Sustainable Development Modeling for Energy Sector

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Abstract: 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 building sector. In this paper the system dynamics model has been verified by a case study using historical data from subsidy scheme and accompanying policy measures in Latvia. The results indicate that the model is valid. 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 major causes of greenhouse gas (GHG) emissions. Moving towards lower energy consumption is at the political agenda worldwide. This implies that sustainable consumption defined by the Oslo Declaration (OECD, 1997), is becoming increasingly important. For promotion of sustainable consumption, the European Commission has adopted the "Energy Roadmap 2050" to reduce energy demand of 41% by 2050 (COM, 2011).

Energy consumption of 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, behaviour of consumers is an important factor underlying the sustainable consumption. Expenditures, income, education, age, family size and social status determine sustainability of 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 decision making process of households on energy consumption. The IPCC mitigation report lists and discusses great variety of barriers that exist in the residential energy efficiency sector, such as misplaced incentives, limitations of the traditional building design process, regulatory barriers, perceived risks, imperfect information, culture, behaviour and lifestyle, and others (IPCC,

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2007). The same report suggests that implementation of energy efficiency measures creates not only direct energy savings but also co-benefits and they are as important as direct savings.

A vast number of models were created over the years for planning end-use energy demand (e.g., Strub, 1979; Lapillonne and Château, 1981). These models can be divided into “black box” or correlation models that are purely based on data and “white box” models or causal-descriptive which are based on explicit representation of causal relations among factors considered in model. Black box models, such as regression models, are used for forecasting purposes and they are valid if the model output matches the “real” output. For white box models the validity of internal structure of the model is essential, hence the behaviour of the system can be modified by adjusting its structure. In most of the cases, demand side energy models are black box models while the white box models have been used less. Barreto et al. (Barreto and Kemp, 2008) identified that one of the major driving forces of technological diffusion process - technology learning, has been included into energy systems models in the recent years, however it still remains a black box model lacking explanation of the factors driving the technology diffusion process. Based on analysis of modeling methods underlying 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. (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 technique that enable 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 problem under review (Forrester, 1961; Sterman, 2000) and 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 are presented by several authors. Grösser (Grösser, 2006; Grösser, 2007) have applied system dynamics modelling to tackle residential energy efficiency in Switzerland, Capelo (Capelo, 2011) has analysed energy performance contracting market in Portugal, and Davis et al. (Davis and Durbachy, 2010) have modelled household response to lighting energy efficiency policy in South Africa.

The main aim of this paper is to validate the system dynamics model for policy analysis of residential energy efficiency constructed when limited amount of historical data were available, and described in our previous paper (Blumberga et al., 2011) by using the data accumulated during later periods. The aim is to evaluate the ability of 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 scheme and accompanying energy efficiency policy measures used in Latvia between 2009 and 2012.

2 Background information

The residential sector is currently the greatest end energy consumer in Latvia, accounting for nearly 40% of the overall energy end-use in the country (LEF, 2011). In 2010, total housing area reached about 61 million m2 (CSBL, 2012) and 62% from total residential building stock are multi- family buildings (CSBL, 2012). Long and cold winters (above 4000 degree days) determine that the greatest energy consumption in residential sector is for heating with an average annual consumption 180 kWh per m^2. By energy efficiency measures in residential buildings in this paper are meant improvement of thermal properties of the building envelope, i.e. "building insulation". The most challenging task for energy efficiency policy is to target 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 and the implementation of common energy efficiency measures in buildings can be performed with an agreement of at least 50% plus one vote 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) Latvian government has prepared the first and the second EEAP (LEEAP) covering periods from 2008–2010 and 2011-2013 (LEEAP, 2008; LEEAP, 2011).

