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Government and municipality owned building energy efficiency system dynamics modelling

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Abstract

The paper describes the government and municipalities’ buildings, policy instruments and financial feasibility analysis, created system dynamics model and use of parameters to change the behaviour of the system. The aim of this research is to outline the dynamics under the market of energy efficiency in both municipality and state owned buildings. A system dynamics approach has been used to show short and medium term impact on municipal and government owned building energy efficiency and the changes which are made by using policy instruments. By the year 2016 the estimated savings set in Latvian energy efficiency action plans will not be reached but by 2020, these goals will be achieved.

Keywords: energy efficiency; government and municipalities; system dynamics modelling

1. Introduction and background information

The largest energy efficiency potential in the world is in the building sector that takes around 40% from all the energy balance. Most buildings were built in a time when energy saving was not topical, materials were not improved as they are now, there were no plans for saving energy and the primary energy resources were cheap. Nowadays the progressive renovation of these buildings is one of the most significant energy efficiency policy areas. Within the Latvian Energy Development Guidelines 2007–2016 [1], the aim for the public sector is to reduce specific energy consumption in its buildings up to 150 kWh/m², however the total energy consumption goal by the

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The general aim of this research is to outline the dynamics under the market of energy efficiency in both municipality and state owned buildings. The paper describes the influence of various policy tools for transition from the current state to the case when the energy efficiency targets are met. Within the study, a system dynamics-based integrated modelling framework is applied. It is used for comprehensive planning and continuing impact assessment to construct a dynamic mathematical model. The chosen methodology enables to obtain interactions between cause and effect in complex and dynamic systems that have delays, feedbacks and non-linearities, thus enabling to examine interactions between market actors both in terms of short and long term effects of decisions that are made.

An increase in the magnitude of carbon emissions can affect climate change negatively. For this reason, the United Nations established the Framework Convention on Climate Change that encourages countries to deal with global warming. The Kyoto protocol was added few years later as an instrument to reduce greenhouse gas emissions. Latvia needed to lower emissions by at least 8% which it did and the rest of the units which Latvia decreased on top of the target which was set for the country, could be sold. As a result of this action, a Climate Change Financial Instrument (CCFI) was established in Latvia [3, 4].

The European Commission developed the Europe climate and energy policy package (20-20-20) which set the goals to be met by 2020 for carbon emission reduction at 20%, 20% improvement in energy process and 20% primary energy sources replacement with renewable energy sources compared with 1990 data. [5]

Energy efficiency is one of the main priorities for the European Union (EU) in the energy field. The Directive 2010/31/EU on the energy performance of buildings is approved to regulate building energy efficiency changes and improvements. The main goal is the medium or low energy consumption buildings heating, ventilation system project and construction energy consumption rational usage. From 2007 until 2016, the goal for specific energy consumption in the buildings from 220–250 kWh/m²/year needs to drop to 195 kWh/m²/year and by 2020 – to 150 kWh/m²/year. The first report shows that in 2009, the data with climate correction is 202 kWh/m² but in 2011 the indicator is lower – 200 kWh/m². [2]

The first energy efficiency action plan for the 2008–2010 period, the second energy efficiency action plan for the 2011–2012 and country energy efficiency action plan for the 2014–2016 are the most important planning documents to stimulate increase of energy efficiency in Latvia. These plans show the main activities that need to be implemented to reach the planned energy savings. The trend for energy savings is growing and by 2020, the savings in all sectors in Latvia are estimated at 6050 GWh as illustrated in Figure 1. [2, 6] The second largest planned energy savings are in the tertiary sector – second to households. Documents are based more on energy efficiency improvement actions in households.

After 2010, high impact is on government and municipality owned buildings because of the EU Directive on the energy performance of buildings – it need to be as an example for households and to make buildings more energy efficient. The Directive 2012/27/EU on energy efficiency sets a specific goal for countries - there needs to be an improvement in building insulation proportion every year by 3% in administrative buildings starting from the year 2014.

