Energy

Assessment of the economic potential of the production and use of renewable energy resources in Latvia and development of policy recommendations, VPP-EM-2018/AER-1-0001

STRUCTURE OF THE SYSTEM DYNAMICS MODEL. INPUT DATA AND MATHEMATICAL RELATIONSHIPS

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ABBREVIATIONS USED

AES – Renewable energy sources
AL – payback time, per year
ANI – reference inconvenience
ApD – insurance
ApLT – lifespan of heating solutions, years
ApN – rate of dismantling of an outdated heating solution
ApU – the pace of installation of a new heating solution
AuP – fleet, vehicle
Av - aviation
bez (EE)- without EE measures
bez (SS) –without heat pumps
BIOdī – biodiesel
BIOdP –advanced biofuels
BIOet – biomethanol
BIOme – biomethane
BU –construction companies
BūvT – the pace of construction of new buildings
C – costs
CA (tr)- impact of vehicle price on inconvenience costs
CAiz – inconvenience costs due to vehicle price, EUR/km
CK – fuel costs
CPL – rate of decline in the price, EUR/year
CSA – district heating
CSa (tr)- vehicle price reduction fraction for a given type of fuel
Csd – fraction of the reduction in the price
CSDD - Road Traffic Safety Directorate
CSP - Central Statistical Bureau
DEM –demand
DĢM – multi-apartment buildings
Di-diesel
DL– duration of operation
DP – fuel consumption
DRN –natural resources tax
DT – time step
DTr- diesel vehicles
DzEl- electric railway
DzI – ageing time
DzP – living space
E - primary energy consumption
E_{Dz} – economic lifespan of investments, years
EE – energy efficiency
E_f- emission factor
EIet – energy savings
ĒK – buildings
Eksp– operating
EIP – electricity consumption
EM – Ministry of Economics
EMS – energy management system
ENJ – rate of commissioning of energy production capacities, GW/year
E_{nod} – amount of electricity transmitted, GWh
EP – electricity consumption, GWh/pc/year
ES - electricity distribution
ETS - Emissions Trading System
EU – the European Union
EXP– exponential function
EII– impact of the net total economic benefit on market share
F – fund, EUR
FC – fixed costs
FP – projects financed, m^2
Fr - freight
FR_{IMP} – decision on the import of electricity, instead of installing additional generation capacity
FrP – rate fraction
GDP – Gross domestic product
GF – funding raised, m^2/years
GPP – annual passenger-kilometre demand, passenger-kilometre/year
GTr- gas vehicles
I – investment costs
IDz –internal combustion engine
Ie –purchased
Ieg – share of investments
IegG – total annual number of cars purchased
IEM –internal combustion electric motor
I_{EP} - electricity transmission costs
Iet – savings
II – annual investments
IKP- gross domestic product per person employed
IKS - impact of the information campaign
IMP –imported electricity
IN – intensity
InA– impact of lack of infrastructure on inconvenience costs
InAP – share of individual heating in buildings
InfT – the pace of information on the possibility of renovation
INIT- initial
InMi – the purpose of saturation of the filling infrastructure
InSH – share of individual heating in buildings
INS_{IMP} – including the electricity import
InvAP – investment part of a particular heating solution

IPA_i – impact of information and experience on the cost of inconvenience for a particular type of fuel
ĪpPat – specific consumption of buildings
I_{PTJ} – transmission network capacity costs, EUR
I_{SD} - investment cost reduction fraction, 1/year
I_{ST} - distribution capacity costs, EUR/A
IT – energy deficit, GWh/year
IT_{EL} – electricity shortage (= import), GWh/year
I_{TJ} - network capacity cost, EUR/kW
izm –costs
J –capacity
jaun - new
Jaun – new buildings, m^2/years
JĒ – new buildings
JL - capacity limit for installed energy production technology, GW
JP – annual rate of ordering capacity of power generation installations, GW/year
JPA – the ratio of energy production to energy demand
J_{PT} - transmission network capacity, VA
jTR-new vehicles
kEL – coefficient to be used for the calculation of RES for electricity
KEP – total electricity consumption, GWh/year
KFK – truck load capacity, tonnes/vehicle
KL – lifetime of energy production equipment, years
KL – Technical life
KL–service life
KMD – disposal
KMD – total number of cars removed from record for all fuel types, vehicle/year
KN – freight mileage, km/year
KP – total consumption, GWh/year
KPFI - Climate Change Financial Instrument
KR – cumulative amount of energy produced
KSP – total heat consumption, GWh/year
KSP – total thermal energy consumption , GWh/year
KV- freight trains
KV_{ETS} – ETS quota price, EUR/tCO_2
KZ – total area, m^2
KI – cumulative investments
L - verification of reaching the limit of installed capacities for a particular technology
L –agriculture
LBN– the requirements of Latvian construction standards
LBN –rrequirements of Latvian construction standards
LPG – Latvian Propane Gas
LPGtr –LPG vehicles
lTR –second-hand vehicles
LVĢMC - State Ltd "Latvian Environment, Geology and Meteorology Centre"
M –Households
MAN_{IN} – the possibility of manually adding technology
$Ma_{reģ}$ – registration fee
MK – Cabinet of Ministers
NĀ -pace of disposal
nesilt - uninsulated houses
NJ – rate of removal of capacity, GW/year
NKEI – net total economic benefits
NN –unrenovated and uninformed buildings
NNE – uninsulated buildings the owners of which are aware of energy efficiency, m^2
Nod–tax
non-ETS - excluded from the Emissions Trading Scheme
NPieaug – annual mileage growth rate
Npieaug– annual mileage growth fraction
O&M – operation and maintenance
OCC – degree of filling
OIK - Mandatory procurement component
OPP-policy on the mandatory blending
P - amount of energy produced, GWh/year
P&D - the impact of R&D on costs
P&ST - transmission and distribution
P+P –services and public sector
P2G - "power to gas"
PA – consumption for buses
PĀ – the rate of emergence
Pal – additional costs
Pār – change of transport mode
Pas-passenger
P_{EL} – total amount of electricity produced from all installations, GWh/year
PĒ-public buildings
P_i – impact of experience on the risk premium
PJ – volume of power generation equipment ordered, GW
pkm- passenger-kilometres
PL – time taken to order energy production technologies, years
Plat –area, m^2
PM – consumption for private transport
$PNĀ_i$ – average annual mileage of a given mode of transport (private, public, air), km/year
PP – potential projects, m^2
PP –demand
PPĪ–demand growth fraction
PPT – growth rate of passenger-kilometre
PR_f – primary energy price, EUR/MWh
P_s – time up to 63% risk reduction, years
PSM - consumption for freight transport
$PTOT_{EL}$ – total amount of electricity provided, GWh/year

PV- passenger trains
r – discount rate
R –Industry
RĀ – annual amount of energy produced, GWh/year
RA- regional bus
RD – share of energy produced by a specific technology
RD – total number of vehicles registered for all fuel types, vehicle
RD– total number of registered
RenT – renovation rate for a specific heating solution, m^2/year
RK – registered size of vehicles
ROI – Return on investment
RP - risk premium, EUR/MWh
RP- transport mode change rate
RPP – possibility of switching on the mode change promotion policy instrument (from private to public)
SC – initial price for vehicles, EUR
SD – System Dynamics
SEG – Greenhouse gases
$SĒK^{temp}$ – the pace of construction of new buildings (single-family and multi-apartment), m^2/year
SEN – subsidised electricity tax
$Silt_{ātr}$ insulation speed
silt—insulated buildings
SP – heat consumption, GWh/pc/year
SP – heat consumption, GWh/year
SPD - initial growth share, 1/year
SRP - initial risk premium, EUR/MWh
St– requirements of building codes,
Sta- filling stations
SUB – intensity of support for renewable technologies
SUB – subsidy
SS – heat pumps
T – energy production tariff, EUR/MWh
TA – technical inspection, EUR/year
TDL – share of electricity transmission and distribution losses
TEH – turn on the possibility of installing technology in the model
tkm- tonne-kilometres
TOTAp – total area of buildings
TOTPat – total heat consumption
Tr – Transport sector
TX_e – fuel excise duty, EUR/MWh
U – network voltage, V
UJ – installed power generation capacity, GW
UL – installation time, years
UN –inconvenience
UNI – the perceived changes in the cost of inconvenience, EUR/m^2/year/years
uzņ- companies
uzņ. – companies without EMS, pcs
UzS – filling stations
UzS– number of filling stations
uzt – maintenance
VC – variable costs
vent -ventilation
VĢM – single-family houses together, m^2
V-trains
WTP – willingness to pay
α–coefficient for behaviour of decision-makers
η – technology efficiency

INTRODUCTION

System dynamic (SD) is a method of studying the dynamic development of complex systems, with the help of which complex problems can be solved. SD theory is based on the study of the relationship between the behaviour of the system and the underlying system structure. This means that by analysing the structure of the system, a deeper understanding of the causes of the behaviour of the system is formed, which allows to better address the problematic behaviour of the observed system (A. Blumberga et al., 2010).

SD was established in the mid-1950s by Professor Jay Wright Forrester of the Massachusetts Institute of Technology. SD was originally designed to help business leaders improve their understanding of production processes, but its application is now much wider, including policy analysis and development in both the public and private sectors.

This report describes the structure of the SD model of the Latvian energy system, which includes centralised and individual energy production, energy consumption in different sectors in order to model the transition to greater use of RES. In the SD model, the use of RES is analysed by planning regions in order to identify the main differences and opportunities in different parts of the territory of Latvia.

Chapter 1 describes the SD modelling method, the overall structure of the SD model and the potential application in energy.

The problem of the SD model is formulated in Chapter 2, which describes the main causal loops and feedback loops, submodels, as well as all the formulas used.

Chapter 3 describes all input data used in the SD model, which covers centralised production of electricity and heat, individual heating in the household, service and industrial sectors, as well as final consumption. The main input data are also summarised in the transport sector. This chapter also sets out the main assumptions related to the technical and economic performance of RES and fossil technologies. RES potential identified and integrated into the SD model in accordance with the established GIS model.

The current version of the model deals only with a baseline scenario that assumes that existing policies, existing or already approved tax rates continue to operate, as well as new European Union funds are not allocated for energy efficiency measures and the promotion of the development of renewables. Tax rates have been changed and support instruments will be tested in the next phase of the project, identifying the most effective policies for increasing the proportion of RES.

1. USE OF MODELLING METHOD TO DETERMINE RES POTENTIAL

1.1. Elements of the SD model

The main elements that make up the system dynamic (SD) model are stocks, flows and feedback loops (Fig. 1.1.1). A stock is a quantity that accumulates over time, while a flow is the speed of changes in the stock. In SD modelling, it is believed that the dynamic behaviour of the system is formed due to the "principle of accumulation", which characterizes the accumulation of flows in the stock, thereby forming the dynamic structure of the behaviour of the system. In SD modelling, flows can move and accumulate both tangible and intangible values in the stocks. Typical examples of stocks are population, equity capital, inventory or perception, which is an example of an information collection. Examples of flow, on the other hand, are birth rates, mortality, amount of investment, etc. The dynamic behaviour of the stock depends on the behaviour of the input and/or output flows.

The value of the stock at a specific time in the SD model is calculated by adding the inflow value to the original value of the item and subtracting the outflow value (D. Blumberga et al., 2016).

