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 increase. 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 policy 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 [1]. 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 [2,3].

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.

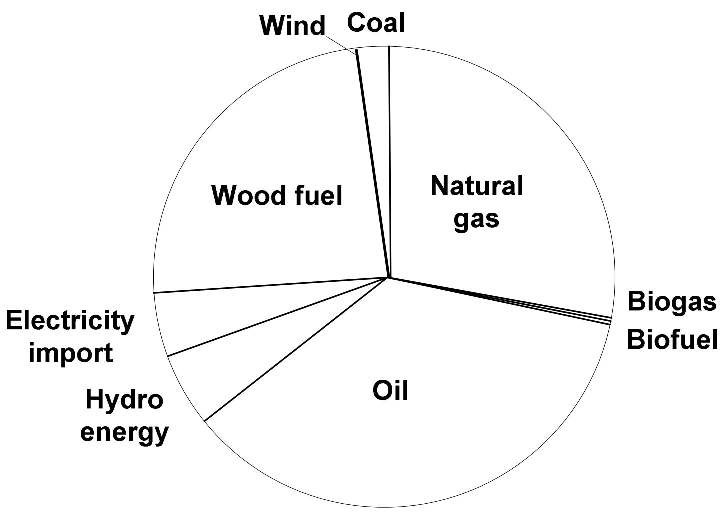

Figure 1 Balance of energy resources in Latvia over the last three years [4,5]

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 [5]. Heat for private homes, that is, single or two-family detached homes, was produced primarily from wood fuel. Although Latvia has a high biomass potential, the share for wood based fuels in the district heating sector has experienced rather slow growth rates. In order to better understand and analyze this trend a system dynamics model was developed.

The objective of the study

The objective of this study based on a system dynamic model is: (i) to precisely simulate the fuel mix structure of the Latvian district heating sector; (ii) to develop a set of alternative solutions for Latvia to reach the targets set for the share of renewable energy sources; and (iii) to determine whether it is possible a complete shift from natural gas to wood based fuels, both considering energy efficiency and Latvian economic growth.

The developed dynamic model is both deterministic and forecasting. For example, it helps to understand the influence that policy measures and economic factors have on the fuel mix structure or the influence that policy measures have on heat energy tariffs.

Development of the dynamics hypothesis

When the model was first being created, it was assumed that the main indicator identifying the fuel structure is the capacity of installations (in terms of installed GW) that use either natural gas or wood fuel to produce the heat energy. Therefore, the central elements of the model were identified as two stocks: the total installed capacity of wood fuel technologies and the total installed capacity of natural gas technologies. As the model is an energy-economic model, in the next step it was assumed that the capacity of installed facilities is influenced by two factors: investment and the depreciation of the equipment over time. Therefore each of the stocks was linked with two flows: an in-flow and an out-flow. The in-flow represents investments aimed to increase the capacity of installed heat energy facilities. The out-flow represents the depreciation of the heat energy facilities, thus reducing the value of total installed capacity. The installed capacity of each fuel represents the proportion of the particular fuel in the fuel structure. Figure 2 represents the stock-flow structure using system dynamics modelling elements valid for each type of installed capacity (wood and natural gas).

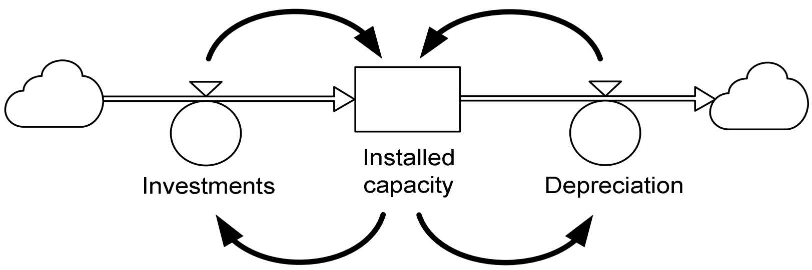

Figure 2 Stock-flow diagram representing the relationship between the total capacity of installations and investment and depreciation flows

Converting the stock-flow diagram into a casual loop diagram as represented by Figure 3 allows a better understanding of the nature of the interaction between installed capacity and investment and depreciation flows.