Fig. 1. Estimated energy savings in first and second Latvian energy action plans.
In Norway, researchers believe that subsidies and economic instruments as the only activities will not help to reach EU targets by 2020. They consider that decision makers at all levels from the EU to local municipalities need to make changes and take part in energy efficiency measures. Research conducted on the technological progress and development of building energy efficiency can better affect strategically based decisions in public buildings. [7]

2. Methodology

Research in Sweden about EU building energy savings in household and tertiary sectors was modelled using a bottom-up technique. The aim of the research was to find out ways how to implement the climate and energy package by 2020 and reach low carbon economy in six EU countries. [8]

In this research system dynamics modelling was applied. System dynamics is a complex research method which can be used to help solve complex problems. The theory is based on a study between system behaviour and the structure of the base of that behaviour [9]. Applications of system dynamics for modelling of energy related and environmental processes as well as economic and social considerations significant for operation of the models are described in details in [9–13].

System dynamic model analysis on the energy efficiency of government and municipally owned buildings is done for the time from 2009 to 2050. The model, which is illustrated in Figure 2, consists of four main blocks – insulation sub-model, the total benefits sub-model, construction companies’ capacity and financing sub-model and policy instruments.

![Fig. 2. Main parts of the model.](image)

The insulation sub-model is set up to specify the shift from an unheated area to insulated area in phases in order to understand the whole process of the structure. Each step is important and it leads to the more accurate measurement of unheated areas change over time. The model assumes that there is only one outgoing flow from the stock which is affected by construction companies, therefore the energy saving companies are not taken into account.

The decision making process and the preparation of technical documentation time is the flow that connects stocks – unheated area and potential projects. At this moment, the authorities have decided that the building needs insulation and are preparing application documents for external funding. Next comes the stock funded projects with inflow project financing acceptance rate. Once the project is accepted the flow continues as project start-up rate affecting the stock ongoing projects. The last flow is insulation rate that fills the stock insulated area. The stock unheated area ($A_{unh}$, m$^2$) is 9628066 m$^2$, according to the Ministry of Economics information report [14].

The basis of the model is the decision making time flow expressed by the formula:

$$T_{dec} = \frac{f(T_{ES} > 0, \frac{f(TB > 0, c_{la} > 0) A_{unh}}{T_{doc}}, W_F)}{T_{dec}},$$  \hspace{1cm} (1)

where $T_{dec}$ – time for decision making, m$^2$/year; $F_{ES}$ – EU funding, EUR; $TB$ – total benefits, EUR/m$^2$/year; $A_{unh}$ – unheated area, m$^2$; $c_{la}$ – local activity, coefficient; $T_{doc}$ – technical documentation preparation rate, m$^2$/year; $W_F$ – government and municipality willingness to finance the entire project, m$^2$/year.
Only 9% of all the local and municipally owned buildings have applied for funding under the CCFI and EU funds, according to publicly available information about implemented projects. This value is used to understand local authorities' decision on the need for thermal insulation, when there is opportunity to receive a subsidy from external funds. The activity is a ratio that expresses the government and municipally capacity to write a project proposal and the ability to get funding for the project [15, 16]. The coefficient of local activity can be determined by dividing the project application preparation capacity of municipalities with the stock unheated area.

Project preparation capacity growth rate is determined by multiplying the municipalities' project preparation capacity and the adjustment coefficient. A lot of information seminars are organized yearly to educate and train stuff for preparing projects. This flow is affected by adjustment coefficient that is 0.018 [15, 16]. If external financial instruments are not spent, this value corresponds to the activity rate of local project submissions. The value of the stock is 144 000 m²/year, according to the average CCFI and ERDF completed projects.

Stock government and municipality willingness to finance the entire project is a parameter that expresses how many m² per year all Latvian authorities want to insulate fully investing their own money and excluding projects with external funding. This parameter is triggered when all the available external funding is exhausted. The stock inflow desire growth rate affects the value of the stock and the perceived benefit from the insulation rate. Flow is calculated as local willingness to fund the entire project multiplied by perceived benefit from the insulation rate. Authorities wish to finance all projects are estimated to be 30 800 m² and initially corresponds to 22 buildings with an average area of 1 400 m². The perceived benefit graphically determines the deviation by how much the willingness of municipalities to finance an entire project changes. If the perceived benefits are higher than 50 EUR/m², the coefficient increases by approximately 6%.