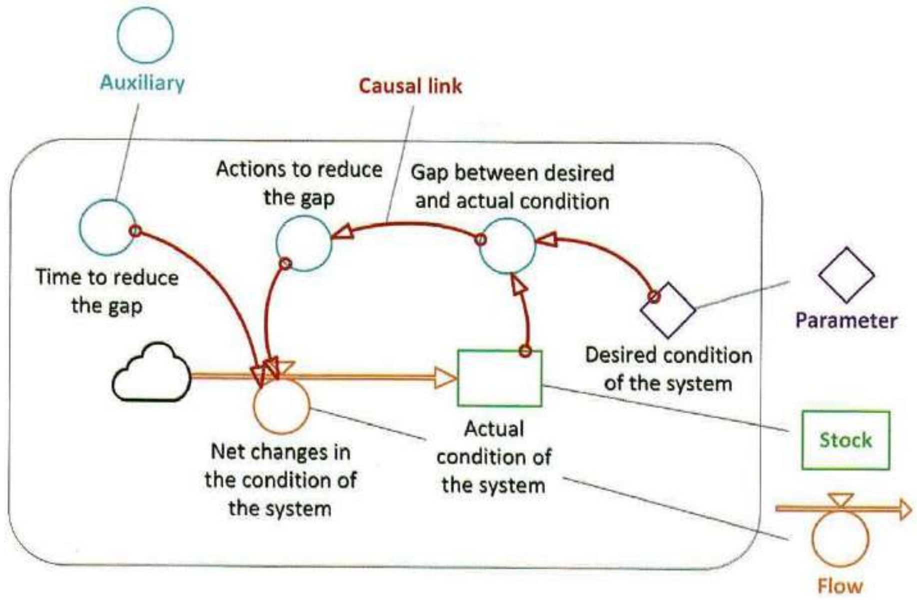


Fig. 1.1.1. Designations used in SD models

The SD system consists of interconnected elements. When creating the structure of a complex system, the interaction of elements is represented using feedback loops. Feedback loops characterize causal relationships between the elements of the system. SD distinguishes between two types of feedback loops – positive and negative, as well as a combination of both. A positive or stimulating feedback loop seeks to amplify any impact and create exponential growth. Growth cannot continue indefinitely, so there are both natural and man-made control mechanisms that limit it and try to ensure the balance of the system. These control systems are called negative feedback loops. A negative or "aim-seeking" loop seeks to counterbalance any influence and direct the system towards an equilibrium position or goal. Interconnected positive and negative feedback loops form combined feedback loops. Combined loops create different behavioural structures depending on the influence of the dominant loop.

1.2. Main principles of SD

SD has three main principles:

- The structure of the system affects the behaviour of the system;
- The feedback loop is the primary structural analysis unit;
- Structural changes need to be made to achieve behavioural changes.

There are five main stages in the process of creating an SD model: formulating a problem; development of the dynamic hypothesis; formulation and simulation of the model; testing of the model; policy making and testing (Figure 1.2.1).

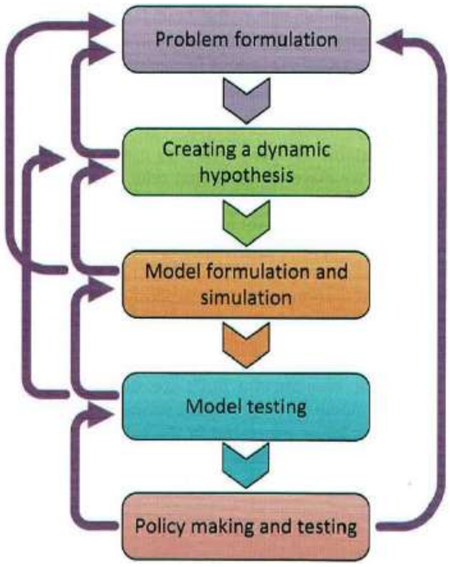


Fig. 1.2.1. Stages of the SD modelling process.

1.2.1. Formulating the problem

Using the available information about a system that exhibits problematic behaviours, a timeline of the representation of the dynamic problem (system behaviour) is created and described. This graph is called a baseline behaviour scenario. If necessary, it can graphically display the behaviour of the main variables.

When defining a problem, the following questions must be answered: What is the purpose of the model? What is the role of the model – is it a descriptive, explanatory or learning model? What is the nature of the problem under study – linear or nonlinear, static or dynamic?

The origin of all problems is systemic. The problem is formulated in two steps – identifying the problem and defining the problem.

1.2.2. Development of a dynamic hypothesis

When a problem and its behaviour are formulated, the main stocks associated with the previously created base scenario behaviour are drawn, as well as the flows that affect these stocks. Labels are given to the elements and describes how the flows could affect stock changes. The hypothesis of what causes changes in flows and how the structure of the stock and flows can create the behavioural structure of the system base scenario originally created is expressed. The structure of stocks and flows is transformed into causal loop diagrams to explain the dynamic hypothesis of the interaction between variables.

SD modelling is based on the recognition that the structure of the system influences the behaviour it generates, thus feedback loops are the primary structural unit to be analysed when creating a system structure model. When SD models are created, the feedback relationships between the elements are represented in the form of causal loop diagrams.

1.2.3. Formulation and simulation

Using modelling software, the dynamic hypothesis is transformed into a computer model that can simulate the problematic behaviour of the real system. At the formulation stage, equations are written that represent the functional relationship between the variables in the model, and they are entered into the computer simulation model. At the simulation stage, the model is powered by a modelling program, such as *i-Think, Stella Architect, Vensim, Powersim*, and the main task of this process is to recreate the real problem in the model. Thus, variable output data are obtained in a graphical form, which is compared with the originally created behaviour of the system base scenario. The discrepancy in the results indicates an error in the established system model. If the modelled system behaviour matches the behavioural schedule of the baseline scenario, this is proof that the system may have been modelled correctly. The possible correctness of the model is always an assumption, since different models can lead to similar behaviours and it is impossible to clearly determine whether it is this model that accurately depicts the behaviour of the real system. Confidence in the model's compliance with the system under study can be increased by various model verification tests.

When defining variables in a model, you need to answer the questions: What are the variables of interest? Is the variable endogenous or exogenous? Are the suitable variables included and the unnecessary variables excluded?

1.2.4. Verification of the model

Verification is the stage of model analysis. The purpose of verification is to provide assurance that the model is complete and useful. There are several system structures and behaviour assessment methods for verification of SD models. Model verification answers the following questions: Is the model boundary fit for purpose? Is not the model too complicated or simple? Are all the elements explaining the problem included?

Crucially, no model exactly coincides with the real object or system that is being modelled, so there are no absolutely reliable models. Models are considered reliable and valid if they can be used with confidence. In order to build confidence in its validity as a result of the validation of a model, the purpose of the model must first be clearly defined.

There are various validation tests for SD models to increase confidence in their validity and reliability. Verification tests for SD models can be divided into three groups:

1) Verification tests of the model structure that assess the structure and elements of the model without analysing the relationship between the system structure and its behaviour;
2) Model behaviour verification tests that assess the adequacy of the model structure by analysing the behaviour generated by the system;
3) Policy impact assessment tests.

1.2.5. Policy making

In SD models, problems are managed and solved by changing stocks, and this is done by regulating flows. The SD policy is a set of decisions that regulate flows, reducing the difference between the desired and real value of the stock. Decision-making requires information provided by existing values of the stocks. The policy is contained in the feedback loops between flows and stocks.

Policy making is a change in the rules governing flow regulating, most often by creating a new feedback loop structure or correcting the existing one, reinforcing the "good" loops and weakening the "bad" loops. When creating a policy, force application points are searched – parameters that when changed change the flow that affects the stocks - slightly changing one parameter changes the whole system very significantly

Policy implementation verification tests analyse the question of whether the real system's response to policy changes will coincide with the model's projected changes in system behaviour under the influence of policy changes. Policy implementation verification tests identify policy actions that have led to improved real-system behaviour and analyse whether policies found to be successful in the model also improve the behaviour of the real system when implemented in it. When analysing possible changes in system behaviour under the influence of different policy actions, the credibility of the resulting behavioural changes should be evaluated. Another type of testing is to test the model response to the existing policy used in the real system to see if the model responds to this policy in a similar way to the real system.

1.3. General system structures and behaviour

The most common types of system behaviour are exponential growth, goal-driven behaviour, S-shaped growth, fluctuating behaviour, increase with overreach, overreach and collapse (Figure 1.3.1).

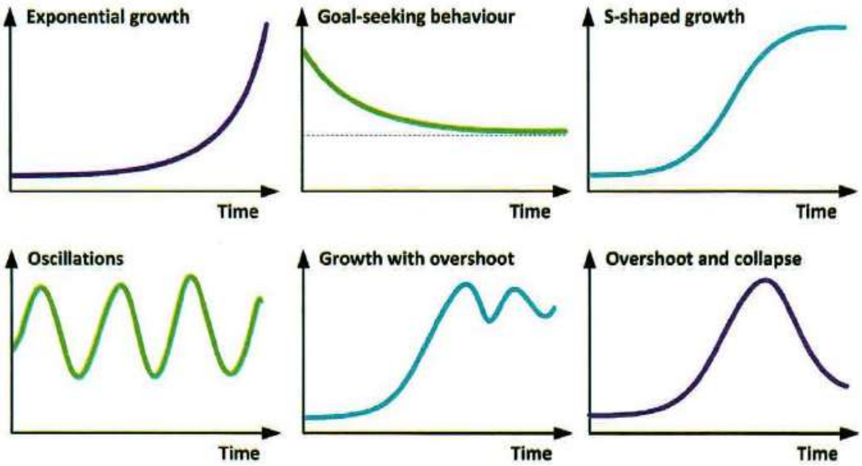


Fig. 1.3.1. The most popular types of behaviours of the system

These types of system behaviours help to interpret the dynamic behaviour of the observable real system. For example, if the system shows an exponential increase, the model builder is looking for a dominant positive feedback loop. In turn, the tendency of the system to return to its original state after some disorder indicates that there is at least one strong negative feedback loop. Fluctuating behaviour often suggests that a loop of negative feedback with a delay is involved. The increase in S-type arises from related positive and negative loops that react non-linearly and in which there are no significant delays. Linear behaviour is characteristic only in those cases when there are is feedback, however, in most real systems feedback loops are. Linear behaviour is also observed in those cases when the system is in balance – the system is not subject to any forces that could make changes to the system, but real systems are always in an unbalanced state and create behaviours that are not linear. The equilibrium position of the systems is used to test policies, shocking the system with some policy.

In the case of *exponential growth or decrease*, there is an initial variable that begins to increase or decrease. Initially, the growth rate is lower, later it increases sharply. In SD this increase is characterized as follows: the more there is, the more occurs. The structure that generates exponential growth has positive feedback loops.

In the case of *goal-oriented system behaviour*, the measured value is either larger or smaller than a specific goal, and over time the system tries to regulate itself in order to achieve this goal. All living (and also lifeless) systems create goal-driven behaviour. Such a system will only be in balance when all stocks are at the same time equal to their objectives. The structure that creates goal-driven behaviour is a first-degree negative feedback loop.

The growth of the S-type is a combination of exponential growth and goal-driven system behaviour. The variable initially grows exponentially, but then transforms into a goal-driven behavioural structure. The structure that produces an S-shaped increase is a combination of positive and negative feedback – both loops fight over who will prevail until the fight ends in long-term balance.

Fluctuating behaviour occurs when the variable fluctuates around a certain value. This is one of the most common types of dynamic behaviour in the world and has many different forms. The structure that generates the behaviour of the oscillation form is a combination of negative feedback and delay. There are four different forms of fluctuating behaviour::

- Uniform fluctuations – periodically repeated;
- Damping oscillations – occur in systems that use dispelling processes, such as friction in physical systems or smoothing of information in social systems;
- Exploding fluctuations – increase until either they become even or break the system. In real life, they are very rare;
- Chaos – fluctuations that occur irregularly and never happen again.

There are cases when the system can exceed its limits or capacity. If this happens and the capacity of the system is not completely destroyed, the system tends to fluctuate around the capacity. It is called a system with growth and fluctuations and is based on a combination of S-shaped and oscillation behaviour. From the beginning, the system creates S-shaped behaviour – the dominant loop is first a positive loop, then when the system capacity is reached, it is replaced by a negative loop, but it is not able to ensure long-term stability of the system, because of the delay in the system, which occurs when the growth rate adapts to the available resources. The probability of exceeding the limits is higher when the system approaches the limit at high speeds. If delays in the system are fixed, the only way to prevent the limit from being exceeded and fluctuations occurring is to reduce the rate of growth.

