

System dynamic analysis for development of renewable energy resources in country

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Summary

The events in the energy sector which are evolving globally put more and more emphasis on renewables, through the use of which it is possible to reduce not only impacts on climate change but also to place a more gradually decline of expendable fossil fuels. Countries more and more are placing importance on development strategies and applying the principles of greening the environment.

The article looks at a situation where it is possible to significantly increase the proportion of renewables in the energy balance, particularly wood fuel, but this is not done due to political reasons. The energy dependence of the country on natural gas and its political dependence on its neighbouring countries increases. This model is applied in order that the economic circumstances within the next decade can be improved, thus allowing for biomass to replace fossil fuels as an energy source in the centralised heating. Three political instruments are chosen in this model: national-level financial support for the replacement of fossil fuel with biomass, information package at all heating supply levels and energy efficiency measures for improving the effective running of technological apparatus which use biomass as an energy source.

Introduction

Growth in energy demand, the depletion of fossil fuels, and problems caused by global climate change are reasons for an increasing interest in renewable energy application options.

Global experience has shown that an increase in energy consumption results in energy shortages, which are offset by increased production of energy resources. Of course, this is the easiest solution, but it cannot be considered a sustainable option. A specific situation has developed in Latvia. Namely, the import of fossil fuels (natural gas) is growing, which, in turn, increases the country's dependence on imported energy resources. The transition from an economy based on fossil fuels to one based on renewable energy is a complex process and requires the development of a long-term strategy and a serious commitment towards its implementation. It is very difficult to think in the long term about the growing energy consumption in Latvia if one thinks of this as a short-term problem. And it is a great temptation to try to solve the energy consumption problem by using the simplest method – importing more energy resources. The more attention is paid to this short-term solution, the less attention will be dedicated to the long term solution, which is renewable energy.

State officials do not think about reducing energy consumption. They rely on increasing energy imports, which exacerbate the country's dependence on imported energy resources. The use of natural gas has been increasing in Latvia. At the same time as the country is importing increased quantities of natural gas, Latvian scientists are employed in researching alternative energy and developing new technologies.

Climate change is affected by the world's increasing consumption of fossil energy, and therefore one of the key issues of energy policy is the use of renewable

energy resources. Energy savings and greater energy efficiency together with the promotion of the use of renewable energy are recognized as key components of the energy policy of the European Union countries, including Latvia, in order to implement the limits set on greenhouse gas emissions by the Kyoto Protocol and the commitments of the European Community after 2012 [1].

The aim of the model analyzed below is to determine if it is possible for Latvia to achieve the high targets in the field of renewable energy it has set as an objective, and to look for alternative ways of how to achieve this. The model evaluates eight different policy strategies (represented by combinations of three policy instruments) with the goal of increasing the proportion of wood fuel use.

The structure of energy resources and energy consumption

Renewable energy plays an important role in the Latvian primary energy balance, but its potential has not been fully exploited. In the national energy mix, natural gas, a fossil fuel imported from Russia, still represents the largest fraction. At the same time, local renewable energy resources, especially wood fuel, are not being fully exploited even though they are available in large-scale quantities.

Current Latvian energy consumption is illustrated in Figure 1. The largest fraction is the share of petroleum products used in the transport sector. Another fossil fuel – natural gas – is with the second largest use. Wood fuel, which is widely available locally, ranks third in the fuel mix. The amount of imported electricity, which occupies 5.3% of the balance sheet, is closely linked to the amount of hydro power available. When water levels in rivers are low, less hydro power can be generated and more electricity imports are necessary. Wind power, biogas and biofuels play negligible role in the balance of energy resources in Latvia.