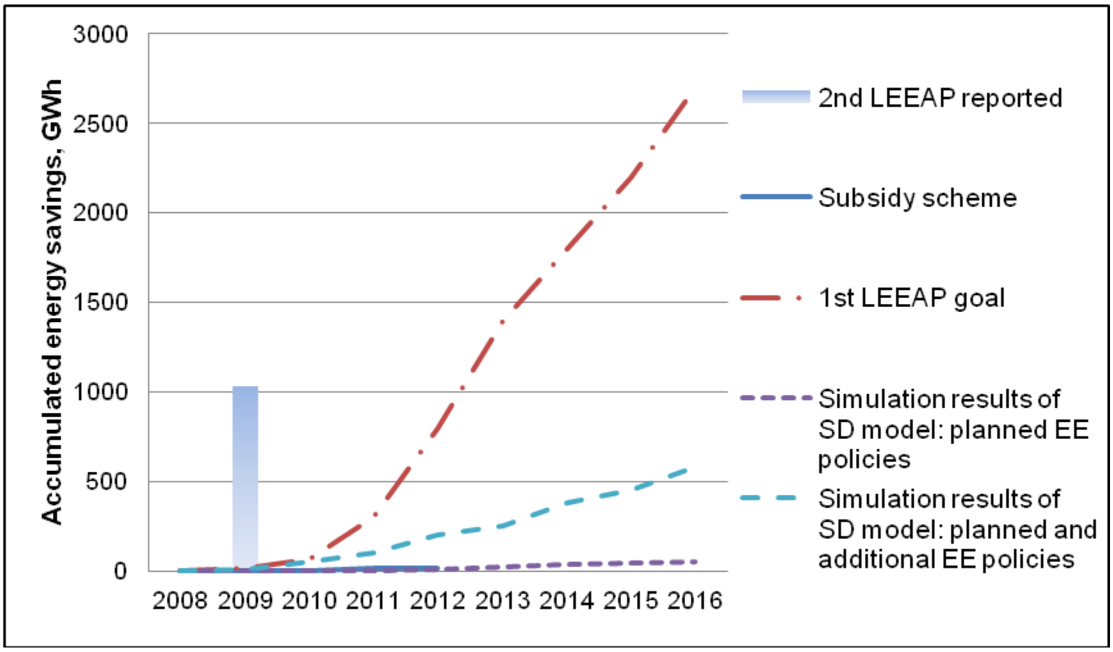

Figure 1: Planned, simulated and actual accumulated energy savings between 2008 and 2016 in residential sector in Latvia

As illustrated in Figure 1, the goal of the first LEEAP is to reduce end-use energy (adjusted with climate) in the residential sector by 2701 GWh (which is 77% from 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, and development of secondary legislation.

Several studies carried out about Latvia's ability to reach the goal by 2016 conclude that first LEEAP is based on oversimplified assumptions (RTU, 2009), the lack of details on underlying assumptions, implementation and impacts of the measures impeding firm conclusions on whether the target can be met (CEC, 2009). In the preceding study (Blumberga et al., 2011) the impact of planned policy tools in LEEAP was simulated with the system dynamics model described in further chapters of this paper, and it was found that only 55 GWh can be saved by 2016 accounting for only 2% of the planned savings (see Figure 1). If additional policy measures are taken, 583 GWh can be saved by 2016 (see Figure 1).

Analysis of actual energy savings reported in the second Latvia's LEEAP (illustrated in Figure 1) shows how improper use of the top-down method fails to capture response of energy users to changing conditions in the event of economic crises, and how the result may lead to absurd and misleading conclusions (Blumberga et al., 2012). Historical data available from the subsidy scheme (described in details in the further chapters) for the period from January, 2009 to February, 2012 show that the actual energy savings are far below the savings planned or reported in LEEAP (see Figure 1).

3 Methodology

The model built and used in this paper is system dynamics based integrated modelling framework for comprehensive planning and continuous impact assessment of energy efficiency policies in residential sector in Latvia, and it is described in details by Blumberga et al. (Blumberga et al., 2011). The main goal of this mathematical simulation model is to help with national residential energy efficiency policy formulation and evaluation analysis that accounts for feedbacks across and within both supply and demand sectors, aiming at identifying both synergies and potential bottlenecks (unexpected side effects) as a result of policy implementation. The model incorporates dynamics of time delays, providing insights to whether policies and investment allocations may lead to a "worse before better" situation due to the presence of the underlying delay times in the analysed system, and includes non-linearities. By generating scenarios over time the model simulates the main impacts of energy efficiency policies in short, medium and longer terms. Model is built using the Powersim software platform.