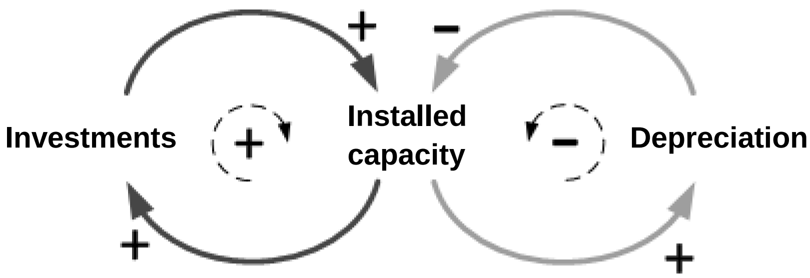

Figure 3 Causal loop diagram representing the relationship between the total capacity of installations and investment and depreciation flows

A casual loop diagram 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. But also the larger the capacity, the larger the depreciation flow. 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 behaviour that can be observed in the results of modelling.

Such stock-flow structure was used for modelling 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 modelling time, thus, if the share of one fuel increases, the share of the other will decrease. Figure 4 represents a causal loop diagram that explains the interaction between the installed capacity of wood fuel and natural gas energy.

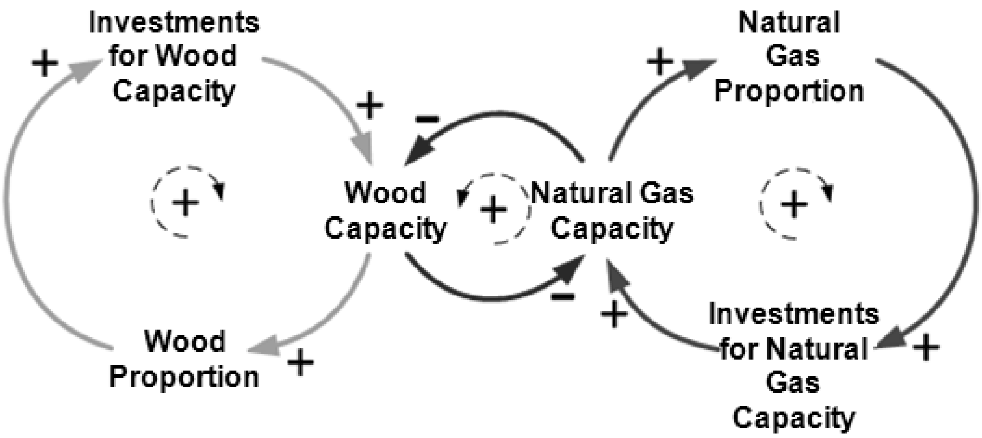

Figure 4 Causal loop diagram representing the formation of installed capacity structure

The casual loop (on the left side) 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 (in the middle) 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 (on the right side) 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 the investment, the smaller the capacity of the natural gas installations.

As can be seen, the situation modelled is characterized as 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 modelled time period.

To formulate the dynamics hypothesis: it can be stated that the behaviour 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 5). 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” (Qw, 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:

$$Q_W^{init} = \frac{Q_T \cdot 15\%}{Q_{bal}} = \frac{8000 \cdot 15\%}{2000} = 0{,}6\,GW \ ,$$

Where:
Q_W^{init} – initial value of the "Wood fuel capacity" stock, *GW;*
Q_T – annual consumption of heat energy, *GWh/year;*
Q_{bal}– duration of the balanced heat load, *h/year.*

A constant, "The Hours" (Q_H), defines the equalized load demand of heat energy per year on the assumption that the plant is operated at full capacity.

Assuming that the current share of natural gas in the structure of fuels is 85%, the calculation of the initial value of the stock "Natural gas capacity" is done similarly to wood fuel capacity calculation:

$$Q_G^{init} = \frac{Q_T \cdot 85\%}{Q_{bal}} = \frac{8000 \cdot 85\%}{2000} = 3{,}4\,GW \ ,$$

Where:
Q_G^{init} – initial value of the "natural gas capacity" stock, *GW;*
Q_T – annual consumption of heat energy, *GWh/year;*

Q_{bal}– duration of the balanced heat load, *h/year*.

The assumptions used for the calculation of the initial values of the elements are made by model builders and are based on the data collected from experts [6,7,8], statistical information [4,5] of the development of the Latvian energy sector and existing national policy planning documents [9,10,11].