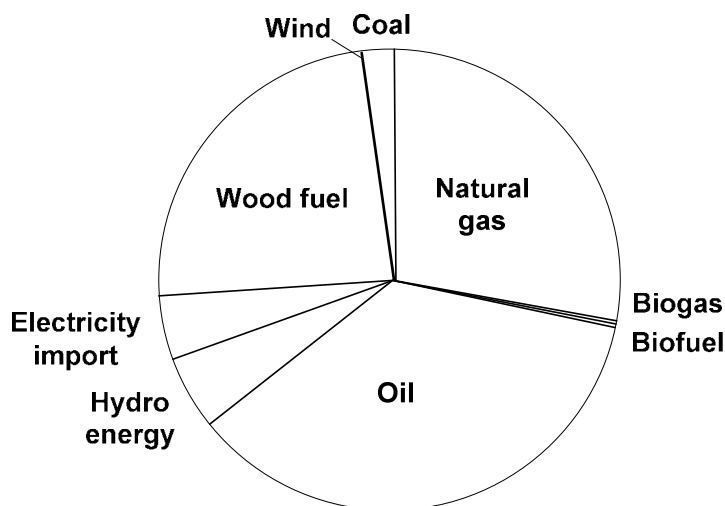


Figure 1 Balance of energy resources in Latvia over the last three years [2]

The largest energy consumption in Latvia is related to the household sector. Although slight changes can be observed over the years, the household sector is still dominating.

Electricity in households is used for lighting applications, household and office equipment needs, and other electrical appliances. Heat is needed for space heating, hot water preparation, and sometimes also to operate ventilation systems.

Heat supply plays an important role in the household energy balance. This can be explained not only by the climatic conditions of Latvia, but also by the low energy efficiency of buildings. Heating can be provided through the district heating systems and local heating, as well as individual heating sources. Latvia is unusual among EU Member States with the large proportion of branched district heating systems that have been established in many towns and parishes.

The development of such systems can be considered as positive in several respects, most important of which are the fuel diversification benefits and energy efficient technological solutions. This means that district heating systems can simultaneously use all types of fuels and still achieve high efficiency. In addition, it is possible to simultaneously produce both heat and electricity (cogeneration).

District heat supply is characterized by three separate system components and their interaction:

- thermal energy users: the number of connected customers and load;
- energy source: the boiler house or cogeneration plant, and energy resources consumed there;
- heat transfer system: the length of the pipelines, diameters, and networking.

In Latvia, oil, coal, and natural gas boiler furnaces were successfully replaced by wood fuel equipment for the first time from 1993 to 1999, after the restoration of independence. This occurred in 15 district heating systems, and it was affected through low interest loans. These were the first “green” joint implementation pilot projects in the Baltic countries. They were implemented within the framework of a Swedish government program. While the projects themselves achieved good results, over the next decade only a few successful biomass energy source projects followed.

Since year 2000, two types of fuel have dominated in the primary energy use of the Latvian district heating sector: wood fuel and natural gas. In 2007 district heating systems produced 80.6% of their heat from natural gas and 14.9% from wood fuel. This accounted for 95.5% of the primary energy consumption of district heating systems. Heat for private dwellings, that is, single or two-family houses, was produced mainly from wood fuel.

All above described characteristics and structure of district heating sector in Latvia have been considered in order to perform a system dynamic analysis for Latvian district heating market by developing a dynamic model. A casual loop diagram in Figure 2 explains the interaction between the installed capacity of wood fuel and natural gas energy and shows the way the nodal part of the model works. The total capacity of installed facilities in both cases (utilization of either wood fuel or natural gas) increases if the investment flow increases. The larger the capacity, the larger the investment flow becomes. Thus, the interaction between the investment flow and the installed capacity stock forms a positive reinforcing loop that characterizes an exponentially growing systems structure. From the other side the larger the capacity causes the larger the depreciation flow of energy generation equipment. Meantime, if the depreciation flow increases, the value of the total capacity decreases. The interaction between the installed capacity stock and the depreciation flow forms a negative balancing loop that characterizes a goal-seeking systems structure. The combination of a positive and a negative loop forms an S-shaped systems behavior that can be observed in the results of modeling.