The model is based on the widely known Bass diffusion model (Bass, 1969). In a technology diffusion technology spreads in the market along an S-shaped curve: initially the technology is accepted slowly, but this is followed by exponential growth and the attainment of an asymptotic stability. Energy efficiency implementation in the residential sector disclose the role of path creation - the role entrepreneurs, such as energy service companies (ESCOs), have in setting the technological diffusion paths (Garud and Karnøe, 2001; Heiskanen et al., 2011). The model also relies on interactions, feedbacks, delays and non-linearity of complex systems, based on microeconomics theory (e.g.,Oikonomu et al., 2009; Kletzan et al., 2002) to address research problems related to the social, economic and institutional dimensions of the residential energy efficiency. The microeconomics theory has been used as a theoretical background providing that the decision process for energy efficiency improvement is based on net benefits of individuals, uncertainty costs and availability of information. Net benefit is the benefit of each individual from implementation of the energy efficiency measures. The net benefit is made up of the difference between costs before and after introduction of these measures including investment in the energy efficiency improvements. Uncertainty costs are an expression of the existing barriers to introduction of energy efficiency measures in monetary terms, e.g. the lower than expected energy savings due to low quality of the construction works; higher than expected investment in the energy efficiency measures; time consuming administrative barriers related to the building insulation process; time consuming process of reaching common agreement among owners of apartments to proceed with the insulation of a building; difficulties to find funding etc. The uncertainty costs increase when these factors pile up and the barriers become harder to overcome. Model structure takes into account time delay for creation of new knowledge, the deployment and diffusion of building energy efficiency measures.

Both government policies from Latvia's EEAPs and additional policies applicable to Latvia's context are used in the model. The policies are such as energy performance standards, improvement of quality of energy audits, financing for research and development, preparation and availability of standard procurement documentation and contracts, improvement of technical supervision of construction works, subsidies, CO_2 tax, raising the awareness level, a "one-stop shop" solution for overcoming administrative barriers in municipal authorities, the "champion effect" which involves a popular and influential person in the community providing a positive lead to problem's solution which is followed by others in the community due to reduced uncertainty costs, and ESCO services. These policies are used to change three values: 1) to increase net benefits; 2) to reduce uncertainty costs; 3) and to increase awareness and investment in energy efficiency measures.

Figure 2 represents conceptual structure of the system dynamics model illustrating important relationships and interactions of elements of the studied system. The main sectors included in the model are demand and supply sides of the building insulation market. Demand side is represented by uninsulated building stock while the supply side is represented by capacity and supply abilities of both the traditional construction companies and ESCOs. The rate of insulation depends on demand and supply for both energy service companies and construction companies, but there are different factors affecting them. Supply of construction companies depends on the capacity of the companies but the supply of energy service companies depends on operations, information, net benefits, and uncertainty costs. The main drivers of demand are net benefits, uncertainty costs and information (both about successful and unsuccessful projects) available to building owners. Different policies are targeting each of those three demand drivers.

