# Development of the Latvian energy sector system dynamic model

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# DEVELOPMENT OF THE LATVIAN ENERGY SECTOR SYSTEM DYNAMIC MODEL

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**Abstract**

One of the most pressing problems in the Latvian economy is related to the energy sector. The most characteristic feature is coupled with the low efficiency of thermal energy consumption of households as a result of poor insulation of existing buildings in Latvia. Solving energy sector problems requires a comprehensive decision, both in energy production and consumption. Latvian energy sector model consists of resources, production and consumption blocks. Resource blocks consist of primary energy resource blocks: petroleum products, solid fuel, wood and gas blocks. Primary energy resources are used for production of heat or electricity, they are shown in the production blocks. Both the primary and produced energy are passed on to final consumers, who make consumer unit blocks. It consists of: transport, agriculture, households and other (industrial and services sectors) blocks. The model key role is to forecast energy consumption by separate groups, both consumers and energy resources groups; to estimate energy sector impact on environment. The model has been developed to estimate the impact of buildings thermo insulation program on Latvian economy, the article reflects these results.

**Keywords**: **energy efficiency, consumption, system dynamic, modelling and simulation, building warming and renovation, the $CO_2$ emissions and quotas**

**Presenting Author's biography**

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## Introduction

One of the most pressing problems in the Latvian economy is related to the energy sector. Energy sector issues are topical throughout the world. The result of increased energy consumption causes problems of energy production increase and environmental pollution problems. Primary energy stocks are decreasing. Therefore, these problems are topical in all countries: everywhere there is a battle for energy-efficiency and efficient energy production. But each country has its own specific character of energy production and use. Latvia has specific features of both - energy production and consumption. Compared to other EU countries, Latvia has a large proportion of hydro resources for energy production; it is linked to national geographic characteristics. Comparing energy consumption, the most characteristic feature is coupled with the low efficiency of thermal energy consumption of households as a result of poor insulation of existing buildings in Latvia.

Solving energy sector problems requires a comprehensive decision, both in energy production and consumption. It is therefore necessary to develop energy sector model to be able to evaluate not only the energy consumption growth and the factors affecting it directly, but also the feedback caused by the increase of the efficiency growth. The most popular Latvian energy sector forecasts use time series forecasting or trend methods. Unfortunately, these methods take into account only historical trends, which may change in the future. The result of these methods is appropriate only for short-term prognosis (up to one and a half year). Regression methods have a better result and longer forecasting period. Regression methods make forecast based on realistic assessment of the factors and use statistically defined relationships. With time or with environmental changes, these relationships can change, which is not reflected by a regression method. The model shown in the article has been developed using system dynamic method. This method is chosen, taking into account the fact that approach allows to evaluate the causes of multi - effect relationships, including the feedback, regardless of operating conditions by adjusting the system behaviour to external changes.

Taking into account the topicality of the problem and the method chosen, the aim of the research is to develop Latvian energy sector system dynamic model. It sets the following tasks:

- to show model elements, to prove the model assumptions and economic relationship included in the model;
- to reflect the pattern of model activity on the example of key economic indicators .

Factors, analysed in the article, are limited to the Latvian economy. All other global factors, such as energy prices, climate changes, average temperature, are not researched.

The article has been developed in cooperation with the NPO "Construction strategic development partnership". After the NPO CSDP order, construction development system dynamic forecasting model was designed; energy efficiency program's for buildings impact on the Latvian economy was estimated. With the project material, work experience, Latvian energy sector system dynamic model was developed. The model allows to estimate the effects of the state program for increasing energy efficiency, to predict the Latvian energy sector development and its impact on the national economy.

## Latvian energy sector system dynamic model general scheme

Latvian energy sector model consists of various sub-models (blocks). The general scheme and relations of sub-models are shown in Fig. 1.