If the capacity of the system is damaged, the system will collapse. It is called a system with growth and collapse – from the beginning the system creates S-shaped behaviour – a positive loop prevails, then when the system capacity is reached, it is replaced by a negative loop, but it is not able to provide long-term stability of the system due to insufficient resources, and a second negative loop turns on. Systems that go beyond their limits are vulnerable to collapse if resources are damaged by too rapid development. This behaviour is very often caused by systems where human and natural systems interact, such as too many fishing vessels at sea, too many livestock pastures, overcrowded areas.

1.4. Use of SD in energy

One of the main areas of use of SD modelling is policy analysis. The world's socio-economic system model WORLD1 and its subsequent versions in the 1970s started the use of SD modelling in the field of environmental policy. At that time, the model sought the necessary policy changes that would be able to steer the global system towards sustainable development in the future, aware of the problem of resource limitation (D. Blumberga et al., 2016). In energy development planning, SD is a useful tool that provides an opportunity to understand the structure of the energy system and the interaction between its elements and to look for alternatives to increase the utilisation rate of EE and RES. In recent years, SD has been increasingly being used to study energy problems. Most SD is used to study specific challenges such as market dynamics, bioeconomy, energy policy and CO_2 emissions (Saavedra M. et al., 2018). The SD use in energy can be conditionally divided into 3 groups (Aslani et al., 2014): assessment of the physical structure of energy systems and development of different scenarios; the environmental impact of energy systems and CO_2 emissions; energy policy in relation to energy security.

For example, scientists from the University of Huelva have used SD to study in depth the impact of changes in the energy system and GDP on Ecuador's CO_2 emissions, with a particular focus on reducing fossil energy consumption and increasing the efficiency of fossil energy (Robalino-López et al., 2014). The model was established for the period from 1980 to 2020, where the period from 1980 to 2010 was used to determine parameters, while the period from 2011 to 2020 was used for extrapolation of data and determination of forecasts. The model includes three sub-models:

1) An economic sub-model using parameters such as GDP, market balance, household expenditure, government expenditure, exports, imports etc.;
2) A sub-model of energy consumption and productive sector structure using parameters on energy consumption and energy intensity of five sectors of the economy, distribution of types of energy resources and contribution to the national economy;
3) A sub-model of energy intensity and energy matrix using parameters on the proportion of different types of energy in the energy matrix.

Four scenarios were created for the forecast period, taking into account GDP growth and the development of the distribution of energy resources types : (1) a baseline scenario with a steady development of GDP, energy distribution and sector structure; (2) doubling of GDP compared to 2010; (3) doubling the GDP and doubling the share of renewable energy; (4) doubling the GDP, doubling the share of renewable energy and improving energy efficiency (EE). The main conclusion of the authors is that CO_2 emissions can be controlled even at continuous GDP growth, if the use of renewable energy increases in parallel, the structure of the production sector is improved and more efficient fossil energy technologies are used. In addition, the model showed that the promotion of renewable energy and the increase of EE have an equal effect on reducing CO_2 emissions.

SD has been used (Aslani et al., 2014) to assess the role of renewable energy policy in Finland's energy dependency by analysing the interaction between variables such as renewable energy promotion measures, energy dependency and energy demand. Article assesses three different scenarios for Finland's renewable energy policy by 2020:

1) Before implementing the renewable energy policy and action plan;
2) Following the implementation of the 100% renewable energy action plan;
3) After 90% biomass, 50% hydropower, 80% wind energy, 100% geothermal energy and 50% solar action plans have been implemented.

The model results show that the introduction of action plans to increase renewable energy capacity would lead to savings of more than $4 billion in natural gas imports (2013-2020).

The SD model is also a useful tool for investment research. For example, , (Liu & Zeng, 2017) has assessed the risks associated with renewable energy investments. The study assesses three main risks: technological, political and market risk. The results show that political risk is a key factor affecting renewable energy investments in the initial phase. Political risk and technology risk, on the other hand, gradually decrease over time, while market risk gradually becomes the main risk factor in the maturity phase of investments. In addition, market risk decreased as installation costs decreased, technological progress reduced the technological risk, and the increase in additional tariff subsidies reduced political risk.

Alishahi, Moghaddam and Sheikh-El-Eslami, on the other hand, have used SD to study the impact of incentive mechanisms on wind energy investments (Alishahi et al., 2012). The model takes into account such key factors as unpredictable demand, fuel price and wind energy production, which influence long-term development planning. In order to address the risks posed, such as the impact of risks on decisions through SD modelling, the article proposes improved incentive mechanisms for wind energy investments.

Meanwhile, the SD model has also been used to assess the impact of capital subsidies and the supply tariff on solar PV capacity to determine which solar PV incentive policies or policy packages offer the greatest economic benefits (Hsu, 2012). The results show that the use of only supply tariffs or capital subsidies with a fixed return on investment (ROI) limit when increasing the supply tariff or subsidies is a successful approach. When the upper limit for ROIs is fixed, the impact of different combinations of supply tariffs and subsidies on the installation of solar photovoltaic (PV) installations is negligible. However, policies with higher subsidies and a lower initial delivery tariff price have lower average CO_2 emission reduction costs.

SD connected to Monte Carlo simulations, Jeon and Shin (Jeon & Shin, 2014) have carried out a long-term assessment of RES technologies using solar PV technologies in Korea as an example. According to the authors of this article, the use of such a method provides an opportunity to identify various possible future uncertainties and measure their impact on the value of technologies, and thus better control uncertainties and risks.

The results suggest that private companies will struggle to profit from PV technology in the near future, making PV technology difficult to spread without government support. Furthermore, indirect aid in the form of tax refunds and subsidies does not significantly help. Government support in the form of a supply tariff is necessary, but not sufficient.

One of Latvia's examples of the use of SD in the field of energy is the model of increasing the share of RES for the district heating system, which integrates various policy instruments (A. Blumberga et al., 2010). The long-term action direction of Latvia's energy policy is to increase the share of RES in energy, thus promoting the security and independence of the country's energy supply and reducing the environmental impact of greenhouse gas (GHG) emissions. A wide range of policies are being implemented globally to promote the development of the market for using RES technologies. The policy instruments for promoting the RES market can be grouped into four quadrants – target groups (Figure 1.4.1).

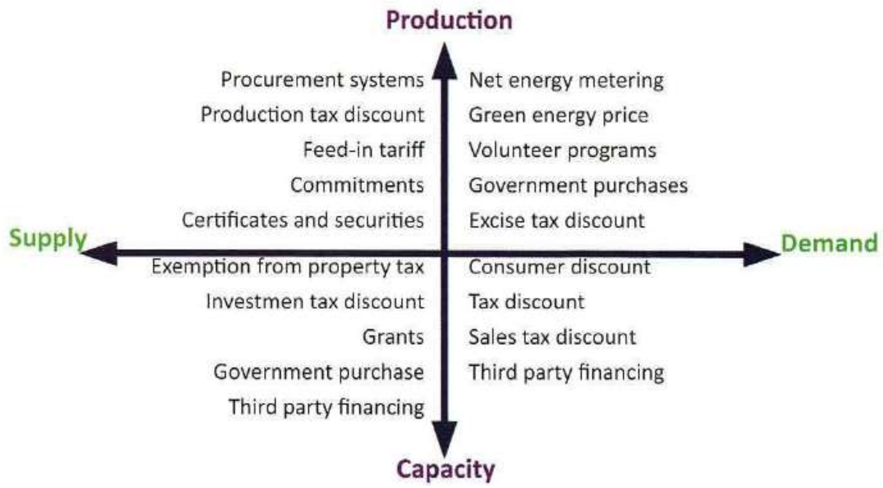


Fig. 1.4.1. Policy instruments for the promotion of RES market.

Policies should target the final energy user (energy demand plane) or energy producer (supply plane). They must be focused on capacity (machinery and capital costs) and production (production or service and buyer-related costs). In addition to the policy instruments for promoting the RES market, administrative and regulatory procedures that are not directly related to financing are also essential, but they have a significant impact on the development of the RES market. Programmes to increase knowledge and the circulation of information also play an important role.

In the particular example of Latvia, the purpose of RERS share increase model is to present as accurately as possible the structure of the Latvian CSA system; to look for alternatives to Latvia's achievement of the set targets for increasing the share of RES; analyse whether this is possible by focusing on increasing EE and making fuller use of RES by replacing natural gas with wood fuels. Three policy instruments have been used to promote the EE and the use of RES and aim to analyse the impact of these three policy instruments by identifying a key policy instrument or a combination of policy instruments that will contribute to the exploitation of the potential of energy wood in the production of heat.

SD has also been used to study the development of the Latvian transport system by creating a model describing the development of the Latvian biofuel market by 2050 (D. Blumberga et al., 2016). The aim of the model is to assess the impact of the different policy support instruments on the share of biofuels in total transport fuel consumption in order to look for the most effective policy strategies for progress towards the national biofuel target in 2020 and beyond. The model was developed in the programming environment of the modelling program *Powersim Constructor* 2.5.

The basic construction of the model consists of three interconnected subsectors – the agricultural or raw material procurement sector; biofuel production sector (biofuel supply); biofuel consumption sector (biofuel demand). The model includes policy instruments such as subsidies to biofuel producers, subsidies for biofuel users to convert existing cars for biofuel use, subsidies for the development of biofuel refuelling infrastructure, reduced interest rates on loans for the installation of new production capacities and subsidies for farmers to grow raw materials for biofuel production. The SD model for the analysis of biofuel development policy instruments for the agricultural sector is shown in Figure 1.4.2.

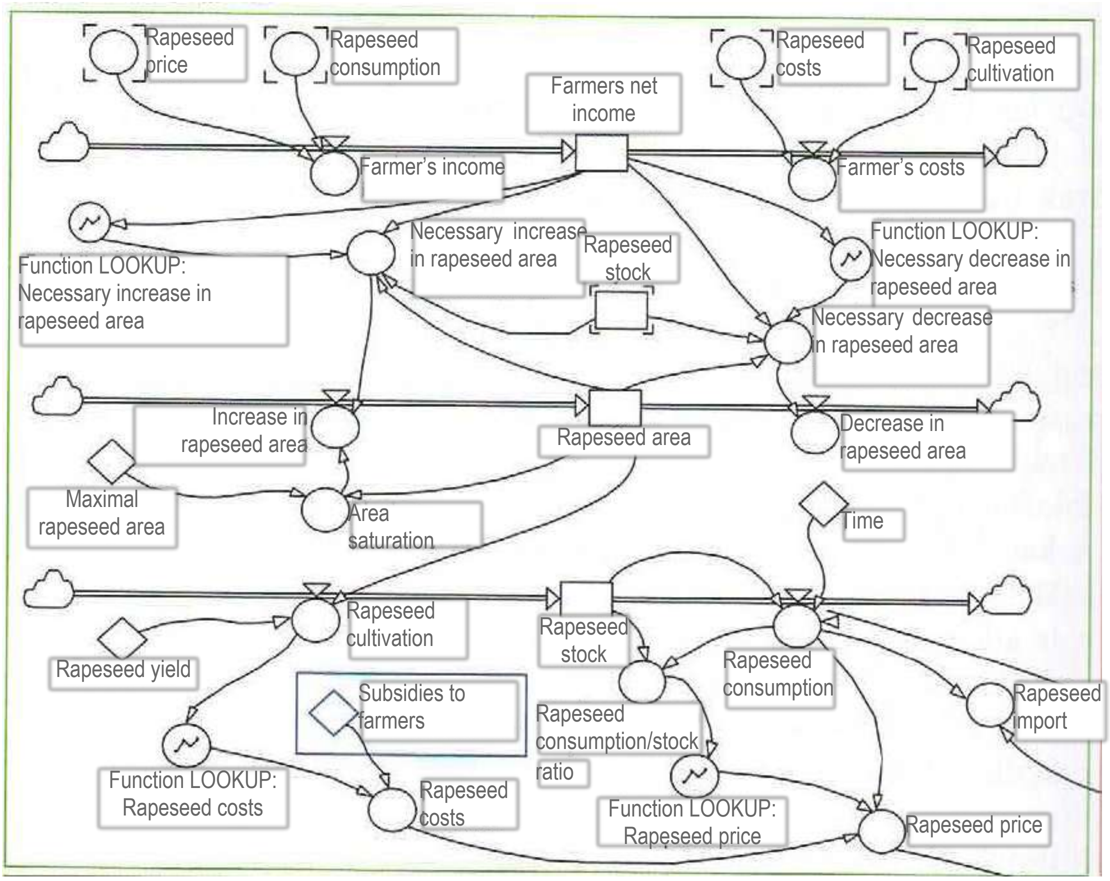


Fig. 1.4.2. SD model for analysis of biofuel production development policy instruments for the agricultural sector

The analysis of biofuel policy instruments is based on the demand for biodiesel in four different scenarios up to 2050:

- Scenario 1: Additional policy support instruments are not implemented in the baseline scenario;
- Scenario 2: Provides subsidies for vehicle users to convert cars to use biodiesel or subsidies for the development of biofuel refuelling infrastructure;
- Scenario 3: provides subsidies for farmers to compensate for the cost of growing rape;
- Scenario 4: Provides subsidies for biodiesel producers to compensate for the cost of production.