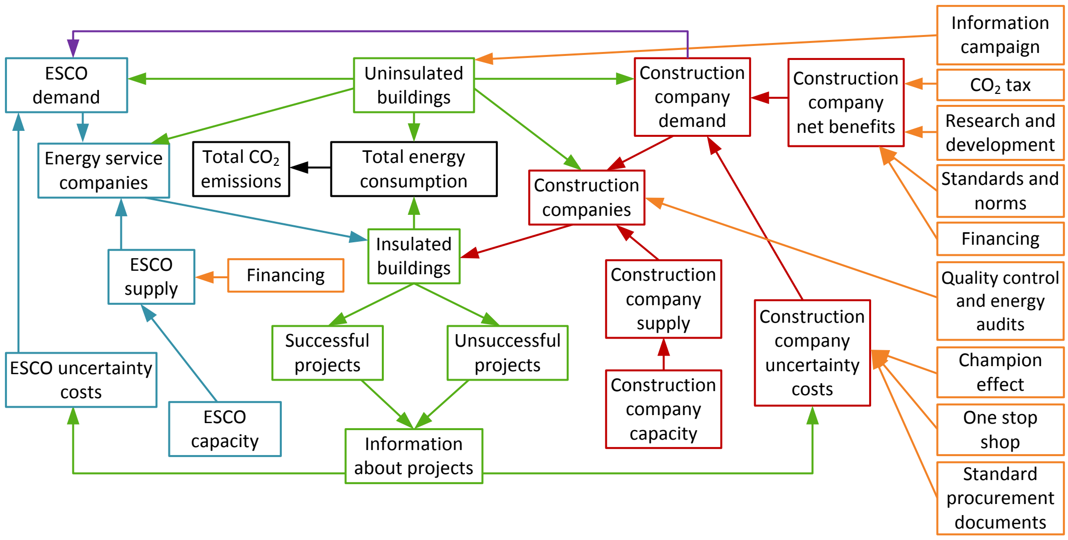

Figure 2: The conceptual model structure

4 Validation of model

Data availability and quality are always the key concern for all modeling studies. There are no models which perfectly represent studied systems and simulated data generate only a trend instead of the accurate numbers. Barlas (Barlas, 1996) explains why the availability of data is not crucial to create a good system dynamics model. He also states that the validation of system dynamics models has to be carried out rigorously, both for structural and behavioural validation. Evans (Evans et al., 2001) suggests that calibration and validation of system dynamics models can be performed using data from field collection and from the literature. The historical behaviour validation test is used to build a confidence in a model (Vennix, 1996).

The previous study of residential sector energy efficiency policy (Blumberga et al., 2011) presented forecasted savings for different energy efficiency policy tools. In this paper, data collected from intervention of actual policies implemented during the period from January 2009 to February 2012 were used to validate the results of the developed model. The main driver for diffusion of energy efficiency in residential sector is subsidy scheme “Improvement of energy performance of multi-family buildings” financed by the European Regional Development Fund and the state budget in amount of 63 million EUR. This subsidy scheme, managed by Investment and Development Agency of Latvia (IDAL), is available for energy efficiency improvements in multi-family buildings and finances 50% from eligible investment costs which are not higher than 50 EUR/m^2. Additional policy tools, such as information dissemination activities, standard procurement documents, requirements for energy audit quality just accompany this scheme.

The tests of the system dynamics model rest on the data obtained from different information sources, including database of projects provided by IDAL, interviews and the other data sources. Analysis of these data and interviews reveal the following situation with the energy efficiency policy:

1. The implementation of the subsidy scheme started in April 2009 and is to continue during 2012 until all funds are spent. Dynamics of application and implementation are illustrated in Figure 3.
2. Before 2009 no ESCO has been active in the housing sector in Latvia. The first ESCO project in this sector was applied and financed by the subsidy scheme in 2009. There is a time delay caused by introduction of ESCO concept to market. Data analysis shows that ESCOs growth fraction is increasing and they have signed agreements for 9 buildings by February 2012. 100% of applications turned into signed agreements so far and it is 2 % of the total contracts signed within the subsidy scheme (IDAL, 2012).
3. 44 % of the total contracts are signed by housing associations founded by owners of apartments (IDAL, 2012). Apartment owners can apply for funding as housing association or by authorizing the housing maintenance company. Association is legal entity established by at least 51% of the apartment owners and is managed by board of three apartment owners (in all cases they are “champions” or opinion leaders). This is a voluntary action and only minor part of multi-family buildings has established housing associations. The board of housing association takes responsibility for the management of the building. In most of the cases building champions are the initiators and managers of energy efficiency projects in buildings.
4. 54 % of contracts are signed by municipal or commercial housing maintenance companies (IDAL, 2012). They are authorized by apartment owners to implement energy efficiency measures in the building. Based on interview methodology provided by project IDEAL EPBD (Gosselain and Bartiaux, 2010) the interviews with municipal housing maintenance companies Liepaja, Ventspils and Valmiera who have signed the largest amount of contracts were carried out. The results reveal that the employees have contributed greatly to convince apartment owners to apply for subsidy program and they continue to help to implement the projects.
5. The implementation agency IDAL has paid detailed attention to the quality of energy audits and some projects were rejected due to overestimated saving figures and other severe calculation errors. As the result IDAL is permanently reviewing complaints of apartment owner associations or building maintenance companies

and are suspending energy auditor certificates (Puce, 2012).

