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Modelling Domestic Lighting Energy Consumption in Romania by Integrating Consumers Behavior

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Abstract

Sustainable energy consumption is a research area of a large interest in last years. New energy-efficient lighting technologies exist, which can significantly reduce household electricity consumption, but their adoption has been slow. A considerable number of international studies show that sustainable development scenarios will be realistic if they involve the human behavior.
The paper provides a solution to integrate consumer behavior with techno-economic energy issues, inside a complex energy model. This approach aims to reduce the error, from the demand side of the energy model. Consumer behavior in energy consumption is described by using specific attributes of energy technologies, namely virtual technologies. The GAMS/TIMES/VEDA energy modelling software tool has been used to integrate the techno-economic energy specific data and consumer behavior, in order to achieve the research purposes. A sociological survey about Romanians' behavior in energy consumption has been conducted and its results have been integrated in the energy based model, in form of virtual technologies. This approach, known as "Social MARKAL", allows the analyst to evaluate the possible contribution of information campaigns in changing lighting consumers' behavior and effect of technology switch. The model is developed for the period 2010-2026, and is implemented by using GAMS/TIMES/VEDA software platform. The results presented this paper focuses on the household lighting technologies.

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Keywords: TIMES/VEDA model for Romania; behaviour change; energy savings; consumer behaviour modelling;

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1. Introduction

Residential lighting technologies endorsed important increases in energy efficiency in recent years. Compact fluorescent bulbs and light emitting diodes require about 80% and 85% less electricity compared to incandescent bulbs and last from 6 to 26 times longer, respectively[1,2].

Thus, widespread adoption of new technologies has the potential to significantly reduce household electricity consumption, which accounts for about 26.7% of residential electricity consumption in the EU-27[3], and about 23.1% in Romania. The main factors that obstructed the diffusion of energy-efficient lighting bulbs are considered to be: bulbs size and shape, perceived lower quality of light, warm-up period before achieving full brightness, and higher initial purchase costs[4]. Many final consumers are not aware of the advantages of new technologies and in that case, information campaigns may improve the rate of technology switch. Information campaigns may also act on consumer behavior. A lot of European countries have implemented measures to speed-up the transition process to new technologies, like: imposing interdictions to import and domestic sales of incandescent light bulbs, by supporting awareness campaigns about new technologies. The implications of proposed scenarios could be evaluate, in advanced, by using optimization models, which integrate both techno-economic approach and social behavior of final consumers.

Optimization models are useful to describe both economic growth, technology richness and structural changes in technology structure[5]. Energy models are also important for examination of energy policies.

Classical optimization models, including economic and energy technologies only, have a major disadvantage. They suppose consumers with perfect economic rationality and consumers with updated and full economic and technological information. But usually, the behavior of final consumer of energy is not rational because they are not in possession of all necessary information and because their personal preferences do not correspond to the economic criterion of minimal costs. For these reasons we are considering not only the economic- technological modelling, but also the consumer behavior to be included in the optimization model.

A sociological survey, representative for Romania's population has been conducted. Some rational, but non-economic factors, which determine the consumption decision for lighting were identified, along with some irrational factors that make people acquire and use old incandescent bulbs or overconsume light.

The results gathered from sociological survey have been modelled and integrated in TIMES/VEDA techno-economic energy model developed for Romania.

The TIMES model is using information about the efficiency of technologies. In order to comply with this requirement, we determine the equivalent of efficiency of virtual technologies by measuring the consumers' information, perception, and behavior.

The rest of paper is structured as following: the next section includes a brief literature review about techno-economic energy models and about the consumers' behavior in energy consumption. Section 3 includes a brief description of TIMES model implemented for Romania, and the section 4 proposes the solution implemented for Romania, to integrate behavior parameters into TIMES/VEDA model. The last section includes main findings and future works.