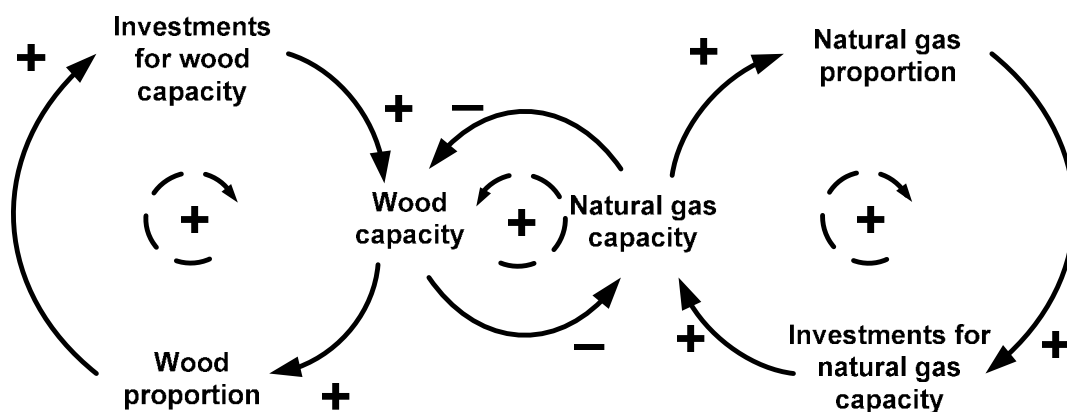


Figure 2 Causal loop diagram representing the formation of installed capacity structure

Such stock-flow structure was used for simulation of the dynamic change of the installed capacity of both fuel types (wood fuel and natural gas). As it is an equilibrium model in which the total installed capacity remains constant over modeling time, thus, if the share of one fuel increases, the share of the other will decrease.

The casual loop (first) representing the installed capacity of energy that has been produced from wood fuel (wood fuel capacity) shows that the larger the investment aimed to increase the wood fuel capacity, the larger the proportion of wood fuel in the fuel structure. Meantime, the larger the proportion of wood fuel in heat energy production, the larger the investment aimed to increase the installed capacity of wood fuel.

The casual loop (second) representing the interaction between the installed capacity of wood fuel installations and natural gas installations shows that the larger the capacity of wood fuel facilities, the smaller the installed capacity of natural gas installations. And, the smaller the installed capacity of natural gas installations, the larger the total installed capacity of wood fuel installations.

The casual loop (third) representing the installed capacity of energy that has been produced from natural gas (natural gas capacity) shows that the lower the installed capacity of natural gas installations, the lower the proportion of natural gas in the fuel structure. Meantime, the lower the proportion of natural gas in the fuel structure, the smaller the investment aimed to increase the installed capacity of natural gas energy. The smaller is the investment, the smaller is the capacity of the natural gas installations.

As can be seen, the modeled situation is characterized by three positive reinforcing loops. These reinforcing loops explain why the installed capacity and thus also the proportion of wood fuel in the fuel structure has a tendency to grow over the modeled time period.

To formulate the dynamics hypothesis: it can be stated that the behavior of the system observed in the reference mode is formed because of interactions between and among investment and depreciation flows and the capacity stock.

Formulation and simulation of the model

Simulation of the behavior of the Latvian district heating system is done using the system dynamics modeling software *Powersim Constructor 2.5*. Using the simulation program tools, the dynamic hypothesis is transformed into a system

dynamics computer simulation model that represents the original structure of the reference scenario.

Key factors affecting the consumption of wood fuel and natural gas in the production of district heat energy are defined in the model in the form of different elements. Values of these elements are defined using mathematical equations and constants.

Model structure and elements

The main structure of the model is formed by two flows of two main energy sources that are used in the production of district heat in Latvia (see Figure 3). Those energy sources are wood fuel and natural gas. Distribution of the fuel is regulated by the central stocks “Wood fuel capacity” and “Natural gas capacity”, which characterize the accumulated change of the installed capacity of district heating over the time. The stock “Wood fuel capacity” (Q_w , GW) represents the installed capacity of heat energy produced from wood fuel. An element is given an initial value to describe the current installed capacity of wood energy and is dependent on the annual amount of heat consumption, the initial share of wood in the structure of fuels (15%), and the duration of the balanced heat load.