6. IDAL has posted on its web site methodology and documentation on standard procurement and contracts. This reduces risk of building owners to be circumvented by the construction companies.
7. The quality of construction works is not strictly controlled by IDAL leaving it to the management of the building. This may cause lower amount of savings than technically possible and it is listed by IDAL among most common failures during implementation of project (Bernfelds, 2012; Lukss, 2010).
8. Housing maintenance companies reported on low level of trust among apartment owners at the beginning of subsidy scheme. It has improved after site visits to implemented projects (Lukss, 2010).
9. Information campaign “Dzīvo siltāk!” (Have a warmer life!) accompanies subsidy scheme, including regional seminars to promote scheme for apartment buildings for both the apartment owners and the building companies, international seminars, competition for the most energy efficient building, and E-map with all buildings who have received subsidies (Puce, 2012).
10. The time between the first discussion of housing association about application for subsidy and the agreement to submit application to the subsidy scheme takes in average 2 months and time to get application funded in average is 4 months (Lukss, 2010)
11. Average savings calculated by energy auditors are 46%, and average investments 71 EUR/m2 including subsidies (IDAL, 2012).

The simulation was performed based on the data described above. It is assumed, that initially in April 2009 there are 63,000 m^2 already successfully insulated, and 17,000 m^2 unsuccessfully insulated buildings by construction companies, and 30,000 m^2 potential projects waiting for subsidy scheme to be started. The rest of residential building stock then remains uninsulated. Heat energy tariff is 63 EUR/MWh. Based on interviews with housing maintenance companies, time to initiate projects is 1 year, champions have initiated 50 % of the total number of projects, and time to perceive net benefits and uncertainty costs as well as construction costs is two years. Policy tools used from the list of the suggested tools are small scale information campaign (value 0.1), subsidy scheme in amount of 63 mill. EUR and champion effect. It is also assumed that ESCO insulation capacity is 15000 m^2 a year.

5 Results and discussion

Figure 3 illustrates both the simulation results and the historical data about project application and implementation activities as resulting insulated cumulative floor area during period from April 2009 to February 2012. Historical data show that in the subsidy scheme only 54% of the total number of applications gets funded. There is a time delay between agreements signed and the completion of energy efficiency measures. Therefore, the number of projects in process: projects that are accepted by the implementation agency IDAL, searching for co-financing, procuring for construction company, implementing energy efficiency measures, and completed projects, is much higher (1,070 thous.m^2) than the number of completed projects (254 thous.m^2). The time delay is in every implementation step, e.g. approval of documentation, search for co-financing, procurement of construction companies and implementation of the construction works (Fig. 3). The trend of both the projects in progress (1,532 thous.m^2) and the completed projects (333.8 thous.m^2; both including 80 thous.m^2 insulated before 2009) from model simulation match the historical data.

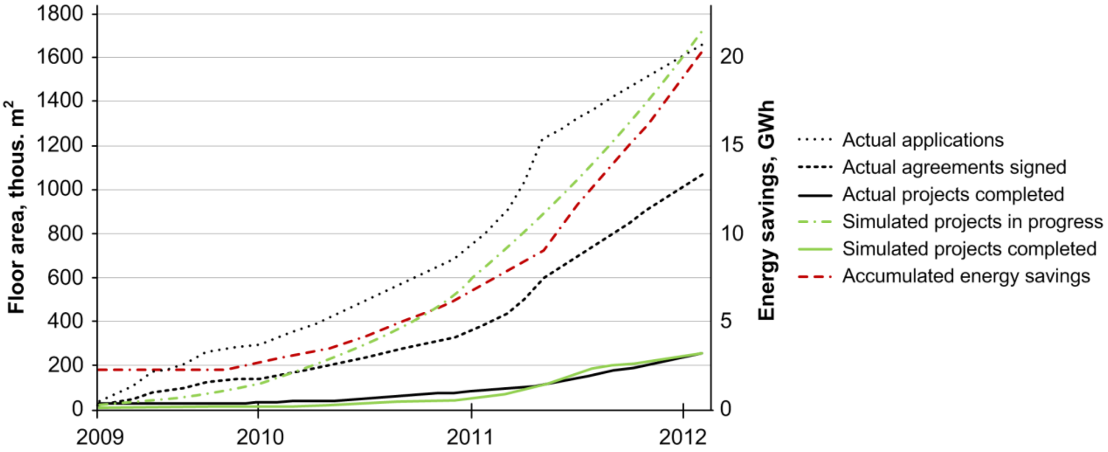

Figure 3: Dynamics of project application and implementation for subsidy scheme "Improvement of energy performance of multi-family buildings" in housing sector from April, 2009 to February, 2012 (EMAP, 2012; Valantis, 2010; Galinska, 2011; IDAL, 2012)

The distribution of market share among construction companies and ESCOs are shown in Figure 4. The construction companies strongly dominate market while ESCOs are increasing their pace at lower rate. The trend of simulated data for project development of both ESCOs and construction companies match the historical data.