The results of the modelling in the baseline scenario showed that additional support measures to promote the production and use of biodiesel need to be implemented in order to reach the 10 % biofuel target in 2020. According to the results of the model, an increase in biofuel demand can be achieved through two policy instruments: subsidies to farmers and subsidies to biofuel producers. Scenario 2, on the other hand, does not differ significantly from the baseline scenario, which shows that the impact of subsidies for vehicle users to convert cars to use biodiesel and the subsidy for the development of biofuel refuelling infrastructure on increasing the share of biodiesel in transport fuel consumption are not significant. However, as the model shows, the most significant increase in the share of biodiesel consumption can be achieved through a policy instrument providing subsidies to biodiesel producers.

Another example in the context of Latvia is the use of SD, studying the increase in the resilience of the natural gas system by integrating renewable methane into the system (Feofilovs et al., 2019). The model includes parameters on gas in the transmission system, gas injection into the storage facility, gas in the storage facility, gas input into the transmission system, natural gas flow in the country, local gas supply and the gas flow out of the country. The model takes into account the technical characteristics of the natural gas infrastructure, as well as the dependence of the natural gas flow and storage regime on the seasonality of gas demand. In this case, it is assumed that the resilience of the energy system can be increased by diversifying the natural gas system with biomethane and renewable methane from P2G technology and thereby increasing energy security. The SD model includes the impact of the policy to promote RES on biomethane subsidies affecting biomethane production and investments in renewable energy technologies affecting biomethane production in P2G installations. The model is characterized by a reinforcing loop for gas input and a reinforcing loop for gas supply, both balanced with three balancing loops. This type of model provides an opportunity to identify weak links in Latvia's RES promotion policy and thus contributes to the CO_2 emission reduction targets.

DEVELOPMENT OF SD MODEL TO DETERMINE RES POTENTIAL

1.5. Formulating the problem

Global energy demand continues to grow, and the average temperature of Earth's atmosphere and ocean waters is also rising, which is a clear sign of global warming. The main cause of global warming is GHG accumulation in the atmosphere, which is largely due to the use of fossil fuels, which are released into the atmosphere as a result of combustion, and accumulate there. Climate change caused by global warming was already recognised as a world-wide problem as early as 1979, when the first global climate change conference was held in Geneva, but the average global temperature continues to rise. One of the main tools to reduce global warming is the transition from fossil fuels to RES, thus preventing GHG emissions from being created and released into the atmosphere. On 11 December 2019, the European Commission presented the European Green Deal, which aims to achieve climate neutrality in Europe by 2050 (European Commission, 2019), which means that Latvia will also have to achieve this goal.

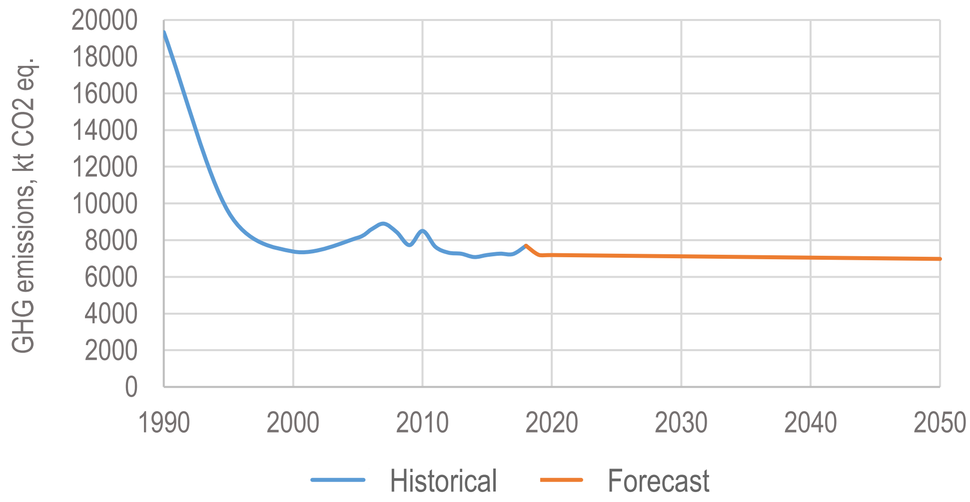


Fig. 2.1.1. Changes in GHG emissions emitted in the energy sector (Latvian Environment Geology and Meteorology Centre et al., 2019).

As can be seen from Figure 2.1.1, the amount of GHG emissions in energy in Latvia has not actually changed in the last 20 years. The greatest drop was observed between 1990 and 1995, when industrial production volumes in Latvia dropped significantly after regaining independence, but since then there has been no sharp drop in GHG emissions. As of 2000, there was even a gradual increase in GHG emissions, which would most likely have continued if Latvia had not been hit by the economic crisis that halted economic growth in 2008 and thus the rise in GHG emissions. Latvia's stagnation is largely due to the level of GHG emissions of 1990, which is taken as a reference point for setting climate targets, and puts Latvia in a better position than many countries, because, without actually doing anything, the 2020 targets have been met. This approach will no longer work in the future, as achieving climate neutrality in 2050 requires a clear vision and targeted actions. GHG emissions will remain unchanged, continuing the practice of the last 20 years.

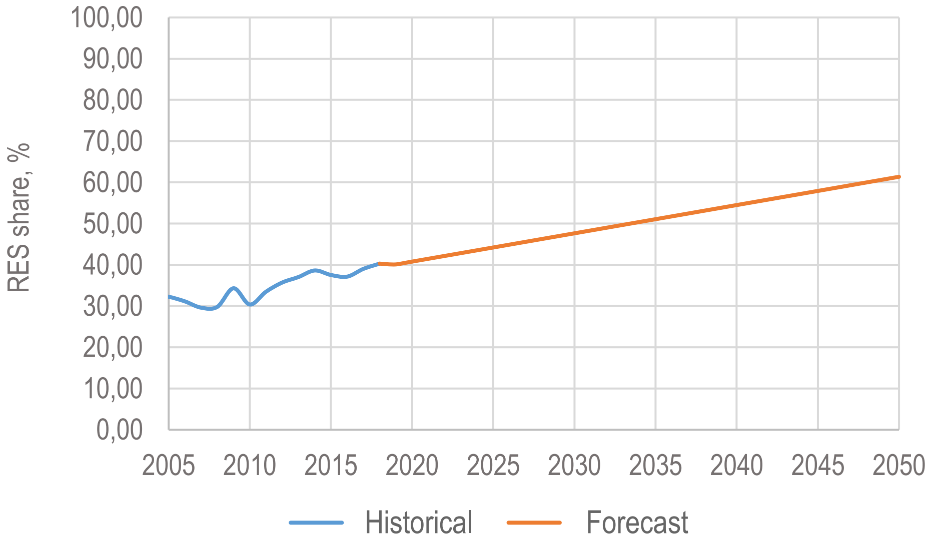


Fig 2.1.2. Change in the share of RES (Centrālā statistikas pārvalde, 2020a).

As with GHG emissions, the trend of changes in the share of RES does not indicate the potential for achieving climate neutrality in 2050. Although the share of RES has increased from 30% to 40% over the last 15 years (Figure 2.1.2) and is one of the highest in Europe, even this rate of growth is not sufficient to reach a RES share above 90% by 2050. With the current rate of development, only 60% of RES could be reached in 2050. The transport sector is in the worst position, where fossil resources account for more than 95% of total final energy consumption.

The EU has taken a course towards achieving climate neutrality in 2050, and Latvia, as an EU Member State, is also bound by this objective. To achieve this, it is necessary to review the current approach to tackling climate issues, as well as to pay much more attention to the integration of RES and the reduction of GHG emissions.

1.6. Development of the model

In order to assess the development of the energy sector and the potential for the use of RES, a tool capable of analysing complex and dynamic systems is required, therefore the SD modelling method was chosen for the research. The model is created in *Stella Architect* computer program.

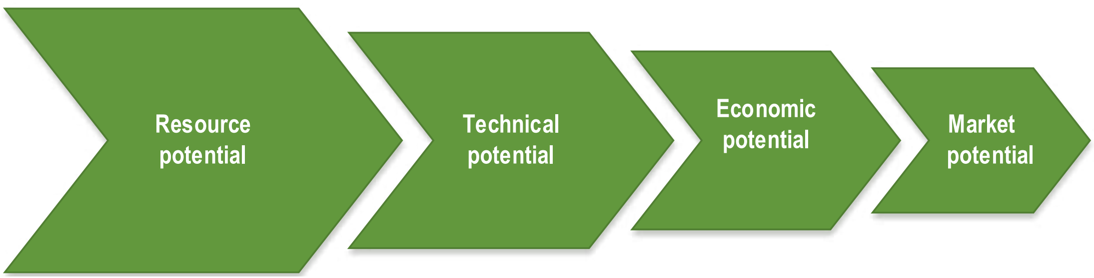


Fig. 2.2.1. Levels of the renewable energy potential (Brown et al., 2016).

The aim of the project is to assess the economic potential of renewable and local energy sources, but in order to understand what economic potential means, it is necessary to understand what other levels of potential exist. Figure 2.2.1 shows four levels of renewable energy potential.

The first level is the resource potential, which is the greatest potential, and describes the amount of energy physically available in the region concerned. For example, the total amount of solar radiation received by a given area or the total available forest area for the extraction of wood resources. The next level is the technical potential, which also takes into account geographical constraints, as well as the operational parameters of the system, but does not look at the economic advantage. An example is solar PV panels – the technical potential would be the amount of energy available if the entire technically available area of land were covered with solar PV panels, taking into account the required area of land for one panel, the desired position against the sun, the efficiency and other technical parameters. The next level of potential is the economic potential, which determines how much of the technical potential can be exploited economically justifiably. For a resource to be economically justified, the cost of producing energy must be lower than the technologies they would replace. In order to determine this potential, the cost components of potential projects and their future forecasts are taken into account, including both technology costs and the costs of operating equipment. Finally, the last level of potential is market potential, which takes into account both competition with other technologies, the amount of energy needed in the region, the policy support instruments available, regulatory constraints, investor interest and other factors determining the potential of each of the resources to develop in the existing market system in a given region.