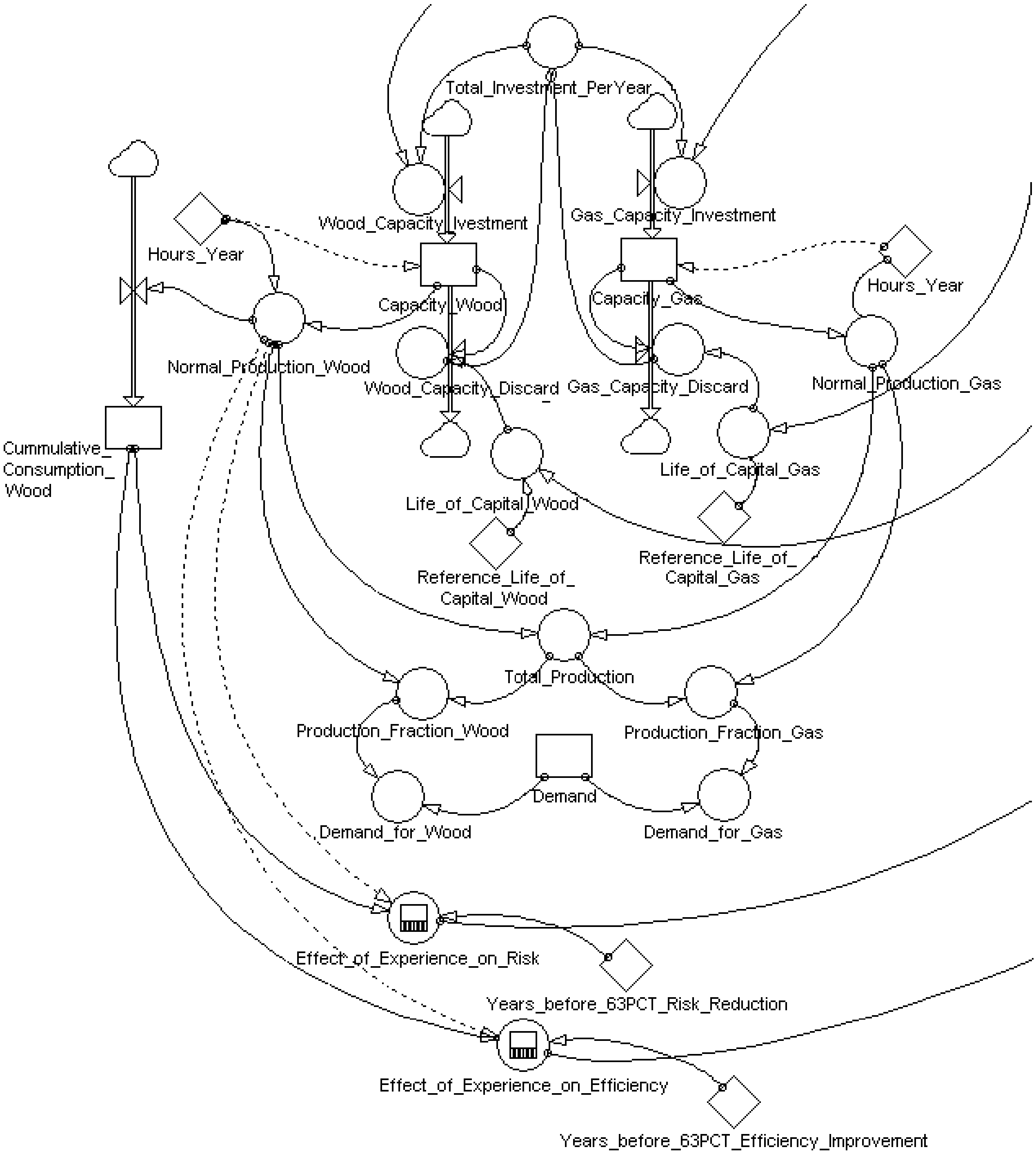

Figure 5 Central stocks – model of the fuel structure

The total installed capacities of wood fuel and natural gas technologies vary during the modelling time depending on the flows that affect the stocks:

$$Q = f(I,D),$$

Where:
I – investment flow, *GW/year;*
D – annual depreciation, *GW/year*.

Flows in the model

There are two types of flows that affect the value of the installed capacity stocks of wood fuel and natural gas: an incoming and an outgoing flow. The incoming flow characterizes the investments required for increasing the capacity of wood fuel or natural gas installations and has a positive effect on the values of "Wood fuel capacity" and "Natural gas capacity" stocks. The outgoing flow characterizes the annual depreciation of the equipment used to produce heat energy, and it reduces the value of the installed capacity – both stocks "Wood fuel capacity" and "Natural gas capacity" are negatively affected.

The parameter "Investments in wood fuel" characterizes the division of investments between natural gas and wood fuel. The sum of the investments for natural gas and wood fuel is 1 (100%), so it is sufficient to calculate only the value of the parameter which expresses the investment share of wood fuel (the element "Investments in wood"). The investment share of natural gas is then calculated as the difference between the amount of the total investments and the investment share of wood fuel.

$$I_W^S + I_G^S = 1,$$

Where:
I_W^S – investments in wood fuel;
I_G^S – investments in natural gas.