The stock funded projects is dependent on inflow project financing acceptance rate that is calculated as potential projects divided by project handling time. The stock potential projects value is 0 m² and project processing time is 0.5 years [15, 16]. The stock ongoing projects that has a start value of 0 m² and depends on flow project start-up rate that is expressed as ongoing projects divided by financing acquisition time. Financing acquisition time is 0.25 years - the duration of the submission of the draft, expect results and a signed contract [15, 16]. The stock insulated area that has a start value of 0 m² depends on the flow insulation pace that is expressed as an insulated area divided by construction duration. Construction duration is 2 years.

The total benefit sub-model is formed from the heating tariff and its’ changes. Tariff start value is 58.17 EUR/MWh [15] and affects both insulated and unheated building energy costs. Tariff change coefficient is calculated as the average value of the heat tariff from 2009 till 2013 and the value of this coefficient is 0.029 [15]. Energy consumption costs are calculated as insulated buildings energy consumption multiplied by the tariff. The average energy consumption before and after energy efficiency measures are sequentially 202 and 100 kWh/m² [1, 15, 16]. Total energy cost saving is the difference between the energy consumption costs.

The total benefit is the amount of money that can be saved through energy efficiency measures and is calculated by the following formula:

\[
TB = TB_{\text{energy}} - \frac{EX_{\text{ins}}}{T_{\text{life}}},
\]

where \(TB\) – total benefits EUR/m²/year; \(TB_{\text{energy}}\) – total savings on energy costs of EUR/m²/year; \(EX_{\text{ins}}\) – insulation costs EUR/m²; \(T_{\text{life}}\) – the lifetime of energy-efficiency measures, years;

Insulated and unheated building's energy consumption can be calculated as area multiplied by the energy consumption, kWh.

The financing sub-model shows the implementation of external funding in the model. There are 442 buildings whose energy efficiency have been improved from 2009 till 2014 using CCFI and spent 85.7 mEUR. During this period, 92 buildings received funding from the European Union Regional Development Fund and the Cohesion Funds given to social residential buildings [15, 16].

Each fund consists of two stocks – spent and available finances. Stock available funds, which is allocated for the energy efficiency of buildings to public authorities consists of European Union funding of the 2009–2020 147.9
mEUR and Climate Change Financial Instrument funds state and local energy efficiency of buildings 85.7 mEUR. The stock spent finances is 0 EUR and when project is finished all the money from the stock available funds will be transferred to spent finances. Stock linking flow is affected by the project acceptance rate, insulation costs and subsidy ratio [17, 18].

The CCFI flow “CCFI funding” is given by the formula:

$$T_{CCFI} = I(F_{CCFI} > 0, \text{T}_{ake} \cdot EX_{ins} \cdot C_{CCFI}, 0),$$

where $$T_{CCFI}$$ – CCFI financial flow, EUR/year; $$F_{CCFI}$$ – CCFI available finances, EUR; $$\text{T}_{ake}$$ – project financing acceptance rate, m²/year; $$EX_{ins}$$ – insulation costs, EUR/m²; $$C_{CCFI}$$ – subsidy ratio, coefficient.

The subsidy ratio of CCFI in the 2009 for government and municipalities’ buildings is 85 % [15, 16]. EU funds flow is calculated analogically as CCFI financial flow.

European Structural Funds cover 75 % of the total costs of the project. In the period of 2014–2020, EU funds will support 85 % of the costs for energy efficiency projects in public buildings.

Construction company capacity correlates with the demand from the municipalities – the more insulation projects are required, the more experience the companies have thus increasing the capacity. These values are affected by delays. The stock insulation costs impacts completed projects, the construction company expenses and construction company capacity.

Inexperienced company capacity growth rate is affected by demand. Inexperienced company capacity is the volume that can be insulated in one year and is expressed by m²/year. Since the flow depends on the company capacity and demand, a situation where the companies are insulating buildings more than the demand is improbable because the construction companies would suffer losses. When the demand is greater than the capacity in order to achieve market equilibrium, the construction companies will invest in additional resources to meet the demand.

