) = 15 capacity units (e.g. 5 for technology A_1, and 10 for B_1)

xyz is a parameter defining the allocation between A_1 and B_1

Box 4. Illustration of the SOMARKAL concept: one technology and two sub technologies, two demand sectors

Tools	Pros	Cons
Regulations and standards	Generally provide some certainty about emission levels.	They may be preferable to other instruments, but they may not induce innovations and more advanced technologies.
Information instruments (e.g. awareness campaigns)	May positively affect environmental quality by promoting informed choices and possibly contributing to behavioural change.	It is hard to measure impact of information instruments.
Financial incentives (subsidies and tax credits)	Often critical to overcome barriers. Certain programs demonstrated that financial incentives coupled with personal interactions can be successful.	Needs to be combined with other tools to ensure long-term change.
Voluntary actions	May limit greenhouse gas emissions, stimulate innovative policies, and encourage the deployment of new technologies.	On their own, they generally have limited impact on a national- or regional-level of greenhouse gas emissions.
Source: Mitigation of Climate Change, IPCC (2007)		

Table 3. Tools to Combat Climate Change

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