The project aims to assess the economic potential of renewable and local energy resources, however, the project stipulates that territorial, spatial planning, regulatory constraints, as well as long-term guidelines for energy, environmental and climate policies should also be taken into account. On this basis, when creating the model, it was decided not to limit itself to assessing the economic potential, but also to assess the potential of the market, as well as to understand what could be the distribution of resources in the future energy mix, taking into account both technical, territorial and economic parameters, as well as regulatory and policy conditions.

The model looks at both the economic potential of whether and how economically viable the RES technology is and its potential to enter the market by competing with existing and traditional technologies. Economic potential does not in itself mean the use of technologies, since the system is subject to resistance from existing market players who do not want to give up their position or are not yet ready for change, but the market potential also takes these factors into account.

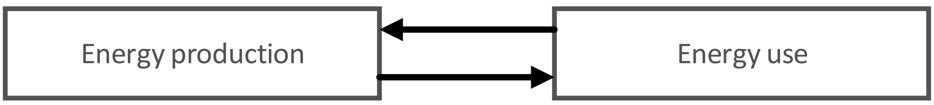


Fig. 2.2.2. Main units of the energy system

The structure of the model is built on the basis of two large blocks – energy production and energy consumption (Figure 2.2.2). Although energy resources are used directly in the part of energy production, where they generate electrical, mechanical or thermal energy, it is also important to take into account the share of consumers. It is consumers who determine how much and where energy is needed. Given that energy users are expected to become EE in the future, as well as new solutions (smart grids, decentralisation, aggregators, low-temperature district heating, etc.) might enter the energy supply system in the future, this will also have an impact on the share of energy production, so both the production and consumption share need to be seen in order to model the potential for energy use.

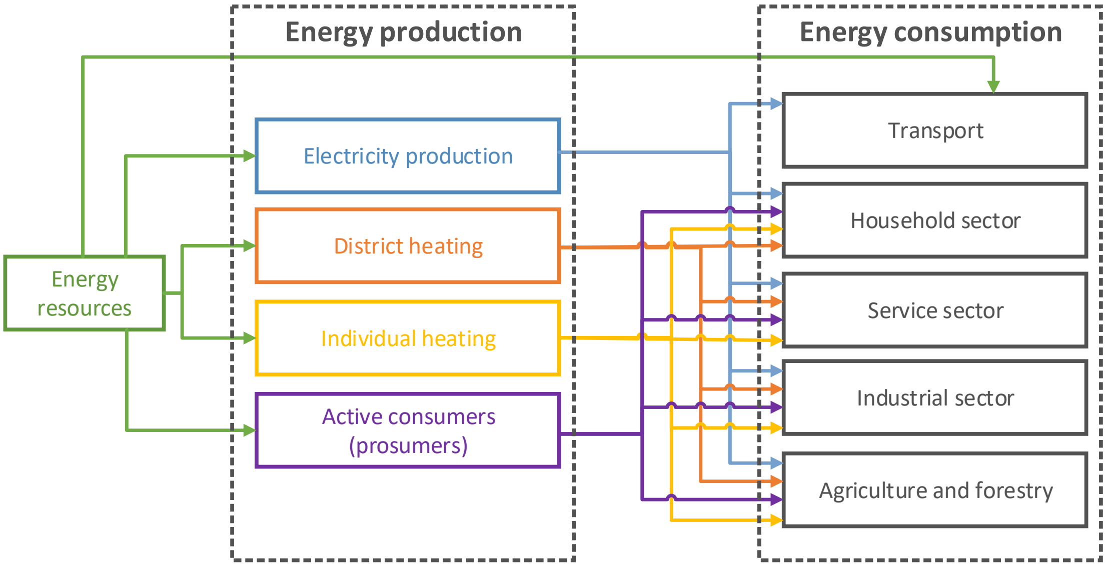


Fig. 2.2.3. Main elements of the energy system

Energy production consists of two large blocks – centralised and individual production. Electricity production is mainly centrally carried out, and the electricity produced is delivered to consumers through the transmission and distribution networks, but decentralised production is also gradually developing, where households or enterprises install microgeneration equipment in their territory, thus becoming both producers and consumers at the same time. Decentralised producers, however, remain largely connected to the distribution network, and when more energy is produced than is consumed, the remaining energy is transferred to the grid. The missing electricity is purchased from the grid. According to the available information on the website of AS "Sadales tīkls", in 2019 around 500 microgeneration equipment units, mainly solar PV panels, were installed and connected to the network in Latvia (LETA, 2019).

The production of thermal energy is also carried out both centrally and individually. District heating is mainly characteristic of cities and other densely populated areas, while individual heating is characteristic of rural regions as well as production enterprises

1.7. Causal loop diagrams

When creating an energy model, diagrams of causal loops were initially drawn to understand the relationships between the elements of the system. This is the first step before creating a model structure. This chapter describes the main loops and relationships that are taken into account in the development of models. The study uses both the relationships previously found and models created by the project performers, which are identified by the project stakeholders.

Figure 2.3.1 shows the main relationships between the use of natural gas and renewables in district heating. As can be seen from the picture, the main driving force is the production tariff. The lower the tariff for any of the technologies, the more economically attractive it becomes for business owners and investors. An additional advantage that can contribute to the use of renewable resources, in particular solar collectors, is the transition to the use of a low-temperature heat carrier in district heating. Given EE's objectives as well as the high efficiency of new buildings, the need for a high-temperature heat carrier will decrease significantly and the temperature schedule of heating networks could decrease to 60/30, or even lower. The use of low-potential heat significantly improves the efficiency of solar collectors, as well as opens the possibility of economically justified use of industrial heat residues in district heating. A lower temperature schedule also helps to reduce heat loss from transmission networks, thereby improving overall system efficiency, and making district heating more attractive. It is also important to take into account the condition of buildings. In order to be able to switch to low-temperature district heating, it is necessary to renovate the current buildings, and adapt them to the use of low temperatures, which means that the production and consumption part cannot be viewed separately, but they need to be viewed and modelled together.

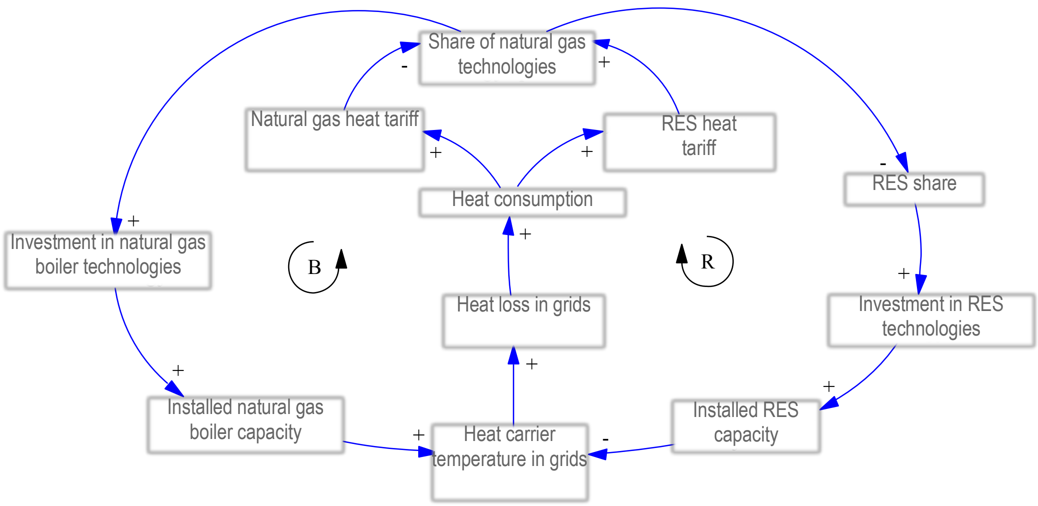


Fig. 2.3.1. Causal loop diagram for the DH system.

Figure 2.3.2 shows the relationships that are taken into account in the electricity generation part. The main elements of the system are technology capacities – fossil and RES capacities. They compete with each other, the lower the costs of one of the technologies, the more attractive it is, and therefore more investment is made in the technology in question. An additional factor that is taken into account is the lack of experience in the use of RES, which increases risks and makes energy production more expensive with the resource concerned. This applies to the use of biomass to a lesser extent than to the use of solar or wind energy, because the use of biomass technologies in Latvia has already accumulated some experience, while wind and solar technologies have not been widely used so far.

In the electricity supply part, it is also important to take into account not only the production part, but also the demand for electricity. Electricity demand is affected both by economic developments that contribute to the increase in electricity consumption and by EE measures that reduce electricity consumption.

From the point of view of energy independency and energy security, it is important that the maximum amount of energy can be produced in Latvia, moreover, making the most of local resources. However, 100% on-site electricity generation is not always economically justified, as it would mean installing excess capacity to cover peak loads that would work only a couple of hours a day and make the overall cost of the system more expensive. Consequently, part of the electricity consumption is covered by imported electricity. Import electricity is purchased in the event that local capacity is unable to meet demand or its price is lower than locally produced electricity.

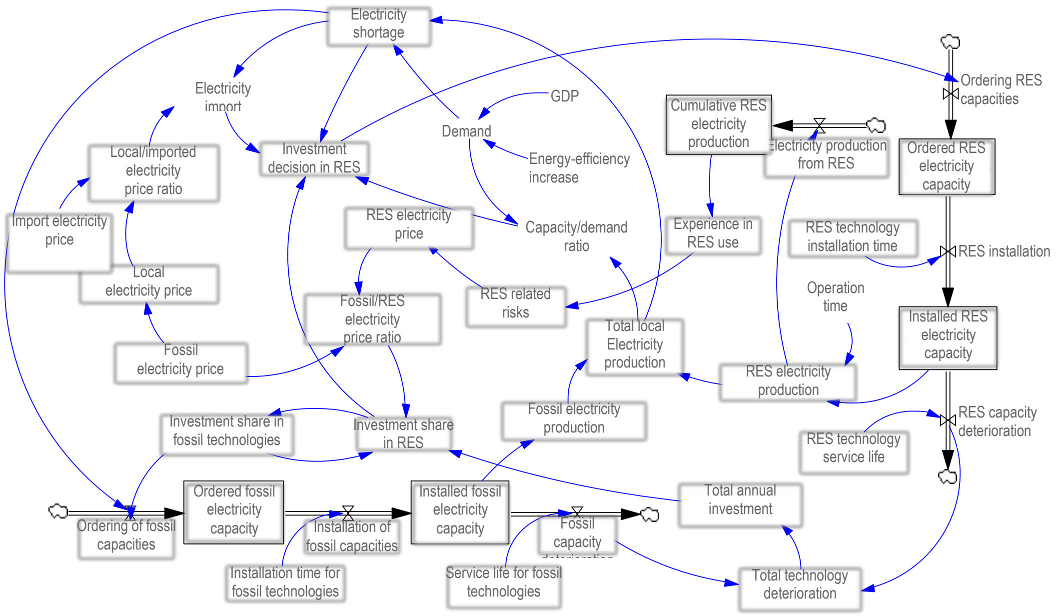


Fig. 2.3.2. Interconnections in electricity generation

Figure 2.3.3 shows the relationships that are taken into account and are essential for the development of wind farms. The figure shows four loops that determine how wind farm capacity will develop. One positive loop has been defined, which contributes to the creation of wind farms and the installation of new capacities, as well as three balancing or negative loops that slow down the creation of wind farms.