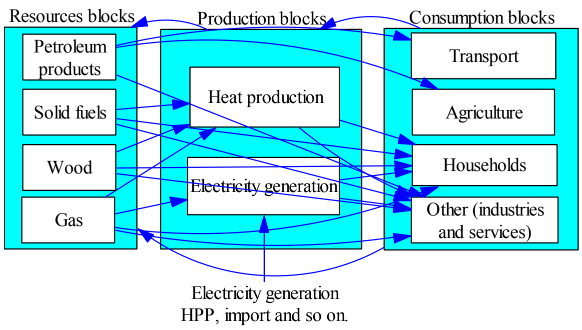


Fig. 1 Latvian energy sector system dynamic model general scheme

Fig. 1 shows that energy sector relations are extensive. Model blocks grouped into three categories: resources, production and consumption blocks. A separate place is taken by electricity generation hydroelectric power plants (HPP), net imports of electricity and so on. Resource blocks consist of primary energy resource blocks: petroleum products, solid fuel, wood and gas blocks. Primary energy resources are used for production of other energy forms, i.e. heat or electricity production, they are shown in the production blocks. Both the primary energy and produced energy (and electricity generated by HPP) are passed on to final consumers, who make consumer unit blocks. It consists of: transport, agriculture, households and other (industrial and services sectors) blocks.

The distribution pattern of the above-mentioned blocks is based on the specific character of the Latvian energy sector, which is dealt with in tables 1 and 2.

Tab. 1 The primary use of energy and energy sources in Latvia, thousands TOE [3]

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 |
|---|---|---|---|---|---|---|---|---|
| Petroleum products | 1174 | 1241 | 1169 | 1294 | 1358 | 1382 | 1479 | 1622 |
| Gas | 1092 | 1270 | 1291 | 1347 | 1332 | 1358 | 1407 | 1360 |
| Wood | 1191 | 1296 | 1259 | 1325 | 1459 | 1481 | 1434 | 1413 |
| Electricity net import | 154 | 162 | 202 | 226 | 180 | 185 | 216 | 258 |
| Electricity generation HPP | 239 | 243 | 210 | 193 | 262 | 282 | 229 | 232 |
| Solid fuels | 135 | 124 | 100 | 89 | 68 | 82 | 87 | 106 |
| Electricity production in wind turbines | 0,3 | 0,3 | 0,9 | 4,1 | 4,2 | 4,0 | 3,9 | 4,5 |
| **Total** | **3986** | **4336** | **4232** | **4478** | **4663** | **4774** | **4856** | **4996** |

Table 1 analyzes primary energy sources in Latvia. It is evident that petroleum products, gas and wood have the highest proportion of resource consumption. They generally make up 88% of all energy consumption in Latvian. Significantly lagging behind are the electricity imports and production by HPP, together constituting about 10%. Solid fuel consumption rate is statistically insignificant, but this fuel has a significant role in environmental pollution, $CO_2$ emissions. Consequently, for each fuel a separate sub-model was designed. In Latvia electricity production in wind turbines is so small that an individual sub-model was not designed here.

Electricity imports, production in HPP and wind turbines are combined into a single sub-model. Latvian energy consumption is analyzed in table 2.

Tab. 2 Final energy consumption in Latvia, thousands TOE [3]

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 |
|---|---|---|---|---|---|---|---|---|
| Households | 1 327 | 1 443 | 1 431 | 1 520 | 1 493 | 1 514 | 1 492 | 1 470 |
| Transport | 747 | 874 | 899 | 959 | 1 012 | 1 066 | 1 179 | 1 333 |
| Industries | 572 | 610 | 621 | 628 | 669 | 705 | 741 | 724 |
| Services | 463 | 489 | 530 | 559 | 589 | 588 | 630 | 679 |
| Agriculture | 129 | 135 | 128 | 146 | 155 | 152 | 154 | 155 |
| Other | 2 | 3 | 4 | 2 | 3 | 5 | 4 | 3 |
| **Total** | **3 240** | **3 554** | **3 613** | **3 814** | **3 921** | **4 030** | **4 200** | **4 364** |

Table 2 shows, that in Latvia the major final energy consumers are households and transport. Industries and services sectors lag behind by about 50%. Industrial and services sectors are combined into one sub-model because their energy consumption depends on one factor - economic development. Similarly, functioning of sectoral content is similar, for both industrial and service sectors. Agriculture and other sectors form statistically insignificant energy consumption. But taking into account agricultural sector's importance in Latvian economy, it is considered a separate consumer and for it a separate sub-model is designed, which, by content, is significantly different from other consumer sub-models.