Accordingly, the flow of investments of natural gas is calculated as following:

$$I_G = I_T \cdot (1 - I_W^S),$$

Where:
I_G – natural gas investment share, *GW/year*;
I_T – total investments for increasing capacity, *GW/year;*
I_W^S – wood fuel investment share.

When creating the model, it was assumed that the investment share is dependent on the heat production tariff. In order to describe the change of the wood fuel investment share over time, a logical function was applied:

$$I_W^S = \frac{e^{-\alpha \cdot T_W}}{e^{-\alpha \cdot T_W} + e^{-\alpha \cdot T_G}} = \frac{1}{1 + e^{-\alpha \cdot (T_G - TW)}},$$

Where:
I_W^S – wood fuel investment share;

α – coefficient characterizing the decision makers in the choice of fuel;
T_W – tariff of wood fuel energy, *LVL/MWh*;
T_G – tariff of natural energy, *LVL/MWh*.

The sum of the wood fuel and natural gas investment parts is 1. This means that the growth in the share of wood investment results in a decrease in the natural gas investment share. When the tariffs of heat energy production are equal for both wood fuel and natural gas ($T_W = T_G$), the investment shares are also equal ($I_W^S = I_G^S$ or $I_W^S = 0.5$). If the costs of heat energy production from wood fuel are higher than those of utilizing natural gas ($T_W > T_G$), the share of wood fuel investments is smaller than the share of natural gas investments ($I_W^S < I_G^S$ or $0 < I_W^S < 0.5$). If the costs of heat energy production from wood fuel are lower than those of utilizing natural gas ($T_W < T_G$), the share of wood fuel investments is larger than the share of natural gas investments ($I_W^S > I_G^S$ or $0.5 < I_W^S < 1$).

The apportioning (or allocation) of the investments regulates the values of the investment flows, which in turn affects the installed capacity of natural gas and wood fuel energy. The installed capacity of fuel energy influences the amount of energy produced from a particular fuel. The parameters "Production of wood energy" (E_W, *GWh*) and "Production of natural gas energy" (E_G, *GWh*) express the amount of district heat energy per year that is produced through the use of wood fuel or natural gas respectively. The values of the parameters during each simulation step are calculated taking into account the installed capacity of both fuel types and the duration of the balanced heat load per year:

$$E = Q \cdot Q_{bal} \ ,$$

Where:
E – amount of energy, *GWh/year*;
Q – installed capacity, *GW*;
Q_{bal} – duration of the balanced heat load, *h/year*

The total production of district heat energy (E_T, *GWh/year*) is the sum of energy produced from wood fuel and natural gas. It is assumed that the total amount of heat energy produced is equal to the total heat energy demand and does not change during the whole modelling period. Total energy demand is assumed to be 8,000 GWh/year:

$$DM_T = E_W + E_G = 8{,}000\, GWh / year \ ,$$

Where:
DM_T – total heat energy demand, *GWh/year*;
E_K – production of wood fuel energy, *GWh/year*;
E_W – production of natural energy, *GWh/year*.

Heat produced from each of the energy sources refers to the total amount of heat produced, expressed as the share of the fuel (proportion) over the structure of fuels:

$$E^S = \frac{E}{E_T} \ ,$$

Where:
E^S – share of each fuel;

E– amount of heat energy produced from each of the energy sources, *GWh/year*;
E_T – total production of heat energy, *GWh/year*.

By contrast, multiplying the total heat demand by the share of each fuel results in the parameters which characterize the demand for energy produced from natural gas (parameter "Gas Energy Demand", DM_G, *GWh*/year) and the demand for energy produced from wood fuel (parameter "Wood Fuel Energy Demand", DM_W, *GWh*/year). This relationship is expressed as following:

$$DM = DM_T \cdot E^S ,$$

Where:
DM – energy demand for each type of fuel, *GWh/year*;
DM_T – overall heat energy demand, *GWh/year*.

The model offers the opportunity to analyse not only the distribution of fuels, but also the cost of district heat energy production over time (see Figure 6).