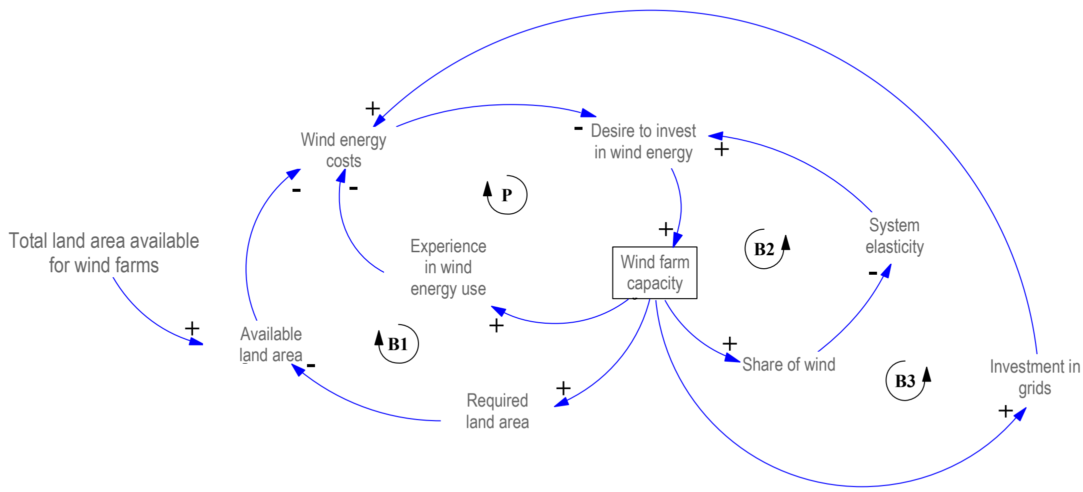


Fig. 2.3.3. Diagram of causal loops for the development of wind farms

The positive loop (P) is associated with the accumulation of experience – the more wind farms are installed, and the more electricity is produced, the more experience is accumulated. This makes it possible to choose technologies more successfully, to operate them more efficiently, and thus to reduce the cost of wind energy, thus raising the attractiveness of technologies in the eyes of investors and promoting the desire to invest in the installation of new capacities. One of the disincentive conditions (loop B1) is the availability of usable land for the installation of wind turbines. Since, on the basis of regulatory and technical restrictions, the area of land where wind turbines are possible and it is allowed to install has been determined, the interest in the creation of wind farms would decrease as this limit approaches. This is due to the fact that it would be increasingly difficult to find places to house new wind farms, as well as the acquisition of the remaining areas, most likely entails additional costs.

Another obstructive loop is due to the flexibility of the system, or the willingness to absorb a high proportion of variable energy (B2). The higher the installed capacity of wind farms, the more energy is produced, which results in a high share of wind energy in the total electricity production balance. The main problem lies in the fact that wind energy cannot be regulated, therefore, in case of a high share of wind, a situation may arise when the schedules of production and consumption loads do not coincide – there is an excess of electricity or a shortage of electricity.. While the share of wind energy is small, this discrepancy can be balanced with traditional technologies, but as the share of wind energy increases, it is necessary to look for solutions to use excess energy, or how to accumulate and use it at times when there is a shortage of electricity in the system. Possible solutions are the use of surpluses for heat generation, hydrogen production, storage in electric car batteries, as well as other solutions, however, this entails additional costs for adapting the system, therefore, in case of a high share of wind energy, interest in new investments to increase wind capacity could decrease.

The obstructive loop B3 is related to the construction of transmission networks. While the installed wind capacity is small and while they are deployed close to nearby network infrastructure, the costs of connecting to the networks are relatively small. As installed wind capacity increases, as well as their location away from the existing infrastructure, additional costs are incurred in the construction of transmission network capacities and capacity increase, which also means higher wind energy costs, thus reducing interest in the installation of new wind capacity.

Depending on which loops are stronger, it depends on whether the installed wind turbine capacity increases in the future, will remain at the current level, or decrease. It would be possible to draw a similar loop diagram for solar PV panels.

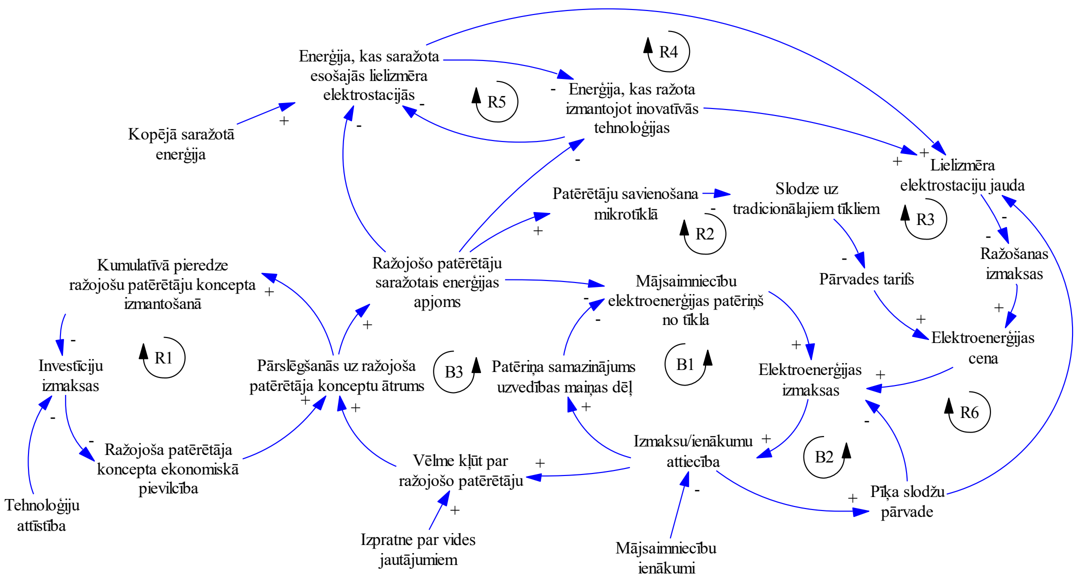


Fig. 2.3.4. Decentralisation of electricity supply and changes in electricity consumption

Figure 2.3.4 shows the main loops in the regulation of household electricity consumption and the transition to decentralised electricity generation. The figure defines six reinforcing and three balancing loops. Loop B1 describes changes in electricity consumption in the household sector as a result of behavioural changes. This is mainly due to an increase in electricity costs. The higher the cost of electricity, and the higher the cost-to-income ratio, the more household members are looking for ways to save. The easiest way is through behavioural change – turning off devices when not in use or using them less. The change in behaviour, however, can occur not only as a result of economic pressure, but also as public awareness of how energy can be saved.

B2 is due to the alignment of peak loads. In this case, costs can be reduced by transferring part of the consumption from peak hours, when electricity is most expensive, to night hours, when electricity is cheaper, thus extinguishing peaks. This applies only to households using dynamic tariffs rather than fixed tariffs.

Loop B3 describes switching from the electricity consumer receiving electricity from the grid to the prosumer, which generates part of the necessary electricity himself. Again, the decision to switch depends on the cost of electricity. If the consumer concludes that the electricity costs account for too much and calculates that it is more profitable to generate electricity himself in the long term, the transition to the concept of the prosumer becomes more attractive. This contributes to becoming a prosumer. In addition to economic benefit, there may be other aggravating factors, such as understanding environmental issues and wanting to be more environmentally friendly, as well as the desire to be energy-independent. The availability of information that this possibility exists is also very important.

The reinforcing loop R1 describes the impact of the experience on the acceptance and development of the concept of the producing consumer. The more households become electricity producers, the more experience is accumulated, and as a result, the attractiveness of individual production increases.

Loop R2 shows the situation that happens when more and more households become power generators. This opens the door for several households or urban quarters to connect to micro-networks that are independent of traditional distribution networks. This, in turn, reduces the amount of energy transmitted over traditional networks, but the costs of the infrastructure to be maintained do not decrease, which leads to an increase in transmission and distribution tariffs, and thus to an increase in the total electricity tariff. The increase in the electricity tariff reduces the attractiveness of the use of centrally produced electricity and facilitates the transition to microgeneration.

Loops R3 and R4 show the impact of microgeneration on the production of centralised electricity. As microgeneration capacity increases, the need for existing centralised production capacities decreases, which also hinders the development of innovative centralised production capacities. Moreover, the development of microgeneration capacities reduces the capacity load of centralised electricity, thus increasing the cost of generating electricity, as fixed costs for electricity plants remain unchanged, while the volume produced and sold decreases. This means an increase in the electricity tariff and contributes to the development of microgeneration.

Loop R5 actually describes competition between centralised production technologies on the basis of lower costs. Existing technologies are replaced by new and innovative technologies (including fossil ones) if their costs are lower than those of the existing technologies. Innovative technologies, of course, also compete with each other.

Loop R6 shows the impact of levelling peak loads on the required generation capacity of centralised electricity. The smaller the difference between peak load and base load, the smaller the peak capacity required, which reduces the total installed centralised electricity generation capacity.

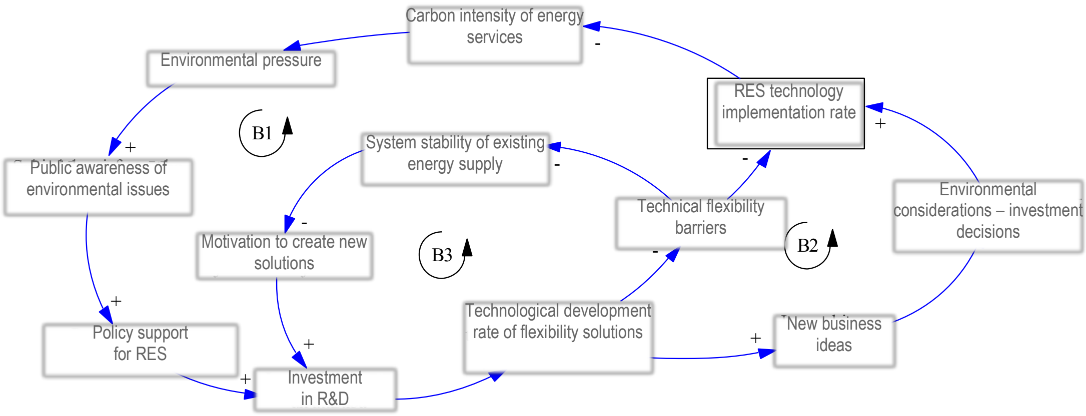


Fig. 2.3.5. The speed of introduction of renewable energy technologies

Figure 2.3.5 describes the pace of implementation of RES, which is largely linked to addressing the flexibility of the system in order to ensure a match between production and consumption loads. The current energy system is not designed for a high share of variable energy, so as the share of variable renewable energy increases, the system is approaching the maximum energy system limit and the pace of deployment of renewables is decreasing in order to prevent system instability and loss of energy produced. This leads to high energy system carbon intensity (B1), as it is not possible to replace the existing fossil technologies needed to balance variable electricity from RES. As the EU has set a goal of moving towards carbon neutrality, maintaining fossil technology capacities cannot be a sustainable solution and support for the development of renewable technologies is needed. The more support is available, the more investment goes to research and development of technologies and solutions that contribute to finding flexibility solutions and reducing flexibility barriers to increase the speed of deployment of RES technologies.

Loop B2 shows that the development of new system flexibility solutions opens up opportunities for the development of new businesses. The arrival of new technologies contributes to the development of new businesses, which in turn stimulates the attraction of investments for the integration of RES.

Loop B3 shows how a decrease in the stability of the existing system due to elasticity barriers can contribute to finding solutions to stabilize the system. While the share of variable renewable energy is low, the system is stable and there is little interest in developing flexibility solutions. As the share of renewable energy increases, the system becomes unstable and the looming collapse of the system motivates us to look for solutions to stabilise the system. This contributes to an increase in investment in the research and development of flexibility solutions, which in turn reduces flexibility barriers and stabilises the system.