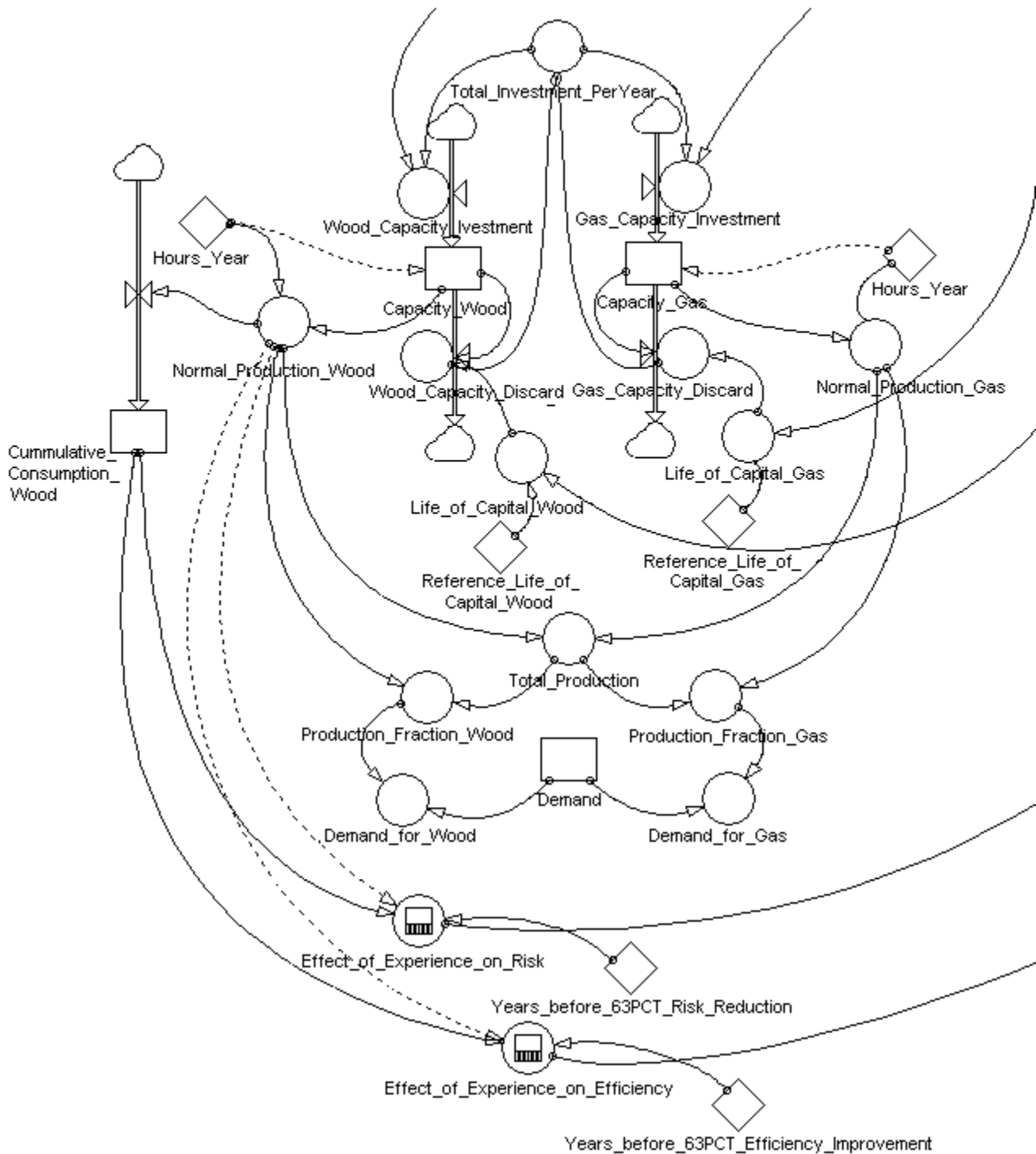


Figure 3 Central stocks – model of the fuel structure

Policy instruments for increasing the share of wood fuel

There are three policy instruments included in the model for increasing the proportion of wood fuel utilization:

- 1) “Subsidies TEST” (P_S) – A policy instrument that provides subsidies for district heat producers for replacement of natural gas installations with wood fuel boilers. This means that natural gas boilers can be replaced with wood-fired boilers before the normal end of life of these installations.

- 2) “Risk Reduction TEST” (P_R) – A policy instrument that comprises an initial short-term campaign to compensate risks related to the use of wood fuel. The aim of the policy instrument is to encourage the public to choose wood-fired technologies. It includes marketing or support measures to initiate the process of disseminating positive experiences of wood fuel use due to information flow.
- 3) “Efficiency Improvement TEST” (P_η) – A policy instrument that includes measures to improve the efficiency of wood fuel use.

These policy instruments are included in the model in the form of constants. The value of the constant can be either 0 or 1, which indicates whether the policy instrument is or is not applied.