In tables 1 and 2 energy consumption distribution by the types and by consumers is considered. It is evident that resources used are greater than consumption. This is understandable because a part of energy is lost in the distribution process, and in the process of transforming into another form of energy. Energy loss assessment does not require a separate sub-model, because energy loss is a specific feature of distribution and energy conversion process. Accordingly, energy loss could be discussed together with the energy conversion or production process. Production process reflected in the model is analyzed in two sub-blocks: heat production and electricity generation.

Previously all blocks of the model were analyzed. From fig.1 it is visible that some model blocks are inter-related, but some are not. Sub-models cross-correlations are identified with logical relations and with energy statistics in Latvia. Logical relations also are related to feedback. That is, from the final energy consumption it is possible to calculate how much energy it is necessary to produce. Taking into account the final energy consumption and energy necessary for production, it is possible to estimate total energy resource needs. Statistics of energy resource use are shown in table 3.

Tab. 3 Energy resource and energy use in Latvia, in 2007, %

| | Transformation | Households | Transport | Industries | Services | Agriculture | Total |
|---|---|---|---|---|---|---|---|
| Petroleum products | 2 | 2 | 81 | 6 | 3 | 7 | 100 |
| Gas | 61 | 8 | 0,1 | 21 | 9 | 1 | 100 |
| Electricity | - | 27 | 2 | 28 | 41 | 2 | 100 |
| Solid fuels | 11 | 18 | 0 | 48 | 22 | 1 | 100 |
| Wood | 14 | 63 | 0,2 | 10 | 11 | 1 | 100 |
| Heat | - | 74 | 0 | 2 | 24 | 0 | 100 |

It is clear that not all of the primary energy resources are consumed by each consumer. Equally, not each energy resource is used in transformation process. Table 3 shows that in Latvia for energy transformation mostly natural gas is used (61% of natural gas consumption in total). Solid fuel and wood are also used in energy conversion. It is important to note that the solid fuels and wood are used mainly for heat production, but natural gas also is used to generate electricity. Oil and petroleum products energy conversion rate is only 2%. This amount is close to the statistical error, from the author's point of view, it allows not to design a separate model. All other columns in table 3 reflect the final energy consumption.

The largest share of oil and petroleum product consumption is observed in the transport (81%); industry and agriculture lags behind significantly, by 6% and 7% respectively. Oil product consumption in other areas is insignificant and is close to the statistical error. Based on the ABC method it is appropriate to create petroleum product consumption models only for three major groups. Based on system dynamic principles it is appropriate to do so only in the case if all groups of consumption are different from each other; like it is in the group of petroleum products. Petroleum products consumption in transport is related to the amount of vehicles and intensity of their use; in industry it is related to the development of national industries; but in agriculture to the land use and type of work. A more detailed analysis of these factors will be presented later. It is important to note that the above mentioned distribution of energy use could be applied not only to prediction of resource consumption, but also to pollution evaluation. So, for example, oil consumption growth in transport will result in almost directly proportional increase of $CO_2$ emissions, but in contrast, oil consumption growth in industry does not give any result (because the model assumes that oil in industry is processed into other chemicals and products without significant $CO_2$ emissions).

As mentioned above, the largest natural gas consumption is associated with conversion into other energy kind. Also gas is used in industries (chemicals and pharmaceuticals), services and for household needs. These same four consumers use also solid fuel and wood. In transport and agricultural areas, these types of resources are not used. It is important to note that despite the statistical data, the author does not explain why and where in the transport sector wood is used as fuel. Taking into account statistically minor amount of separate data, the author has simply eliminated them. At the same time the roughly planned approach can significantly improve the predictive quality of the Latvian energy sector.

Electricity consumption in Latvia is mostly related to the service sector, industry and households. Heat is consumed only in households and service sector.

This sub-chapter has discussed the general scheme of the Latvian energy sector system dynamic model. Further separate sub-models are discussed in detail.