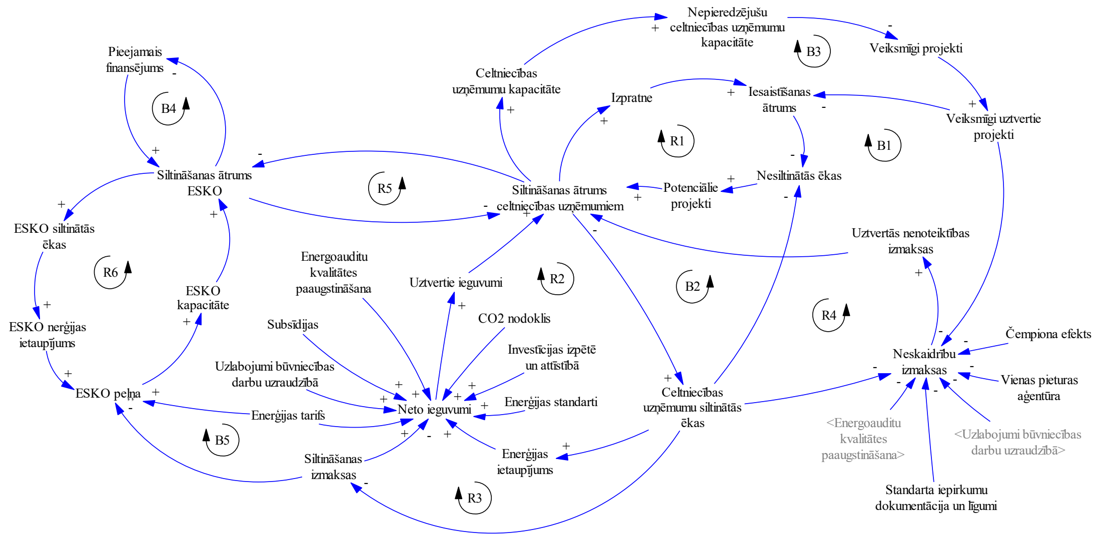


Fig. 2.3.6. Diagram of causal loops for the promotion of EE in residential buildings.

Figure 2.3.6 illustrates only the most important variables and 11 causal loops (6 positive loops and 5 balancing loops) that determine the dynamics of the insulation process of residential buildings. The main sectors included in the model are the demand and supply shares of the building insulation market. Demand is characterized by the stock of buildings that have not yet been insulated, while the share of supply is determined by the capacity and capabilities of traditional construction companies and energy service companies (ESCO). The ratio between supply and demand has a particularly significant impact on the system as a whole. It is this ratio that determines the rate of insulation.

The SD model includes the industrial, service, public, household and transport sectors. In addition, a number of sub-models have been developed concerning decentralised generation of electricity, the use of electricity for hydrogen generation, etc., which will be integrated into the model by analysing potential policy instruments to increase the potential of RES.

1.8. Model structure and mathematical relationships

2.4.1. Structure of the energy production model

The structure of the model shown in this subsection is used both for modelling the electricity generation sector and for modelling the DH, as well as for modelling individual heating in the industrial, commercial services, households and public sectors. Only input data differs in each sector, and the different nuances that will be described in the following chapters.

Figure 2.4.1 simplifies the main stocks and flows that form part of energy production in the model. The main stocks are planned capacities and installed capacities. Installed capacities are those used for energy production, but the planned capacities are those that are planned to be installed to replace worn capacity, as well as to install additional capacities in the event of increased energy demand and an energy shortfall in the system. There are two delays in the system that prevent the system from instantly increasing the installed capacities – the time needed to identify the capacity shortfall, complete the necessary formalities, and order new capacities, as well as the time required for the installation and commissioning of the purchased technologies.

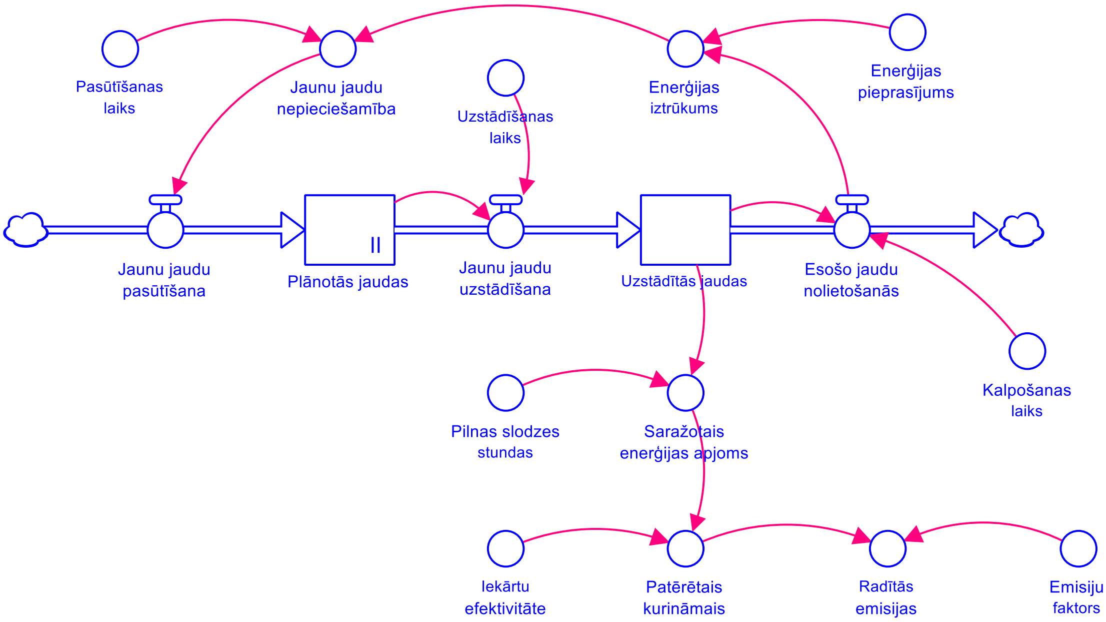


Fig. 2.4.1. Production technology capacity and energy production

Installed power modelling submodel

One of the main sections of the SD model is the installed capacity modelling submodel (see Figure 2.4.2), which, taking into account various influencing factors (feasibility of installation of technologies, availability of investments in the proportion of end-of-life equipment. etc.), models the capacity installation capabilities of RES technologies.

Volume of energy production capacities ordered:

$$PJ = \int_{t_0}^{t} [JP\ (t) - ENJ\ (t)]\ dt + PJ(t_0), \quad (2.1)$$

where

PJ - the volume of capacity of the ordered power production equipment, GW;
JP - annual capacity ordering rate of power generation installations, GW/year;
ENJ - Rate of commissioning of energy production capacities, GW/year.

Annual rate of ordering power generation capacity:

$$JP = IF\ (TEH = 0{,}5, 0, I), \quad (2.2)$$

where
TEH – turning on the possibility of installation of technologies in the model;
I – investment decision in ordering a particular technology, GW/year.

Turning on the possibility of installation of electrical technologies in the model:

$$TEH_i = \ L_i\ OR\ MAN_{IN}\ , \quad (2.3)$$

where
TEH_i – turning on the possibility of installing a particular power technology in the model;
L_i – verification of the achievement of the capacity limit for a particular technology;
MAN_{IN} – possibility of manual addition of technologies.

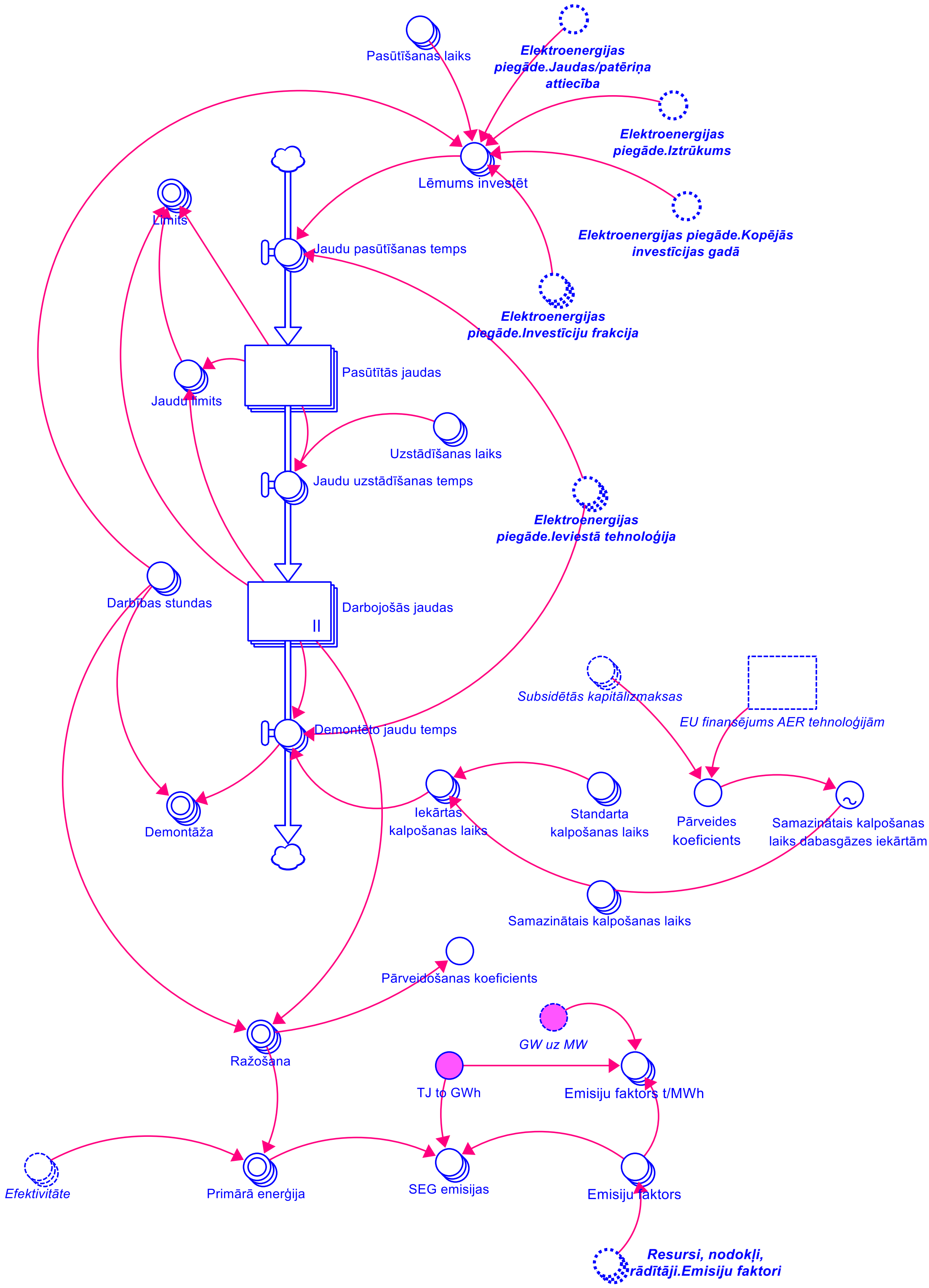


Fig. 2.4.2. Structure of the installed power modeling submodel

Investment decision in ordering a particular technology:

$$I = IF\ (JPA > 1, 0, INV_i * \frac{(I_D + IT)}{PL * DL}), \qquad (2.4)$$

where

JPA - the ratio of energy production to energy demand;

INVi – investment decision in one of the energy production technologies;
I_D - the amount of energy to be covered as a result of dismantling of existing installations, GWh/year;
IT - energy deficit, GWh/year;
PL - the time taken to order energy production technologies, years;
DL - the number of full-time hours of power generation installations, h/year.

Rate of commissioning of energy production capacities:

$$ENJ = \frac{PJ}{UL}, \quad (2.5)$$

where
UL – installation time, years.

Installed capacity of power-generating installations:

$$UJ = \int_{t_0}^{t} [ENJ\ (t) - NJ\ (t)]\ dt + UJ(t_0), \quad (2.6)$$

where
UJ - installed power generation equipment capacity, GW;
NJ – rate of dismantling of worn-out capacities, GW/year.