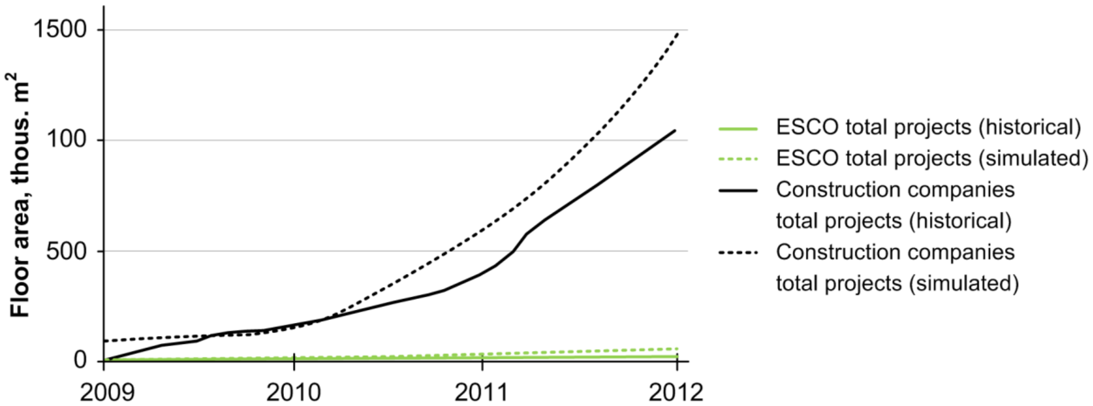

Figure 4: Simulation results for the total projects implemented by ESCOs and construction companies for 2009-2012 (IDAL, 2012)

The major cause of delay between the signed and the implemented projects is lack of capacity of construction companies that cannot follow the demand driven by reinforcing energy efficiency policy. Figure 6 illustrates that capacity of construction companies is higher than demand in the first years and then the demand surpasses capacity and increases at much faster rate than the capacity. This situation can be seen in real life when the capacity of both construction companies and the construction material suppliers cannot bear the demand (Lukss, 2010; Kupčs and Kudrjavceva, 2012).

The simulation shows that with the energy efficiency policy being implemented during 2009 and 2012 energy consumption of residential sector decreases from 10.79 GWh per year in 2009 to 10.77 GWh per year in 2012 and accumulated energy savings during this period reach 27.8 GWh. This figure is based on the assumption that average savings per project are 46%. This figure has to be verified as soon as monitoring results from the implemented projects are published by IDAL because of the rebound and other effects.

As the validation indicated that model is valid, the simulation time has been extended to year 2020 to simulate whether the LEEAP goal can be achieved by 2016 and to see longer term effects. The subsidy scheme will be over in the middle of 2012 and it is assumed that only minor energy efficiency policy tools are employed after 2012, e.g., small scale information campaign. This is translated into model structure as the time to initiate projects is 3 years, champions initiate 10 % from the total number of projects, time to perceive net benefits and uncertainty costs as well as construction costs is 3 years, small scale information dissemination activities are implemented, and energy tariff growth rate is 3% a year.

Figure 5 shows simulation results of both the total completed and the projects in process. The diffusion process follows S-shape growth, but it slows down because of lack of reinforcing policy tools after 2012.

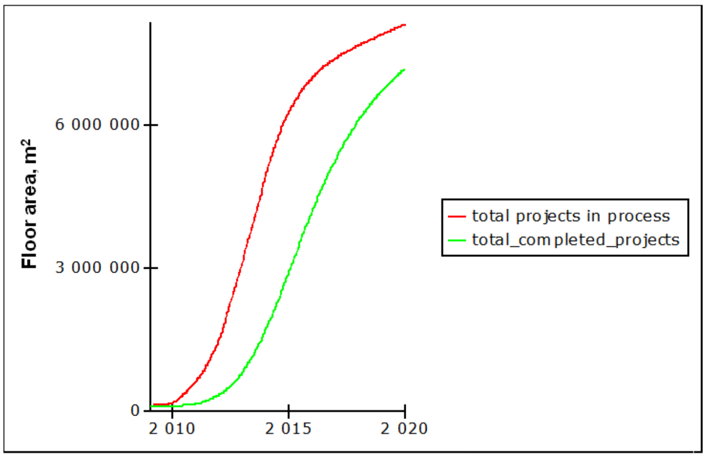

Figure 5: Simulation results for total completed projects and total projects in process by 2020

Figure 6 depicts that demand and supply for construction companies changes after subsidy scheme is over in 2012. Demand falls radically from 6.5 million m^2 to 2.3 million m^2 reaching the capacity of construction companies and decreasing below it leaving the construction companies with overcapacity.