## Energy recourses sub-models

As mentioned above, the energy group consists of four sub-models (petroleum products, gas, solid fuels and wood). Taking into account that resource consumption sub-models are similar, it is useful to show only one of them. Figure 2 shows a gas consumption sub-model, on the basis of which also all other resources are analyzed.

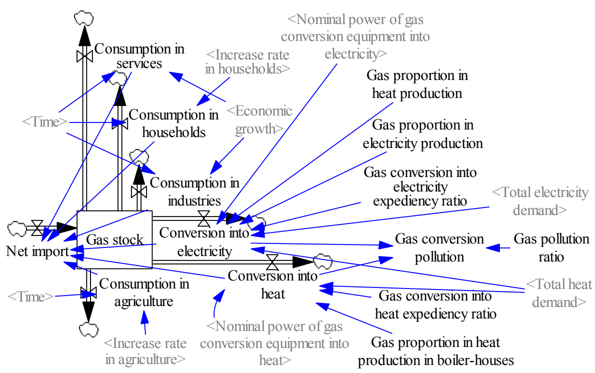

Fig. 2 Gas consumer sub-model

Fig. 2 shows that gas resource turnover is dependent on net gas import, gas consumption in the service sector, households, industrial use, agriculture and production of heat and electricity. "Gas stocks" represent incoming and outgoing flow balance. The model implies that imports are equal to aggregate consumption. In fact, import and consumption could fluctuate slightly.

Fig. 2 shows a versatile model. Some flows are useless in gas consumption sub-model, but they are presented to explain other sub-models of resources. So, for example, it was previously determined that the gas consumption in agriculture is negligible, so it may not be a separate flow. This example indicates that gas consumption in agriculture is dependent on time and growth rate in agriculture, which is estimated in related agricultural sub-model. The same way as in oil and petroleum consumption sub-model, oil consumption in transport is dependent on transport, which is estimated in transport sub-model. Energy resource import flow could be supplemented by internal production flow, for example, wood fuel.

Energy consumption in industrial and services sectors depends on the overall economic situation development (economic growth). Therefore, they have similar consumption models. But they are not merged into one, because as it was mentioned before, in industry energy recourses are transformed into other chemicals and products without significant $CO_2$ emissions. This distinction could be applied later for assessing environmental pollution.

Energy consumption in households is not dependent on the economic situation, but depends on the number of households, or on population. Household consumption growth is calculated in a separate sub-model.

Next resource consumption flow is associated with primary energy recourses conversion into thermal and electrical energy. Gas consumption sub-model is chosen as an example of the model, because from primary energy recourses gas is used for both heat and electric energy production in Latvia. Other primary energy recourses are almost not used for electricity generation, but for heat production.

Fig. 2 shows that the gas consumption for thermal energy production depends on the heat demand, the total capacity of gas boiler houses (both taken from the related sub-models), efficiency ratio and the proportion of gas boiler houses in heat production. Efficiency ratio is a technical factor, which does not depend on any relationship. In long-term the proportion of gas boiler houses is a variable factor, but in short periods it does not change, so in the study it is taken as fixed. This assumption has also been associated with the model design goals, and targeted funding, to show heat energy demand, regardless of its source. Therefore, if there is funding to continue research and develop a model, this ratio might be replaced by system dynamic relationship.

Gas use for electricity production is similar to the heat sub-model. The difference lies in the fact that gas power plants produce both electricity and heat. Fig. 2 displays that gas conversion into electricity in addition depends on both gas proportion in electricity generation and proportion in heat production.

Also resources sub-model shows pollution of gas conversion, which depends on gas consumption and pollution ratio. Pollution ratio is a technical factor which depends on energy recourse and type of conversion process, and it cannot be described with the help of system dynamic instruments.

Above natural gas example described an energy resource sub-model. Creating four primary fuel (petroleum products, gas, solid fuels and wood) sub-models, it is possible to create a general Latvian primary energy consumption model.

## Energy conversion sub-models

Energy conversion model considers electricity and heat production from primary energy resources. According to four kinds of primary energy resources it is possible to create four heat production sub-models and one electricity production sub-model (gas based). All of these sub-models would be similar, with a slight difference of gas sub-model, in which not only electricity is generated, but also heat produced. Consequently, from sub-models be viewed only one, cogeneration of electricity and heat production based on natural gas.

