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Sustainable development modelling for the energy sector

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A B S T R A C T

Sustainable residential energy consumption involves a complex, socially embedded and socially constructed market. A system dynamics approach has been used to explore the short, medium and long term impact of different national consumer-oriented energy efficiency policies in the residential building sector. In this paper the system dynamics model has been validated by a case study using historical data from a subsidy scheme and accompanying policy measures in Latvia. Results obtained by the validity tests showed that the model generated behaviour is consistent with available data and is capable of generating "*the right behaviour for the right reasons*". Simulation results show that national energy efficiency goals cannot be met by 2016 and the absence of major consumer-oriented policy tools slows down the diffusion process of energy efficiency projects. It also highlights that system dynamics has a high potential to be used for sustainable end-use energy policy planning at both national and sub-sectoral levels.

1. Introduction

Household energy demand is continuously growing worldwide and is among the major causes of greenhouse gas (GHG) emissions. Moving towards lower energy consumption is on the political agenda worldwide. This implies that sustainable consumption, as defined by the Oslo Declaration (OECD, 1997), is becoming increasingly important. For the promotion of sustainable consumption, the European Commission has adopted the "Energy Roadmap 2050" to reduce energy demand by 41% by 2050 as compared to the peak in 2005–06 (COM, 2011).

Energy consumption in the residential sector is determined by two factors – installed capacity of energy consuming technologies and habits of use. Households make decisions on how much energy they consume by both selecting energy technologies with improved efficiency, and reducing their demand for energy services (such as heating, lighting and cooling) by behavioural change. Hence, the behaviour of consumers is an important factor underlying sustainable consumption. Expenditures, income, education, age, family size and social status determine the sustainability of a household's consumption. Behavioural change is related to lifestyle and daily life routines that are rooted in social and cultural context. Resistance to change is deeply tied with this context and strongly influences the decision making process of households respecting energy consumption. The IPCC mitigation report lists and discusses a great variety of barriers that exist in the residential energy efficiency sector, such as misplaced incentives, limitations of the traditional building design process and technology, regulatory barriers, perceived risks, imperfect information, culture, behaviour and lifestyle, and others (IPCC, 2007). The same report suggests that implementation of energy efficiency measures creates not only direct energy savings but also co-benefits, which are as important as direct savings.

A vast number of models have been created over the years for planning end-use energy demand (e.g. Strub, 1979; Lapillonne and Château, 1981). From the point of view of model validity, these models can be divided into "black box" or correlation models that are based purely on data and "white box" models or causal-descriptive models, which are based on the explicit representation of causal relations among factors considered in the model. Black box models, which do not have a claim to causality in structure, are used for forecasting purposes and are valid if the model output matches the "real" output. For white box models the validity of the internal structure of the model is essential. Hence the behaviour of the system can be modified by adjusting its structure (Barlas, 1996).

In most of the cases, demand side energy models are black box models. White box models are less widely used. Barreto and Kemp (2008) identified one of the major driving forces of the technological diffusion process - technology learning. This has been included in energy systems models in recent years. However, technology learning still remains a black box model lacking

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explanation of the factors driving the technology diffusion process. Based on an analysis of modelling methods underlying the National Energy Efficiency Action Plans (EEAP) of EU member states required by Directive 2006/32/EC on energy end-use efficiency and energy services (EPC, 2006), Hull et al. (2009) conclude that while some countries have developed sophisticated energy end-use models, many still use simple accounting analyses.

Modelling and simulation, offered by one of the white box modelling tools (system dynamics) is a technique that enables one to make the relationship between cause and effect explicit in complex, dynamic systems that have delays, feedbacks and non-linearities. System dynamics is a methodology used to develop computer simulation models of problems under review (Forrester, 1961; Sterman, 2000). It supports the coordination of policies that take effect after various delays. The system structures are visualised as stock-and-flow diagrams that are built from stocks representing accumulation processes, and inflows/outflows affecting the stocks, as well as auxiliary variables and constants. The structural transparency of system dynamics modelling tools facilitates communication between stakeholders, i.e. specialists, policy designers and the public at large.

System dynamics models of technology and innovation diffusion related to energy efficiency of the residential sector have been presented by several authors. Grösser (2006, 2007) have applied system dynamics modelling to tackle residential energy efficiency in Switzerland, Capelo (2011) has analysed the energy performance contracting market in Portugal, and Davis and Durbachy (2010) have modelled household response to the lighting energy efficiency policy in South Africa. Even though Kiss et al. (2013) have not used system dynamics in their research, their conclusions on the role of policy instruments in supporting the development of mineral wool insulation in Germany, Sweden and the United Kingdom reveal the feedback structure of the policy tools driving the market.