If $P_S = 0$, no grant is given to replace natural gas heating equipment with a wood fuel heat production installation. By contrast, when $P_S = 1$, the state provides subsidies for the immediate replacement of the natural gas installations with wood-fired equipment. As a result, the lifetime of natural gas facilities is no longer 20 years but something less, because in this case they are being replaced with wood fuel boilers.

The value $P_R = 0$ means that there is no initial impulse in society that would reduce the negative aspects relating to the use of wood fuel. The information about the positive experience with the use of wood fuel is not being spread around. In consequence, potential new users are not being attracted. Society believes that the use of wood fuel is inconvenient, uncomfortable, expensive, etc. This value ($P_R = 0$) denotes the negative aspects associated with the use of wood fuel. Conversely, if $P_R = 1$, this indicates that an initial impulse is given (by way of a marketing campaign or other forms of support) to compensate for the perceived negatives related to the use of wood fuel. As a result, word of a positive experience associated with the use of wood fuel technologies is spreading, thus attracting new consumers.

The value $P_\eta = 0$ means that nothing has been done to improve the efficiency of the wood fuel equipment. $P_\eta = 1$ means that some policy measures to improve the efficiency of the wood fuel installations have been introduced.

The simulation model allows us to change the values of a given policy instrument from 0 to 1. By forming various combinations of these parameter graphs describing the distribution of fuels for heat energy production and changes in heat production, tariffs or charges covering a 25-year period may be obtained.

Such modeling is important because relationships between and among parameters are not linear. System dynamics modeling allows simulating system behavior depending on the parameters or combinations of different parameters.

Analysis of the impact of policy instruments

Scenario analysis

The model incorporated three policy instruments which have been combined in all possible ways, resulting in eight simulation scenarios. An overview of the scenarios with the appropriate combinations of policy instruments is given in Table 1. A value of “1” indicates that the policy instrument is activated, while a value of “0” indicates that the particular policy tool is not used in the scenario.

Henceforth, each of the scenarios will be discussed separately, giving a graphic representation of the modeling results regarding the structure of fuels and heat production tariffs.

Table 1

Combinations of policy instruments used in scenarios

Scenario	Policy instruments		
	P_S	P_R	P_η
1 st scenario. None of the instruments is applied	0	0	0
2 nd scenario. Subsidy package	1	0	0
3 rd scenario. Information package	0	1	0
4 th scenario. Energy efficiency package	0	0	1
5 th scenario. Subsidy and information package	1	1	0
6 th scenario. Subsidy and efficiency package	1	0	1
7 th scenario. Information and efficiency package	0	1	1
8 th scenario. All three instruments are applied	1	1	1

Comparison of scenarios

By comparing dynamic changes in the share of wood fuel and natural gas (see Figures 4 and 5), two trends can be observed. The first trend is a gradual and moderate increase in the use of wood fuel along with a decrease in the use of natural gas. A slightly different rate of change was noticed (Scenarios 1, 2, 3, 4, 6, and 7). The second trend, a sharp increase in the share of wood fuel along with a reduction in the share of natural gas (Scenarios 5 and 8) was also observed.