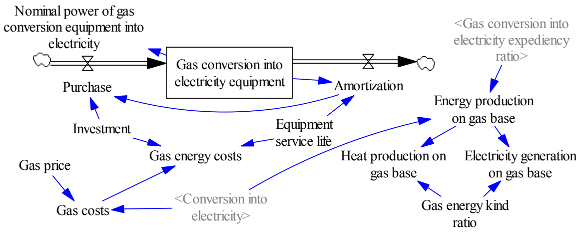


Fig. 3 Conventional thermal power plants sub-model

As shown in Fig. 3 production facilities have the key role in the process of cogeneration. Statistical sources present information about the amount and capacity of boiler houses and CHP plants. Energy production is balanced with equipment capacities. It is not possible to produce more energy than capacity allows. Fig. 3 reflects equipment analysis system, which consists of two flows: amortization and purchasing. Amortization of equipment depends on its intended lifetime.

Purchase of equipment depends on amortization and investment. It is evident that investment determines the purchased volume of equipment, but amortization shows to what extent the equipment should be restored, not to decrease energy output.

Investment, together with resource amount and cost define energy production price, which is another important parameter, which the model allows to forecast.

Energy created in the cogeneration process is divided into two types: thermal and electrical energy (Fig.3). This distribution is based on a fixed ratio, which was developed in accordance with the technological process. Distribution is only suitable for cogeneration process; boiler houses produce only one energy form-heat.

Energy conversion sub-models are not difficult and their review is completed, further consumption sub-models are discussed.

## Energy consumption sub-models

If above-described model groups have similar models, consumption sub-models are significantly different from each other. Therefore, it is necessary to view each of them. Fig. 4 shows transport energy resources consumption sub-model.

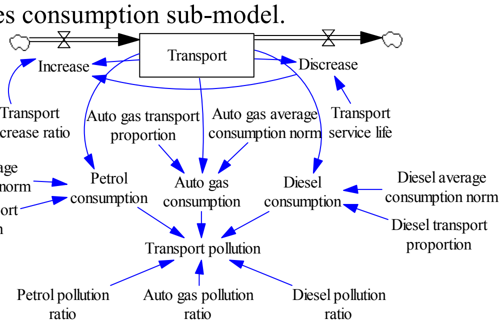


Fig. 4 Transport energy resources consumption sub-model

As shown in Fig. 4, in transport energy resources consumption sub-model the key role is played by the number of transport. Decrease of the number of transport depends on its lifetime, but increase on the increase coefficient.

Based on statistical data means of transport are divided into petrol, diesel and auto gas transport. For each group energy (fuel) consumption is estimated separately, according to them it is possible to calculate impact on transport pollution.

Next energy consumption sub-model is related to agricultural sector, and it is shown in Fig. 5.

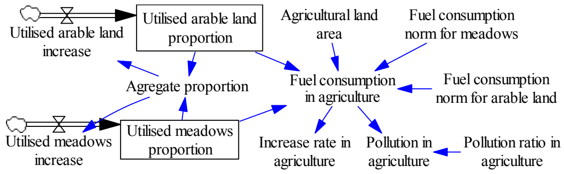


Fig. 5 Agriculture energy resources consumption sub-model

Main assumptions in agriculture energy resources consumption sub-model are related to specifics of the sector. The more utilised land, the more energy is being consumed by the agricultural sector. It is necessary to stress that the land cannot increase, that is why energy consumption in agricultural sector is limited. If we are talking about a highly developed country, which uses its resources fully and rationally, then energy consumption in agriculture is not growing. But, with the increase of efficiency, it is decreasing.

In Latvia unused agricultural land proportion in 2008 was 23% (in 2000 - 29%). Despite the reduction in the proportion of unused land, energy consumption in Latvia is not growing, because previously unused land is used now not as arable land or meadows, but as forests. That is why the developed agriculture energy resources consumption sub-model has only theoretical significance, which may indicate how agricultural sector development could affect energy consumption in Latvia.