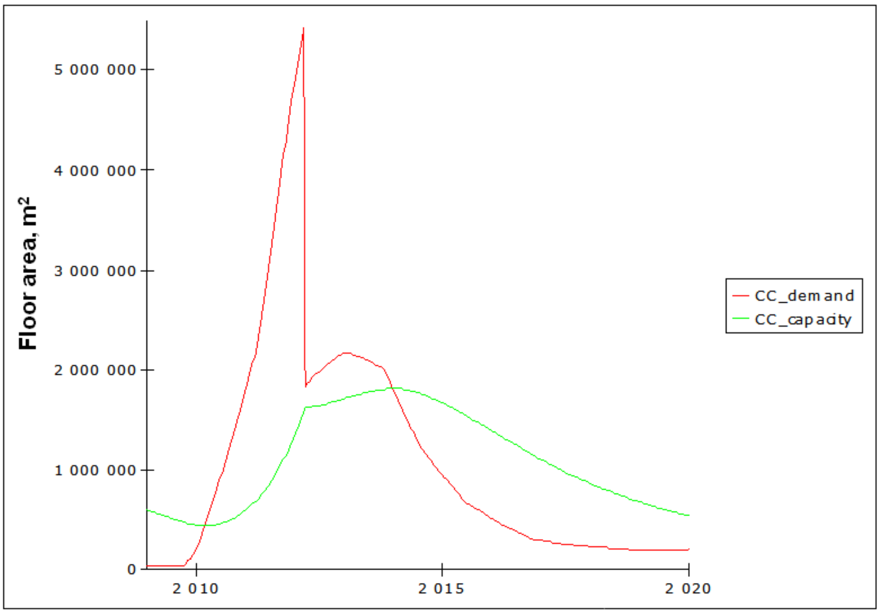

Figure 6: Simulation results for demand and capacity of construction companies between 2009 and 2020

Total energy consumption decreases from 10.8 GWh per year to 10.2 GWh per year by 2020 which is equivalent to accumulated energy savings of 597 GWh. The simulation shows that 348 GWh of savings or 12.9% of the overall goal of Latvia's EEAP will be accumulated by 2016.

6 Conclusions

Activities needed to reinforce sustainable energy consumption in the residential sector were discussed in this paper. The model for Latvian housing sector was built before historical data about energy efficiency subsidy scheme and complementary policy tools were available. The data available from IDAL were used to test the model for period between 2009 and 2012 in this paper. The validation tests provide support for the structure and behavior of the model. Results reveal close agreement between the historical and simulated values, which suggests that this model is valid.

While the model was used to simulate the short term events between 2009 and 2012, its main purpose is to determine the long term development of the studied system considering delays, non-linearity and feedbacks. As simulation results reveal, when the subsidy scheme ends, the diffusion process slows down unless additional policy measures are taken. The structure of the studied system dynamics model reveals that residential energy efficiency market is socially embedded and socially constructed.

The model presented in this and previous papers is to be used as the tool that can be adapted and tailored to specific social, economical and environmental conditions of other countries and residential energy consumption sectors.

The results of this study agree with the previously published work (Blumberga, 2012) and indicate that savings reported in Latvia's second EEAP are not generated by technological improvement of energy efficiency measures but have to be attributed to reduced demand for energy services through reduction of comfort requirements caused by economic downturn.

Results also agree with the other study (Blumberga et al., 2011) showing that LEEAP goal cannot be achieved by the year 2016.

In the research presented in this article the data that are available after two years of operation of subsidy scheme are used. The further research will continue to elucidate verification of model based upon the energy consumption monitoring data as soon as they become available. Improvements and adjustments will be made in the model for different effects, such as rebound effect, structural effects etc. This, in turn, can bring about improvements in energy policy planning.

Project: No.2DP/2.1.1.2.0/10/APIA/VIAA/003

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