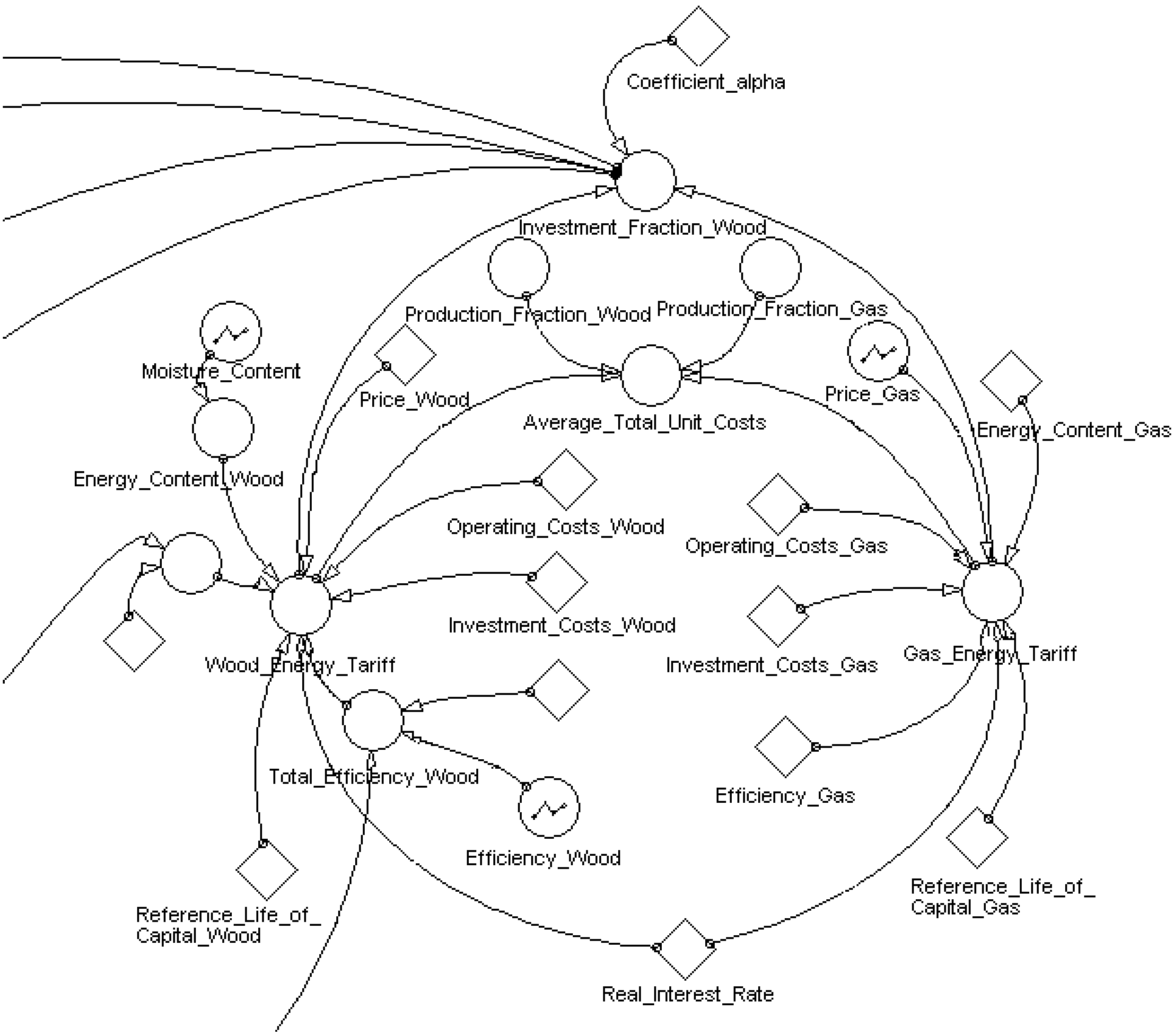

Figure 6 Calculation of heat energy tariffs

It is assumed that the heat energy tariff in the case of using wood fuel is affected by the price of wood fuel, the investment and operating costs, efficiency, the reference life time of the technologies used, the calorific value of the wood fuel, the annual interest rate, and the risk factor. The tariff for wood fuel energy is calculated as following:

$$T_W = \frac{C_W \cdot \eta_W}{Q_{zK}^d} + C_W^O + \frac{C_W^I \cdot 10^3}{Q_{bal}} \cdot (i + \frac{1}{\tau_W^{ref}}) + R,$$

Where:
T_W – heat production tariff for wood fuel, *LVL/MWh*;
C_W – wood fuel price, *LVL/t*;
C_W^I – capital costs of wood fuel technology, *LVL/MW*;
C_W^O – operating costs of wood fuel technology, *LVL/MWh*;
Q_{bal}– duration of the balanced heat load, *h/year*;
η_W – efficiency of wood fuel use;
τ_W^{ref} – reference life time of wood fuel technology, *years*;
Q_{zK}^d – calorific value of wood fuel, *MWh/t*;
i – annual interest rate, *%/year*;
R – risk factor.