2. Literature Review about Techno-Economic Energy Models and Consumer Behavior

Sustainable energy consumption is a research approach of a large interest in last years. New energy efficient lighting technologies exist, which can significantly reduce household electricity consumption, but their adoption has been slow. A considerable number of international studies show that sustainable development scenarios will be realistic if they involve the human behavior.

Elaborating techno-economic energy models is the first step toward identifying and understanding the key issues, driver and barriers to development sustainable solutions for energy consumption.

A techno-economic energy model is a mathematical representation of an energy system, describing its configuration, technologic and economic characteristics of its components[6]. Long term techno-economic energy models can be used to determine the optimal configuration of an energy system in terms of: efficiency, costs, environmental impacts, and to predict future behavior of a system. A variety of techno-economic energy models has

been developed, like: MARKAL, TIMES (The Integrated MARKAL-EFOM System), and OSeMOSYS (The Open Source Energy Modeling System), each serving particular purposes.

MARKAL framework model has been developed by the IEA-ETSAP (International Energy Agency) under the auspices of the Energy Technology Systems Analysis Program. It has been widely applied for energy system modelling on global to community level, to facilitate investigation of possible energy futures.

TIMES has been developed by IEA-ETSAP as a successor of the MARKAL framework and includes several features adopted from EFOM model as well as new enhanced features.

OSeMOSYS is an open and compact modelling framework, developed by some cooperating organizations including: SEI (Stockholm Environment Institute), the IAEA (International Atomic Energy Agency), the UK Energy Research Center, and the KTH (Royal Technical University of Sweden).

Since 2005, there has been an emerging trend to apply social and behavior science to energy research[7]. Often, the effectiveness of energy is studied without examining the underlying behavioral determinants of energy use and energy savings. Only few studies examine both the effectiveness of an intervention as well as changes in determinants of energy use, and fewer provided detailed impact evaluation[7].

Sustainable energy consumption supposes to reduce the energy consumption. This goal can be achieved by improving the energy efficiency by investing in better technologies, or by energy conservation which means changing the behavioral habits when it comes to energy consumption. Thus there are two types of behavior that people can adopt to save energy are investment behavior and consumption behavior that occur with different time scales. Investment behavior occurs occasionally, and involve the adoption of new technologies or the acquisition of new appliances. Habitual behavior is a routine behavior which individuals repeat automatically without conscientiously weighting the pros and cons, such as switching off the lights when leaving a room[8]. The two types of behavior, energy savings and technology switch, are covering all the cases of behavioral change[8].

3. TIMES/VEDA Model Implementation for Romania

TIMES (The Integrated MARKAL EFOM System) is a long term optimization model developed by the Energy Technology Systems Analysis Programme, under the aegis of International Energy Agency. This tool combines a technical engineering approach and an economic approach to represent technologies, fuels, emissions and their effect on economic sectors.

TIMES model establish relationships between the variables aiming modelling extraction, transportation, storage, energy conversion processes from one form to another, towards the final consumer, according with Reference Energy System (RES). RES is a formal analytical tool of network form, designed to represent the activities and relationships of an energy system.

TIMES models are constructed from some basic entities[9]:

- Technologies (processes) are physical devices that transform commodities into other commodities. Technologies are used to satisfy demands. It takes energy as input and transform it so that to be able to satisfy demands, on the output. The technology is characterized by economic indicators like: efficiency, capacity, costs and so on.
- Commodities (including fuels) are energy carriers, energy services, materials, monetary flows, and emissions; a commodity is either produced or consumed by some technology.
- Commodity flows are the links between processes and commodities. A flow is of the same nature as a commodity but is attached to a particular process, and represents one input or one output of that process.

To set up the energy model the following data sources have been used:

- Romanian Reference Energy System statistics for the base year (2010), used to calibrate the model;
- 2014 Population and Housing Census (provided by Romanian National Institute of Statistics) for data about demand drivers.
- For technologies we developed the Romanian technology database.