The main aim of this paper is to validate the system dynamics model for policy analysis of residential energy efficiency constructed when a limited amount of historical data are available, and described in our previous paper (Blumberga et al., 2011) wherein data accumulated during later periods were used. The aim is to evaluate the ability of the model to explain actual behaviour and to investigate how inhabitants respond to different energy efficiency policy measures. The model is tested against the data collected from consumer-oriented policies, such as, subsidy schemes and accompanying energy efficiency policy measures used in Latvia between 2009 and 2012.

The paper starts with the background information about Latvia's residential building stock and energy efficiency policy. It is followed by an overview of the methodology used to build up the system dynamics model. The following section contains information about the validation of the model. It is followed by the results obtained and a discussion. The paper closes with conclusions.

2. Background information

The residential sector is currently the greatest energy consumer in Latvia, accounting for nearly 40% of the overall energy end-use in the country (LEF, 2011). In 2010, the total housing area reached approximately 61 million m^2 (CSBL, 2012). About 62% of the total residential building stock is multi-family buildings (CSBL, 2012). Long and cold winters (above 4000 heating degree days) determine that the greatest energy consumption in the residential sector is for home heating with an average annual consumption of 180 kWh per m^2. "Energy efficiency measures in residential buildings" in this paper means the improvement of the thermal properties of the building envelope by the use of insulation. The most challenging task for the energy efficiency policy is how to resolve collective action problem arising from the ownership structure of multi-apartment buildings. As in most of the East-European and post Soviet countries, apartments are owned by individual occupants. The implementation of common energy efficiency measures in buildings can only be performed with the agreement of at least 50% plus one of the apartment owners.

To ensure the implementation of the European Union's Directive 2006/32/EC on energy end-use efficiency and energy services (EPC, 2006), the Latvian government has prepared the first and the second EEAP (LEEAP) covering the periods between 2008–2010 and 2011–2013 (LEEAP, 2008; LEEAP, 2011).

As illustrated in Fig. 1, the goal of the first LEEAP is to reduce the consumption of energy (adjusted with climate) in the residential sector by 2701 GWh (which is 77% of the total savings in all sectors planned by 2016). To reach the goal, LEEAP includes consumer-oriented policy measures, such as energy audits in buildings and building energy certification, subsidies for energy efficiency measures in multi-apartment buildings, subsidies for energy efficiency measures in public buildings (social housing), information campaigns for energy consumers, as well as the development of secondary legislation.

Several studies carried out, talk about Latvia's ability to reach that goal by 2016. They concluded that the first LEEAP is based on oversimplified assumptions (RTU, 2009). They also cite the lack of details on underlying assumptions and the implementation and impacts of the measures impeding firm conclusions on whether the target can be met (CEC, 2009). The system dynamics model for policy analysis of residential energy efficiency described in the preceding study (Blumberga et al., 2011) and shortly presented in Chapter 2 of this paper was built when policy tools suggested in the first LEEAP were at the planning stage and limited amounts of historical data were available. The simulation was done to forecast the impact of policy tools planned in the first LEEAP. It was found that only 55 GWh may be saved by 2016, accounting for only 2% of the planned savings (see Fig. 1). The simulation showed that if the additional policy measures (described in Chapter 3) are taken, 583 GWh might be saved by 2016 (see Fig. 1).

The graph (see Fig. 1) of the actual energy savings based on historical data available from the subsidy scheme (described in detail in Chapter 4) for the period from January, 2009 to February, 2012 shows that they are far below the savings planned in the first LEEAP.

At the same time when the results of the actual energy savings were reported by the government in the second LEEAP, they revealed surprisingly significant savings (see the grey column in 2009 in Fig. 1). A detailed analysis of the second LEEAP by Blumberga et al. (2012) showed how the improper use of the top-down method fails to capture the response of energy users to

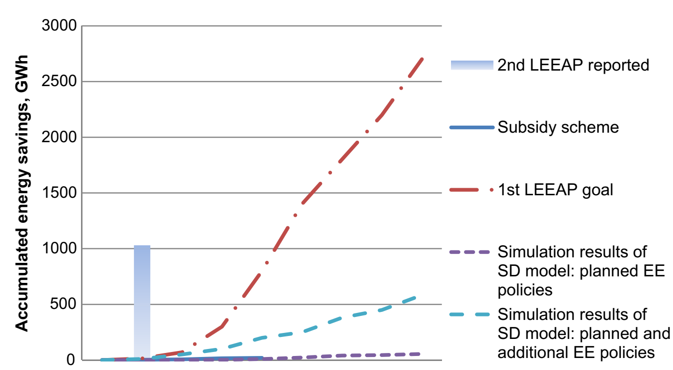

Fig. 1. Planned, simulated and actual accumulated energy savings between 2008 and 2016 in the residential sector in Latvia.