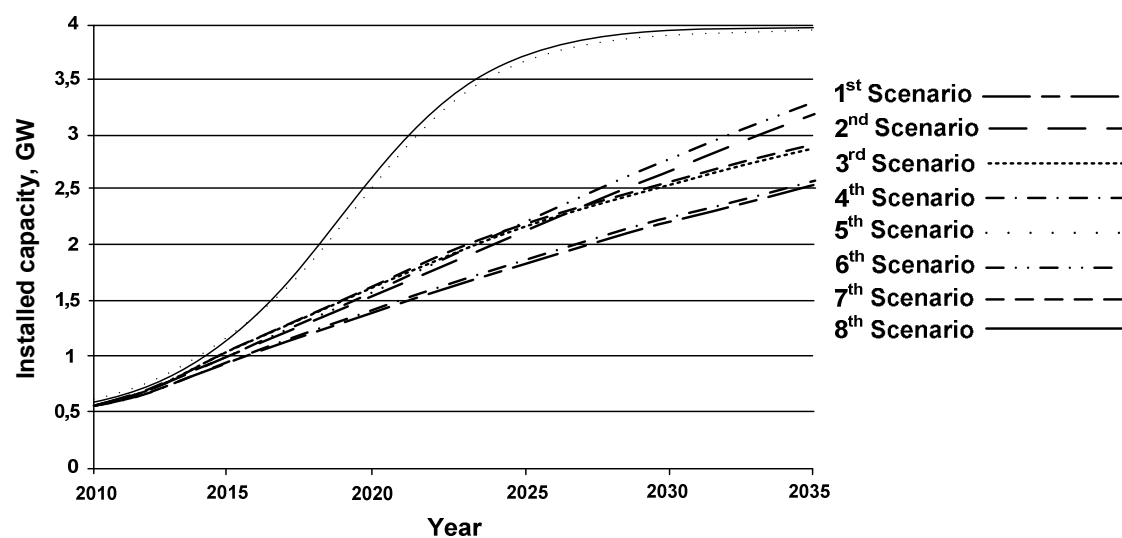


Figure 4 Comparison of installed capacity of wood fuel-based heat production

It can be seen from the chart that the most significant impact on the promotion of wood fuel use would be a combination of the first and second policy instruments (P_S and P_R).

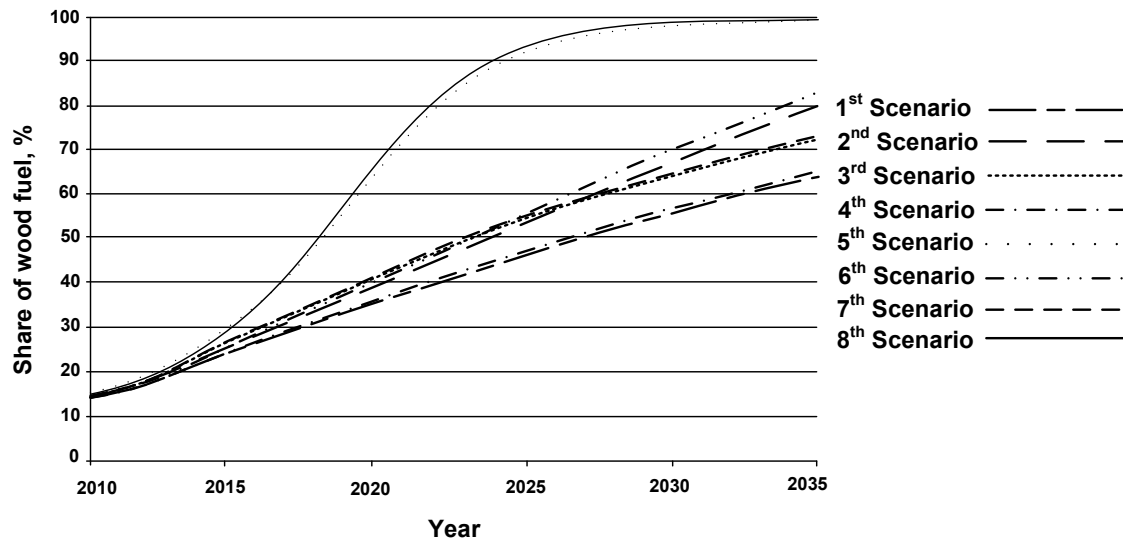


Figure 5 Comparison of changes in the share of wood fuel

Discussions

The energy and economical analysis and energy sector modeling in state level in general depends on target. [3] Difference sometimes is only in use of mathematical models, initial data and assumptions. System dynamic modeling presents beside other factors analysis of impact of policy instruments as additional value.

The main objective of the Latvian renewable energy policy is to increase the proportion of renewable energy sources in the primary energy balance to ensure compliance with country commitments to the European Union. This has the effect of both reducing greenhouse gas emissions and decreasing Latvia's dependence on imported fuel and energy. The main problems facing Latvia are the absence of long-term state support; inadequate, outdated heat production infrastructure and technology; and a very low level of community involvement in the use of renewable energy technologies. All of these delay the achievement of national renewable energy policy goals.

A robust, proactive policy at the state or national level is required to promote the use of renewable energy sources in order to achieve national renewable energy policy objectives. Support to increase the use of wood fuel in district heating systems is particularly important as wood fuel represents a large untapped renewable resource.

A variety of modeling techniques for analysis and planning in the energy sector in Latvia have been applied on multiple occasions. The system Dynamics model for district heat production is, however, the first attempt in this area in which system dynamics modeling is used. System dynamics modeling is based on the behavior demonstrated by a system. This behavior is dependent on the structure of the system and is an important tool to address problems that arise in the system's behavior.