The goal of our paper being to introduce the social behavior of lighting consumers, we developed a very simple but also robust TIMES model for Romania[10].

From the complete Romania's TIMES model we detail in this section only the household energy consumption segment.

The demand side of household energy consumption uses various energy carriers and services, by using Reference Energy System of Romania as the basis, as presented in figure 1.

The modelled processes are: lighting (with various fuels: kerosene, incandescent, fluorescent, led), space cooling (electricity), space heating (fuels: natural gas, biomass/wood, oil products, coal, solar energy), combined space heating - hot water SH-HW, hot water (fuels: natural gas, biomass/wood, oil products, coal, solar), refrigeration (electricity), washing machine (fuel: electricity), dish washing (fuel: electricity), cloth dryers (fuel: electricity), others (fuel: electricity).

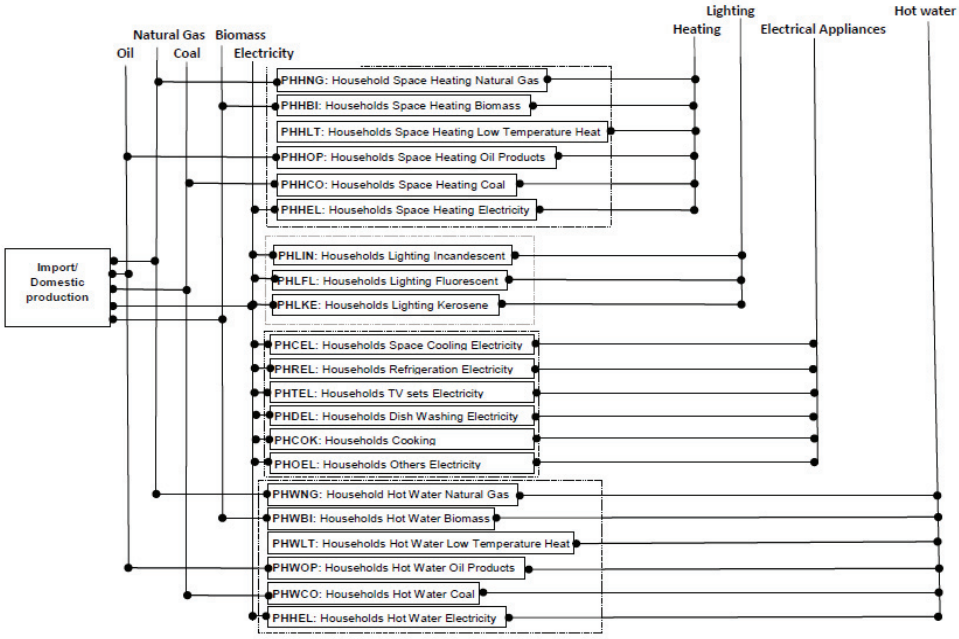

Fig. 1. TIMES model of Romania. The households sector

The formulation of the model was made by using TIMES model generator that creates the resulting model in GAMS (General Algebraic Modelling System). GAMS is a computer language specifically set up to facilitate the development of algebraic models.

Construction, handling, and maintenance of large scale models are difficult without a performing user-friendly interface. VEDA (VErsatile Data Analyst) interface offers the user a customized tool for handling files, databases and results from large - scale mathematical and economic models. The proposed implementation makes use of both VEDA components:

- VEDA-FrontEnd for input data handling, being used in several multi-region applications in USA and Europe;
- VEDA-BackEnd, a versatile and powerful interface to look at a variety of data, including exposure of results from the model, in different presentation formats.

4. Modelling Consumer Behavior and Integrating in the Techno-Economic Energy Model

Because the classical TIMES model is not designed to assess the consumer behavior, virtual technologies have been introduced, in order to model the consumers' behavior. Virtual technologies are used to model both the investment and the habitual behavior, that complete the competition between demand technologies, modelled based on techno-economic energy approach.