The model shows that knowing the area of agricultural land, distribution between arable land and meadows, as well as fuel consumption norms, total fuel consumption in agriculture can be calculated. Based on fuel consumption, $CO_2$ emissions in agricultural sector can be calculated. The model shows that with economic development both utilised arable land and meadows proportion in agricultural land grow.

Household energy consumption sub-model is reflected in Fig. 6.

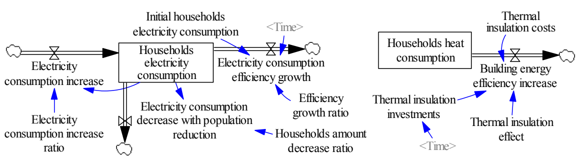


Fig. 6 Household energy resources consumption sub-model

Household energy consumption sub-model is divided into two parts, according to energy forms, electricity and heat. Taking into account that this article reflects the first version of sub-model, which is not much detailed, it is important to note that developing sub-model it would be good to supplement it with a gas consumption part. Because, as it was specified in table 3, households consume not only finished energy but also primary energy recourses, such as gas. As to solid fuels and wood fuel, households use them for heat production. To analyze the volume of their consumption a simple model can be applied, but gas consumption is associated with both heat production and use in cooking. Consequently, household gas consumption forecast in complex. In this article it has not been done because of low gas consumption role in households sector.

Households electric energy consumption is influenced by the increase of technical progress, well being level increase and reductions, associated with efficiency growth and population reduction. Parameters such as population reduction can be predicted easily, but for forecasting other parameters (one of them may be related to the increase of energy efficient light bulbs usage and its impact on electricity consumption in Latvia) separate researches are need. In the model for forecasting these parameters fixed growth rates are used.

Household heat consumption is dependent on the number of population and characteristics of residential houses. Daily households use hot water for their needs, and its forecast does not cause problems. Heat consumption for residential buildings is not dependent on the number of population, the amount of households or any other parameters. Heat consumption would not change significantly, even if some apartments in multi-storey buildings are not inhabited. Consequently, heat consumption for residential buildings can be taken as a fixed indicator, associated only with technical characteristics of buildings. In April 2009 energy efficiency increase program of buildings started in Latvia, which can change technical characteristics of buildings. Forecasting model of these changes is shown in Fig. 6.

Energy efficiency of buildings is related to their thermal insulation. Sub-model evaluates insulation costs, investments and its effect.

## Model practical use. Conclusions

In practical application of the model it is important to note that its key role is to forecast energy consumption by separate groups, both consumers and energy resources groups; to estimate energy sector impact on environment. Taking into account that the model has been developed to estimate the impact of buildings thermo insulation program on Latvian economy, the article reflects these results (Fig.7).

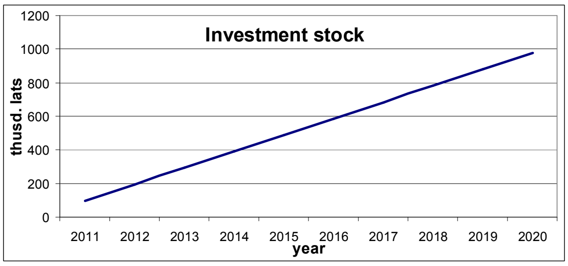


Fig. 7 Investment formed by result of thermo-insulation program

Investment is calculated as income from sale of $CO_2$ emissions, which will be unused after implementation of thermo insulation program, provided that in 2010 buildings insulation program would be fully realized using funds accumulated in past years from sales of $CO_2$ emissions and emissions selling price would be 15 Euro / emission. Despite the low impact of thermo insulation program on the economy, it has an important role in energy conservation and environmental improvement.

This research is only the first step to development of detailed Latvian energy sector system dynamic model. The author has been promoting use of system dynamic methods in various fields for already several years. In this article the author has tried to highlight possibilities of system dynamic method and its benefits in energy sector forecasting. The research shows only the basic energy sector models, they cannot be considered fully complete and it is necessary to expand some models and assumptions. The article shows the actual situation of model development in Latvia.

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