The price of wood fuel, the capital and operating costs of the technologies used, and the efficiency and calorific value of wood fuel are calculated as a weighted average of the three wood fuel types used in Latvia: logs, chips, and pellets. The overall energy efficiency of wood fuel utilization (the parameter "Total efficiency of wood fuel") is defined as an expression between the efficiency of wood fuel technology and the impact of the learning effect determined by the parameter "Effect of experience on efficiency":

$$\eta_W = \eta_W^{'} + (1 - \eta_W^{'}) \cdot (1 - EXP_\eta) \cdot P_\eta ,$$

Where:
η_W – total efficiency of wood fuel use;
η'_W – efficiency of wood technologies;
EXP_η – effect of experience on efficiency;
P_η – policy instrument to improve efficiency.

It is assumed that the efficiency of wood fuel equipment (η'_K) will increase over time.

The calorific value of wood fuel is calculated by taking into account the moisture content:

$$Q_{zW}^d = (18{,}317 - (0{,}2018 \cdot W_W)) \cdot 0{,}28,$$

Where:
Q_{zW}^d – lowest calorific value of the wood, *MWh/t*;
W_W – moisture content of wood, %.

It is assumed that in accordance with European Union requirements, the moisture content of wood fuel that is being used for heat production will decrease over time.

The model assumes that the heat energy production tariff in the case of natural gas is affected by such factors as the price of natural gas, the capital and operating costs of natural gas technologies, their efficiency, their planned lifetime, the calorific value of the fuel, and the annual interest rate of investment growth. The price of natural gas in Latvia is defined and regulated according to the amount of fuel consumed. The greater the consumption of natural gas per year, the lower the tariff. The second factor which affects the tariff for natural gas is the quoted price of natural gas (or heavy fuel oil) on the international exchanges. The quoted price of natural gas on the global energy market depends on the overall global economic situation. Natural gas tariffs are calculated using the following formula:

$$T_G = \frac{C_G \cdot \eta_G}{Q_{zG}^d} + C_G^O + \frac{C_G^I \cdot 10^3}{Q_{bal}} \cdot (i + \frac{1}{\tau_G^{ref}}),$$

Where:
T_G – heat production tariff for natural gas, *LVL/MWh*;
C_G – price of natural gas, *LVL/1000m^3*;
C_G^I – capital costs of natural gas technology, *LVL/MW*;
C_G^O – operating costs of natural gas technology, *LVL/MWh*;
Q_{bal}– duration of the balanced heat load, *h/year*;
η_G – efficiency of natural gas use;
τ_G^{ref} – reference life time of natural gas technology, *years*;
Q_{zK}^d – calorific value of natural gas, *MWh/t*;
i – annual interest rate, *%/year*.

The price of natural gas C_G, *LVL/1000 m^3* was calculated in two steps. First, an initial value for the price of natural gas was determined. This was done based on the forecast for the price of natural gas made by the Latvian joint-stock gas company ”Latvijas Gāze” for June 2010 [12]. Secondly, the forecast for the annual change in the price of natural gas till 2035 made by the U.S. Energy Information Administration [13] was added to the initial value.

Changes in the structure of the average tariff for heat unit production depend on the tariff for heat production and on the share of each resource:

$$T_T = E_w^S \cdot T_W + E_G^S \cdot T_G, Ls/MWh,$$

Where:
T_T – average heat production tariff, *Ls/MWh*;
E_W^S – share of wood fuel energy;
E_G^S – share of natural gas energy;
T_W – heat production tariff for wood fuel, *Ls/MWh*;
T_G – heat production tariff for natural gas, *Ls/MWh.*

Policy instruments for increasing the share of wood fuel

The increase in the share of wood fuel in the composition of fuels results in a growing value for the stock "Wood fuel consumption" (B_W). The stock "Wood fuel consumption" represents the consumption of energy produced from wood fuel and, thus, also the public experience with the use of wood. It is assumed that the initial value of the stock is equal to 0 ($B_W^{init} = 0$). This means that at the beginning of the simulation (first step) society has no experience using wood fuel. In the future, however, increasing the share of wood energy increases the experience of using wood fuel in the society as a whole. The greater the consumption of wood fuel (and energy produced from wood fuel), the more experience in the use of wood as fuel accumulates in society as a whole.