The consumers' opinions could be influenced in various ways: from energy labels through marketing campaigns, by legal measures and restrictions imposed by governmental institutions. Like in the case of tangible technologies, there are costs associated with virtual technologies, investment cost of an information campaign, but the downstream behavior change is free. By mixing tangible and virtual technologies, the optimal solution may include social change triggered by cost-effective information campaign as a competitor of mere technology progress[11].

To model the consumers' behavior we used data from sociological survey, about consumers favorable for technology switching and about consumers' favorable for rational energy usage.

In order to measure Romanians' perception, attitudes and behavior, a sociological survey, representative for the adult population of Romania has been conducted. 400 residents of urban and rural localities, from all regions of Romania were surveyed, between September-November 2013. The survey used a representative sampling technique – the sample used a random geographic sample across Romania. The target of this survey is the adult population Romania, and face-to-face interviewing method has been applied. For proportions, the theoretical margin of error at 95% confidence level is +/- 4.75. The aim of the survey questionnaire is to assess the potential contribution of behavioral change in end-use lighting energy consumption pattern.

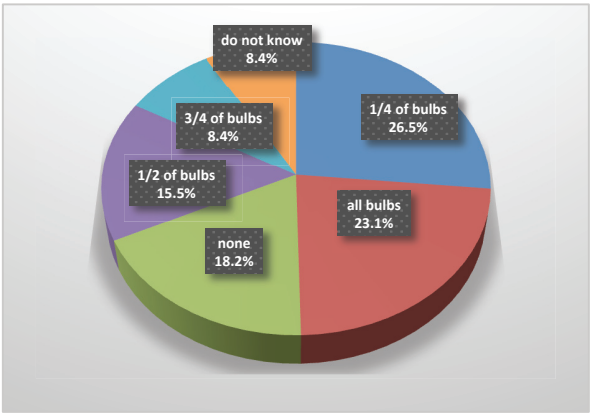

Fig. 2. Ratio of incandescent bulbs replaced with low-consumption bulbs

Habitual behavior is addressed in the sociological survey through to the reasons for turning light on when entering in a room. More than half of the respondents (50.6%) indicate a practical reason for turning on light: the need to see entire room. The need of comfort is indicated by 40.5% of the respondents. Interestingly, habitus is the reason for 33.4% of the respondents, 17.7% of respondents turn on light from security purposes, 12.8% because of the problems of vision, 6.1% because of the fear of obscurity, and 4.4% because of the need to illuminate all the rooms.

Investment behavior of households lighting consumers from Romania, is detected through the question: "During the last two years, how many classical incandescent bulbs did you replace by low-consumption bulbs?" As indicated in figure 2, 23.1% of the respondents own only low consumption bulbs in their own residence; for 8.4% of respondents the share of low-consumption bulbs is 3/4; 15.5% of respondents have around half of low-consumption bulbs; for 26.5% of respondents around a quarter of existing bulbs are low-consumption bulbs; 18.2% of respondents do not own any economical bulb in their own home.

To model the consumer behavior we introduce two technologies: CAMP1 - Information Campaign Habitual Behavior Change, CAMP2 - Information Campaign Investment Behavior Change and four commodities: RLD1 - Existing Incandescent Bulbs, RLD2 - Existing Low Consumption Bulbs, RLD3 - Moderate Use of Incandescent Bulbs, and RLD4 - Switch to Low Consumption Bulbs. The structure of consumer behavior model contains the relationships between components and is presented in figure 3.

RLD1 and RLD2 represent real commodities flows, receiving electricity as input and generating residential lighting.

RLD3 and RLD4 represent virtual commodities flows, corresponding to virtual technologies. They receive intangible inputs (information campaigns) and generate residential lighting.