Company capacity delay is a constant value, which characterizes the market response time to demand changes. This value is 2 years. The stocks inexperienced and experienced company capacity are connected by flow the company experiences growth rate. It is expressed as a company expertise, which increases the capacity of the company experience over the years therefore the total capacity increases. Flow is calculated by dividing inexperienced company capacity with experience increase over time.

The total capacity is formed by summing the stock inexperienced company capacity and experienced company capacity and affect the flow capacity growth rate. At the beginning, both inexperienced and experienced company capacities are 300 000 m². [2]

Capacity sufficiency or company capacity and demand ratio and the average capacity sufficiency are designed as functions, which contribute to the first level delay. These values directly affect the indicated price therefore makes an impact on the total costs of insulation.

$$C_{CA} = \frac{CA_{In, C}}{DELAYINF(1f, D; 3)}$$

where $$C_{CA}$$ – capacity sufficiency of construction companies, coefficient; $$CA_{In, C}$$ – inexperienced company capacity, m²/year; 1f, D – if demand, m²/year.

$$C_{avg} = DELAYINF(C_{CA}; 1),$$

where $$C_{avg}$$ – average capacity sufficiency, coefficient; $$C_{CA}$$ – capacity sufficiency of construction companies, coefficient.

The indicated price is a complex variable, which is affected by the capacity sufficiency effect, stock construction company perceived costs, the construction companies profit and additional costs. Indicated price is the payment for the construction company to perform the service. Indicated prices can be calculated as:
\[ P_{EX} = EX_{u2tv} + EX_{per} \cdot c_p \cdot E_{KA} + EX_{u2tv} \cdot c_{ac}, \] 

(6)

where \( P_{EX} \) – indicated price EUR/m²; \( EX_{per} \) – construction company perceived costs EUR/m²; \( c_p \) – profit, coefficient; \( E_{KA} \) – capacity sufficiency effect, coefficient; \( c_{ac} \) – additional cost, coefficient.

Profit expresses the amount of money the company has provided for the construction of the insulation measures. In this model this value is 0.2. This value may vary and construction companies can determine the situation in the insulation market. If demand is low then earnings should decrease in order to decrease the overall costs and increase demand. On the other hand, if demand is high, construction companies can maintain a high price. Additional costs are unexpected expenses that arise during construction. It is assumed that these costs are 0. A simulation with different values was carried out to see the impact on total costs. Stock construction perceived costs is the total cost of 1 m² with a start value of 140 EUR/m² that depends on the flow changes in perception. Incoming flow is the difference between construction companies perceived costs and expenses divided by perception years. Perception time is a value that describes construction companies’ expenses perception time and it is one year therefore there are yearly changes in construction companies perceived costs. With the growth of insulated buildings, the proportion of completed projects increases.

The flow insulation cost rate changes affect the stock insulation costs. The start value of the stock is 142 EUR/m², which is estimated in the EU funds planning documents. The relative insulated area increase makes company capacity growth and will reduce unexpected costs because of learning from their mistakes. As a result they can reduce insulation costs. [18]

The relationship is described by the formula:

\[ T_{EX} = \frac{(c_{iz} - EX_{beg})}{T_{ins}}, \] 

(7)

where \( T_{EX} \) - insulation cost rate changes, EUR/m²/year; \( P_{EX} \)-indicated price EUR/m²; \( EX_{beg} \) - insulation cost start value EUR/m²; \( T_{ins} \) - insulation cost changes time, years.

After the main model was built, the policy instruments were implemented into the model. The author chose 5 – support for science and research, CO₂ tax implementation, increasing regulatory requirements, penalties implementation and increasing funding. For example, CO₂ tax implementation is used as a constant value that is added to the tariff. 0 EUR/MWh and 1 EUR/MWh was used for the main model and this difference can help to save 300 GWh by 2050.