Whether the society has or has not accumulated experience in the use of wood fuel affects the elements "Effect of experience on risk" (EXP_R) and "Effect of experience on efficiency" (EXP_η) that describe what is the public experience regarding the risks associated with the use of wood fuel technologies and their efficiency. Initially (first step), when there is no broad social experience with the use of wood fuel ("Wood fuel consumption" $B_W = 0$) the values of both variables $EXP_R = EXP_\eta = 1$. This means that there is in society the highest risk regarding the negative aspects and the lowest efficiency in the use of wood fuel. As society accumulates experience with wood fuel use, the values of both elements decrease exponentially, which means that the risk regarding the negative aspects of wood fuel use decreases and the efficiency of wood fuel use increases. This is due to the "learning effect". In order to realize the effect of learning, it is necessary to apply two policy instruments "Risk Reduction TEST" (P_R) and "Efficiency Improvement TEST" (P_η).

The effect of experience on risk reduction and the effect of experience on efficiency of wood fuel using technologies are calculated using following formulas:

$$EXP_R = e^{-\frac{B_W}{E_W^{init}} \cdot \beta_R},$$

Where:

B_W – wood fuel consumption, *GWh/year*;

E_W^{init} – initial amount of energy produced from wood fuel, *GWh/year*;

β_R – years before 63 percent risk reduction ($\beta_R = 10$ years).

$$EXP_\eta = e^{-\frac{BW}{E_W^{init}} \cdot \beta_\eta},$$

Where:

B_W – wood fuel consumption, *GWh/year*;

E_W^{init} – initial amount of energy produced from wood fuel, *GWh/year*;

β_η – years before 63 percent efficiency improvement ($\beta_R = 100$ years).

The negatives associated with the use of wood fuel (such as a lower level of automation compared to natural gas, etc.) in the model are represented by the parameter "Risk" (R). The value of this parameter depends on the amount of accumulated societal experience with wood fuel use and whether the policy instrument "Risk Reduction TEST" is used to promote the use of wood fuel. Without the use of this policy instrument, the value of this parameter is fixed. If the policy instrument is used, the value of the parameter decreases, thus representing a decrease in risk.

All together 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.

Feedback loops

The elements and relationships of the previously described model form feedback loops (see Figure 7). The model consists of two key feedback loops, which allow for dynamic development of the installed capacity of both wood fuel and natural gas energy.

The first causal loop shows that the larger the installed capacity of wood fuel equipment (Q_W), the more heat energy is produced using wood fuel (E_W). It also shows that the consumption of wood fuel (B_W) increases. The increase of wood fuel consumption in each simulation step also serves to add to the societal experience with the use of wood as fuel. This in turn leads to a reduction in the risks associated with the negative aspects of utilizing wood fuel (EXP_R) and an increase in the efficiency of wood fuel utilization (EXP_η). Reduction of risks and improvement of efficiency reduce the tariff for heat energy produced from wood fuel (T_W). If the tariff decreases, investments leading to an increase in the share of wood fuel increase (I_W^S). As a result, the installed capacity of wood fuel energy (Q_W) increases. As the equilibrium model is used, if the capacity of wood fuel energy (Q_W) increases, the capacity of natural gas energy decreases (Q_G).