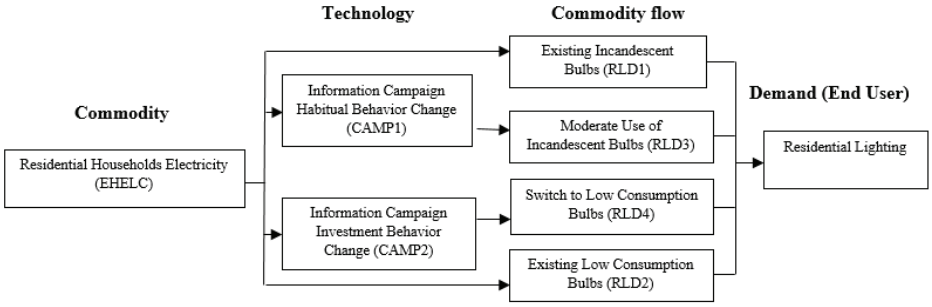

Fig. 3. Consumer Behavior Reference Model Diagram for Residential Lighting Sector

The relationship between new added virtual technology (CAMP1) and corresponding commodities (RLD1 and RLD3), displayed in VEDA-Front End software interface is presented in figure 4.

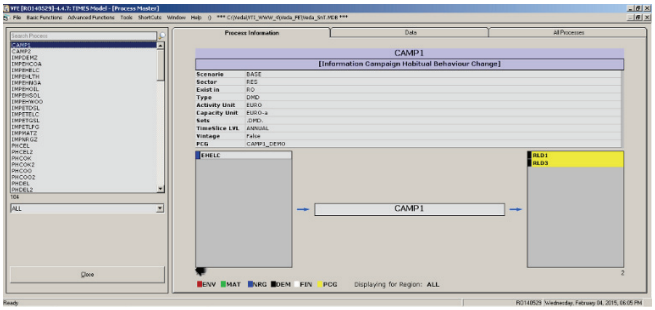

Fig. 4. VEDA-Front End Interface, with new virtual technology

The output results modelled for both information campaigns, in term of commodity production by process, are presented in figure 5.

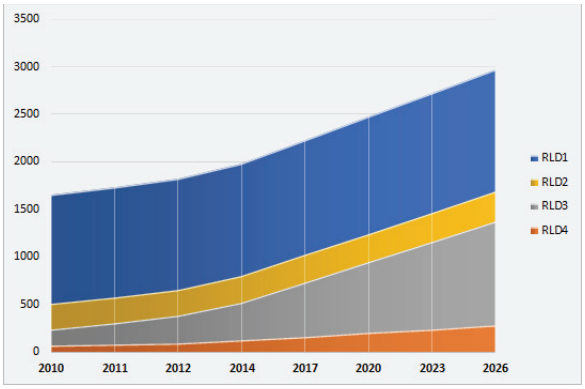

Fig. 5. The outcome of information campaign, in term of commodity production by process

As presented in figure 5, the overall demand for light bulbs is expected to grow by about 50%, over the evaluation period: 2010 -2026.

According with the output results generated by using the implemented model, the demand for the incandescent bulbs will increase easily in Romania, from 115,100 bulbs in 2010 to 128800 bulbs in 2026. This is true if no legal measure aiming to restrict the incandescent bulbs consumption will not be adopted. The rate of demand for low consumption bulbs will increase more, from around 26,400 bulbs in 2010 to around 31,700 bulbs in 2026. But, the outputs of information campaigns modelled by using virtual technologies suggest that the energy savings and technology switch may influence the spontaneous purchase of real bulbs.

5. Conclusions and future works

The paper describes a method to integrate habitual and investment consumer behavior into a techno-economic model using a TIMES/VEDA framework in order to reduce the systematic error at the demand side of the energy model if the consumer behavior is neglected. Consumer behavior is described by virtual technologies with attributes similar to tangible technologies. In this approach, the possible contribution of information campaigns, in changing energy consumers' behavior and the effect of technology switch is in direct competition with technology progress. The model concerns household lighting. Next steps will extend the approach to other demand sectors such as residential heating and cooling, and transport sectors.

Acknowledgements

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