There are no wide studies and analysis about system dynamics models for building energy efficiency till now. There are different researches using bottom-up and top down methodology, which is offered in scientific databases.

3. Validation of the model

Testing and validation of the model is an important part of the research. All the parameter units, their connections and input formulas have been tested. Also the verification tests, sensibility test, parameter verification test, extreme policy and extreme condition tests were made. Interviews with the Liepaja municipality administrative personnel were made and data collected from 2009 till 2013. There are three buildings left in Liepaja where there have not been any energy efficient activities before now. In 2014, this area constitutes 10 676.9 m² and the specific heating energy is lower than in the country – 163 kWh/m². In the area where any energy efficiency activities have been implemented this parameter is lower than average – 93 kWh/m².

There are municipalities in Latvia that have enough information and knowledge to write building energy efficiency project proposals. Other municipalities do not know how to prepare such proposals to reach the advisable goals or they do not have the human resources to do so. For this reason there is a necessity to instruct staff who work in municipalities on building energy efficiency project development about available grants, documentation preparation and project management. Our study of Liepaja municipality shows that total energy consumption can
reach around 15 GWh per year by 2020. To make this parameter lower, the municipality has to make long term plans and implement low energy consumption buildings.

Fig. 3. Total energy consumption till 2020 in Liepaja municipality

4. Results

The findings of this study show that CO₂ tax policy implementation reaches the best results in increasing the proportion of buildings to reach energy efficiency – 88 % of the total goal by 2016. Simulations show it is not possible to reach the goal of 408 GWh by 2016 but it is possible to experience considerable growth and achieve 80 % more than expected by 2020. Table 1 lists the more precise values of results by 2016 and by 2020.

Table 1. Policy instrument influence on energy efficiency action plan estimated savings

<table>
<thead>
<tr>
<th>Policy</th>
<th>Energy consumption savings 2016 (GWh)</th>
<th>Energy consumption savings from estimated (%)</th>
<th>Energy consumption savings 2020 (GWh)</th>
<th>Energy consumption savings from estimated (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No policy instruments used</td>
<td>318.9</td>
<td>78.2</td>
<td>1048.09</td>
<td>159.5</td>
</tr>
<tr>
<td>Support for science and research</td>
<td>318.94</td>
<td>78.2</td>
<td>1050.48</td>
<td>159.9</td>
</tr>
<tr>
<td>CO₂ tax implementation</td>
<td>359.73</td>
<td>88.2</td>
<td>1182.23</td>
<td>179.9</td>
</tr>
<tr>
<td>Increasing regulatory requirements</td>
<td>318.9</td>
<td>78.2</td>
<td>1048.09</td>
<td>159.5</td>
</tr>
<tr>
<td>Penalties implementation</td>
<td>318.9</td>
<td>78.2</td>
<td>1048.69</td>
<td>159.6</td>
</tr>
<tr>
<td>Increasing funding’s</td>
<td>318.9</td>
<td>78.2</td>
<td>1089.2</td>
<td>165.8</td>
</tr>
<tr>
<td>All policy instruments</td>
<td>359.7</td>
<td>88.2</td>
<td>1228.48</td>
<td>187.0</td>
</tr>
<tr>
<td>Estimated energy savings (GWh)</td>
<td>408</td>
<td>657</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Regulatory requirements and support for science and research does not make any difference in the short-term but CO₂ tax is easier to implement and to gain much more impact in the medium to long-term as well. It is possible to reach the goals by 2020. The study shows that when all the external funds will be spent, there will be a dramatic drop in the desire of authorities to make buildings energy efficient. To make a change there is a need to show decision makers the financial impact that energy efficiency activities have. There is a need to conduct active monitoring on the country’s long-term planning documents in order to reach better results over the entire planning period. Total energy savings using all policy instruments could be around 1450 GWh by 2050. It is not enough to reach system saturation. This shift requires a larger pool of funding and CO₂ policy implementation. The requirements for building energy efficiency will be stricter and there is a need to promote low energy consumption.
buildings. It is necessary to conduct research about policy instruments and specific actions, which will be implemented in every municipality to reach estimated energy savings.

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References