On assessing the effects of policy instruments included in the model for increasing the share of wood fuel in district heating systems in Latvia, it can be concluded that local wood fuel resources are not being used to their full potential because of the lack of a determined, proactive, and sustainable policy of state support to

promote the use of wood fuel. The results of the simulation show that by searching out opportunities for applying specific policy support instruments, the share of wood fuel could be significantly increased in district heating systems, thereby guiding the country towards the implementation of its renewable energy policy goals. Equally as important, an increase in the share of wood fuel consumption in a district heating system would have a positive impact on the cost to the consumer of heat from wood fuel. To take advantage of the potential for using local wood fuel in district heating systems, energy policy makers should assess for reasonableness those policy instruments designed to increase the proportion of wood fuel used. These policy instruments should be looked at from an economic, technological, and political perspective.

If a key objective of Latvia's energy policy is to slowly and painlessly increase the share of wood fuel in district heating, this can be achieved by implementing a policy that provides subsidies for replacing natural gas installations with wood-fired installations. Alternatively, a policy that includes an initial short-term campaign could be implemented to compensate for the real or perceived risks associated with the use of wood fuel.

If the key objective of the national energy policy is a rapid increase in the use of wood fuel in district heat production, this can be achieved by implementing a blend of two policy support instruments. The blend would include subsidies for district heat producers to replace natural gas equipment with wood-fired equipment and initial incentives to offset the negatives associated in peoples' minds with the use of wood fuel.

In order to reduce the costs associated with heat energy produced from wood fuel (primarily the tariff for wood fuel), measures to offset the initial real or perceived negative impacts associated with the use of wood fuel should be implemented. This would help ensure that people begin to look at wood fuel in a positive light. The accumulation of positive experiences also tends to reduce the perception of risk associated with this energy source in the minds of potential wood fuel users.

The average heat energy production tariff that has been calculated in each scenario can be looked at as a benchmark for heat tariffs. It can be used as the base or measure in comparing the tariff for a variety of fuels used by producers throughout the district heat system. Based on the ranking of the heat tariff proposed by an energy producer relative to the benchmark, further incentives could be put in place. These would serve to encourage those district heat producers using natural gas whose proposed heat tariff is higher than the benchmark to implement measures for transition to the use of wood fuel. It would also encourage the district heat producers using wood fuel whose proposed heat tariff falls below the benchmark by offering advantages or bonuses, or by allowing them to deduct the difference between the benchmark value and the tariff for heat that they proposed to charge.

Although in the view of authors the system dynamics model representing the mix of fuels in district heat production systems adequately describes the existing situation, it is possible in the future to improve the model by:

- incorporating prognoses or predictions for wood fuel prices that more realistically reflect where the market appears to be headed;
- integrating three separate smaller models where wood logs, chips, and pellets are used, thus providing an opportunity to analyze the impact of changes in the proportion of each wood fuel type used in the future. This

could influence both heat energy tariffs and the structure of fuels. It could also significantly affect the efficiency of wood technologies.

- including in the equation the amount (that is, the potential upper limit) of wood fuel and natural gas resources available to Latvia to see if and how this might affect the proportion of wood fuel and natural gas in the fuel mix;
- including other policy instruments and assessing their impact. For example, the effect of a CO₂ tax as one of the possible policy instruments could be analyzed. This could be an additional component or factor in the calculation of the tariff for heat produced from natural gas, which is a fossil fuel.

Conclusions

1. Analysis of policy instruments for development of renewable energy resources in district heating system illustrates wide potential of system dynamic modeling use for statement of priorities of fuel diversification for state strategies and programmes in energy sector.
2. The combination of three policy instruments: subsidies for district heat producers for replacement of natural gas installations with wood fuel boilers, information campaigns and energy efficiency measures for improvement of the efficiency of wood fuel use plays significant role in development of Latvian district heating market on environmentally sound direction and to reach the renewable energy target of European Union.
3. The policy instrument that provides subsidies for district heat producers for replacement of natural gas installations with wood fuel boilers must be the first priority in list of policy instruments. This would allow to replace natural gas boilers with wood-fired boilers before the normal end of life of these installations.

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