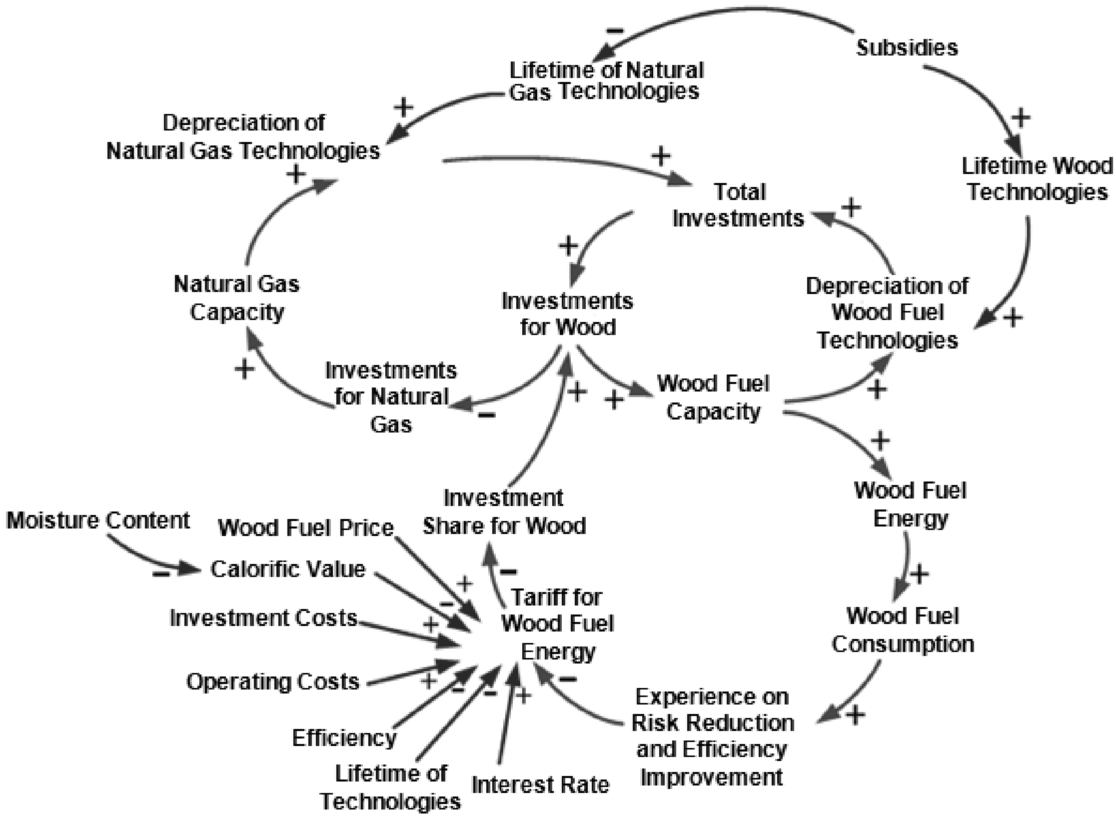

Figure 7 Causal loop diagram describing the model

The second causal loop shows that if one of the policy instruments (subsidies for the replacement of natural gas installations with wood fuel installations, P_S) is implemented, the real or useful lifetime of the natural gas equipment decreases (τ_G), thus resulting in a decrease in the amount of investment for natural gas (I_G) and an increase in the investments in wood fuel (I_W). This is because investments leading to the increase in installed capacity of fuel are dependent on the depreciation costs of equipment (D_G, D_W). As a result, the share of wood fuel increases and processes represented by the first causal loop continue.

Analysis of the impact of policy instruments

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

By comparing dynamic changes in the share of wood fuel and natural gas (see Figure 8), 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.

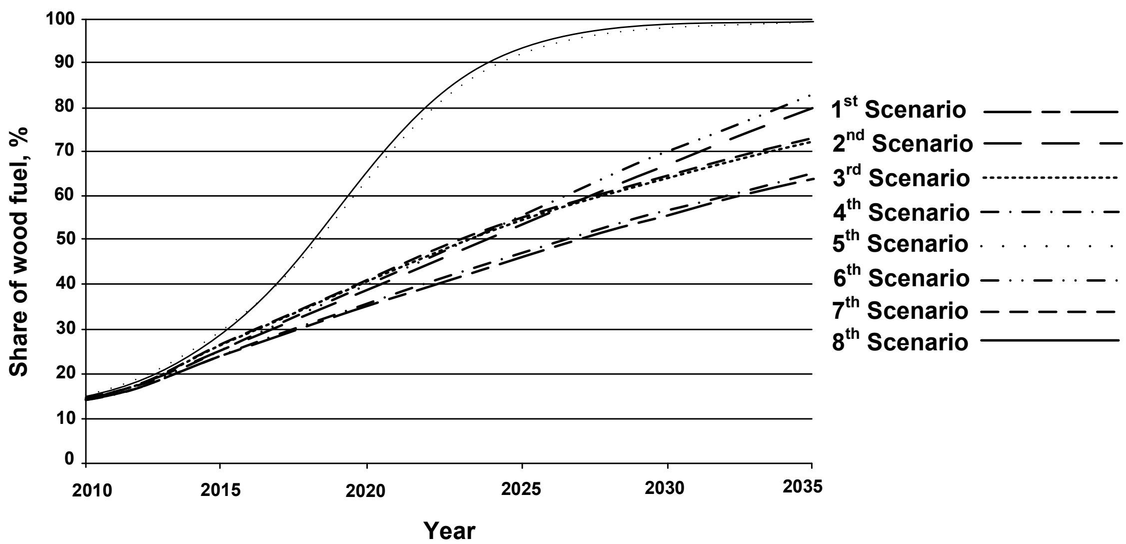

Figure 8 Comparison of changes in the share of wood fuel

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).

The relationship between policy measures and the resulting share of wood based fuels in the primary energy mix is not linear. The combination of different policy measures has different effects on the market. In particular on scenario 5 and scenario 8 enable a 100% switch to renewable energy sources in district heating systems with rapid growth rates. All other scenarios present more gradual growth rates and the share of wood based fuels by 2035 ends in the range of 65%-85%.

Discussions and conclusions

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 CO_2 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.

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