Rate of demonstration of worn-out capacities:

$$NJ = IF\ (TEH = 0{,}5, 0, \left(\frac{UJ}{KL}\right)), \quad (2.7)$$

where
KL - service life of energy production equipment, years

Life of power generation equipment:

$$KL = KL_S * Eff_{KL}, \quad (2.8)$$

Where
KL_S – standard service life, years;
Eff_{KL} – the effect of availability of RES technologies' support instruments on the service time of fossil technologies.

Support intensity of RES technologies:

$$\mathrm{SUB}_{IN} = IF\ (F_{AER}^{ES} > 0,\ \sum_{i=1}^{n} SUB_i\, , 0), \quad (2.9)$$

Where
SUB_{IN} – support intensity of RES technologies;
F_{AER}^{ES} – the amount of support available for the integration of RES into the system, in EUR;
SUB_i – support intensity of RES technologies for individual technologies;

The effect of availability of RES support instruments on the lifetime of fossil technologies:

$$Eff_{KL} = GRAPH(SUB_{IN} \quad (2.10)$$

Verification of the achievement of the capacity limit for a particular technology:

$$L = IF\ \left((PJ + UJ) < JL, 1, 0\right), \quad (2.11)$$

where
L - verification of the achievement of the limit of the installed capacities for a particular technology;
JL – capacity limit of the installed energy production technology, GW.

Lost amount of energy produced as a result of dismantling of the equipment:

$$EP = \mathrm{NJ} * \mathrm{DL} * \mathrm{DT}, \tag{2.12}$$

where
EP - the lost amount of energy produced as a result of dismantling of equipment, GWh/year;
DT – time step: 1 year.
Taking into account the installed capacities and the operating time for each technology, the amount of energy produced is determined:

$$P = UJ * DL, \tag{2.13}$$

where
P – the amount of energy produced, GWh/year.

Primary energy consumption is determined by taking into account the efficiency of each technology:

$$E = \frac{P}{\eta}, \tag{2.14}$$

where
E – consumption of primary energy, GWh/year;
η – efficiency of the technologies.

GHG emissions are calculated taking into account the emission factors of each energy source:

$$SEG = P * E_f * 3{,}6\,, \tag{2.15}$$

where
GHG - GHG emissions, t/year;
E_f - emission factor, t/TJ;

Emission factor expressed in tonnes of CO_2 equivalent per MWh:

$$E_{f(MWh)} = \frac{E_f * 3{,}6}{1000}, \tag{2.16}$$

where
$E_{f(MWh)}$ – Emission factor expressed in tonnes of CO_2 equivalent per MWh, t/MWh.

Economic calculation submodel

The decision to install the capacity of RES technologies in the replacement of fossil fuels in the model is influenced by economic factors such as capital costs, operating and fuel costs. The cost in the model is calculated taking into account the items shown in Figure 2.4.3. These consist of discounted capital costs, operating and maintenance costs, which are divided into fixed and variable costs, fuel costs, risk costs, as well as other costs.

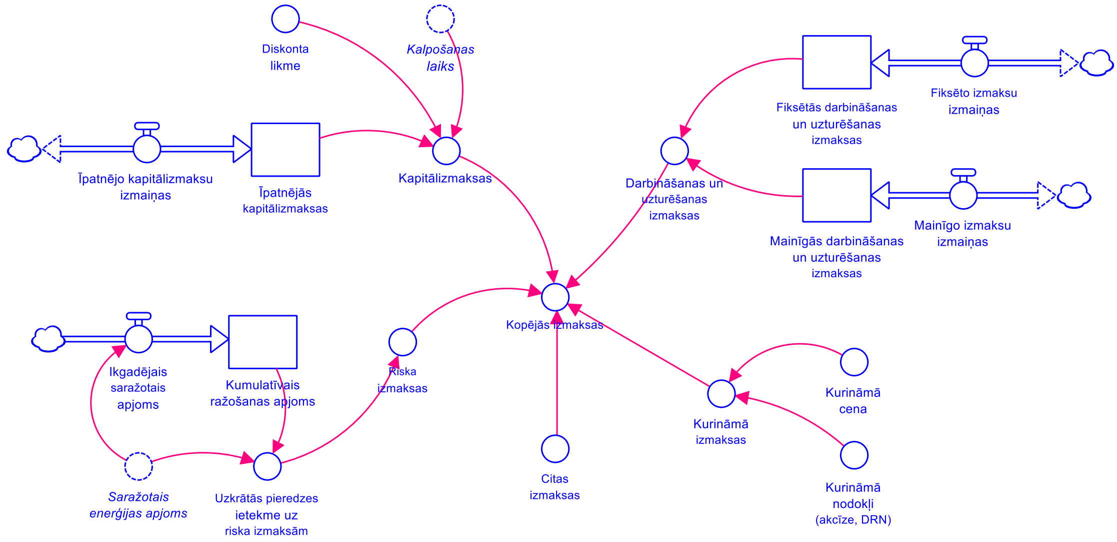


Fig. 2.4.3. Calculation of production costs

The risk costs are related to the use of RES technologies and the accumulation of experience. The use of technologies such as wind or solar technologies has very little experience in Latvia, therefore additional risks and costs are associated with the use of technologies. As experience builds, risks decrease, much more information is available on the proper operation of equipment, which contributes to a more successful use of technologies and a reduction in risk costs.

Fuel costs are limited to technologies in which the combustion process takes place – natural gas, biomass, biogas technologies. In wind, solar and water technologies the energy resources are free of charge, so no costs are incurred. Fuel costs also take into account tax rates, including excise and natural resource tax rates.

Capital cost calculation sub-model

The capital cost calculation sub-model (see Figure 2.4.4) sets the capital costs of each technology, taking into account the lifetime, the discount rate, the available co-financing for RES technologies, as well as the potential reduction in capital costs due to technological developments. The discount rate used in the model is 7%.

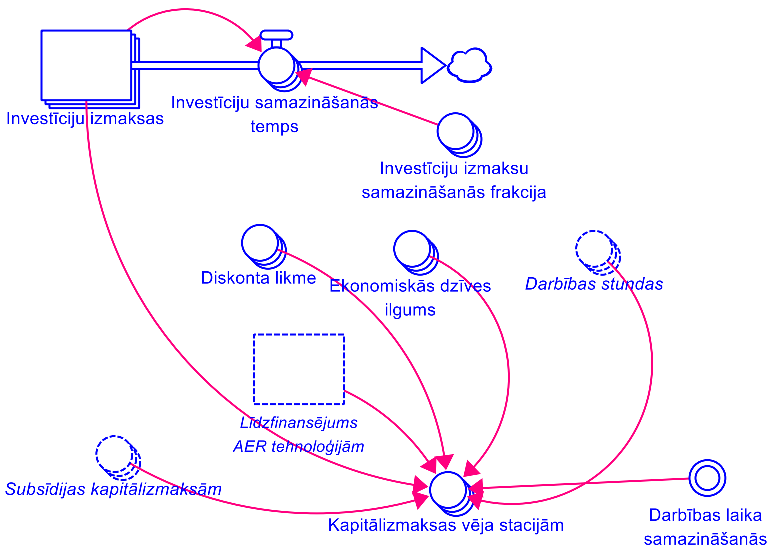


Fig. 2.4.4. Structure of the capital cost calculation sub-model

Investment costs of energy production technologies:

$$I_K = -\int_{t_0}^{t} I_s(t)\, dt + I_K(t_0), \qquad (2.17)$$

where

I_K - investment costs of energy production technologies, EUR/MW;

I_s – the rate of reduction of investment costs as a result of technological developments, EUR/MW/year.

Investment cost reduction fraction:

$$I_s = I_K * I_{SD}, \qquad (2.18)$$

where

I_{SD} - investment cost reduction fraction, 1/year.

Capital costs of the energy production technology:

$$I_i = IF\left(r = 0, \frac{I_K * IF\left(F_{AER}^{ES} > 0, (1 - SUB_i), 1\right)}{E_{Dz} * DL}, I_K * r * \frac{IF\left(F_{AER}^{ES} > 0, (1 - SUB_i), 1\right)}{1 - \frac{1}{(1+r)^{E_{Dz}}} * DL}\right), \qquad (2.19)$$

where

I_i – capital costs of the energy production technology, EUR/MWh;

r – discount rate;

E_{Dz} – the economic lifespan of investments, years.

Operation and maintenance cost sub-model

The sub-model for the operation and maintenance of energy production costs (see Figure 2.4.5) sets out the variable and fixed operating costs of a particular RES technology, which may decrease over time as a result of technological developments.

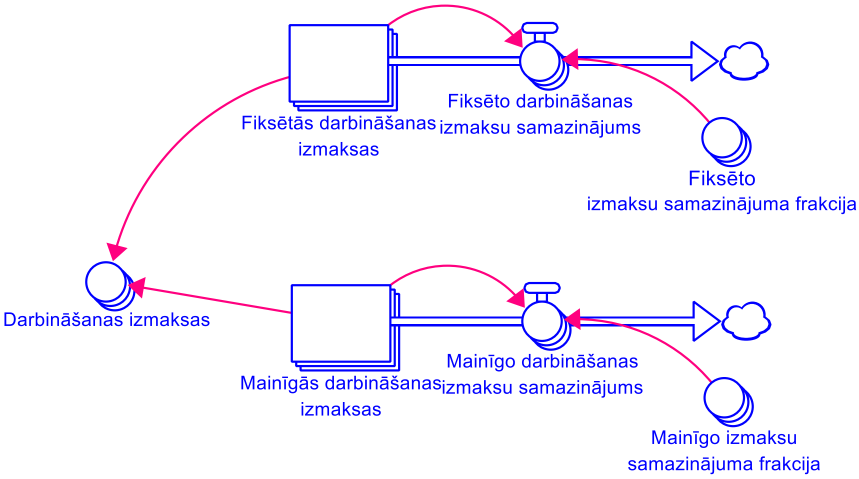


Fig. 2.4.5. Structure of the operation and maintenance cost sub-model

Fixed costs of operation and maintenance:

$$FC_{O\&M} = -\int_{t_0}^{t} FC_{O\&M}^{S}(t)dt + FC_{O\&M}, \quad (2.20)$$

where

$FC_{O\&M}$ – fixed costs of operation and maintenance, EUR/MW/year;

$FC_{O\&M}^{S}$ – reduction of fixed costs of operation and maintenance, EUR/MW/year/years;

Reduction fraction of fixed costs for operation and maintenance:

$$FC_{O\&M}^{S} = FC_{O\&M} * FC_{O\&M}^{DS}, \quad (2.21)$$

where

$FC_{O\&M}^{DS}$ – reduction fraction of fixed costs for operation and maintenance, 1/year.

Variable costs of operation and maintenance:

$$VC_{O\&M} = -\int_{t_0}^{t} VC_{O\&M}^{S}(t)dt + VC_{O\&M}(t_0), \quad (2.22)$$

where

$VC_{O\&M}$ – variable costs of operation and maintenance, EUR/MWh;

$VC_{O\&M}^{S}$ – reduction of variable costs of operation and maintenance, EUR/MW/gadi.

Reduction fraction of variable cost component of operation and maintenance:

$$VC_{O\&M}^{S} = VC_{O\&M} * VC_{O\&M}^{SD}, \quad (2.23)$$

where

$VC_{O\&M}^{SD}$ – reduction fraction of variable costs for operation and maintenance, 1/year.

Operation and maintenance costs:

$$C_{O\&M} = \frac{(VC_{O\&M} + FC_{O\&M})}{DL}, \quad (2.24)$$

kur

$C_{O\&M}$ – operation and maintenance costs, EUR/MWh.

Calculation of fuel costs

In the SD model, fuel costs are calculated separately in the ETS and non-ETS sectors, taking into account the different costs of emissions generated. Fuel price, excise duty and natural resources tax are taken into account in determining fuel costs (see Figure 2.4.6).

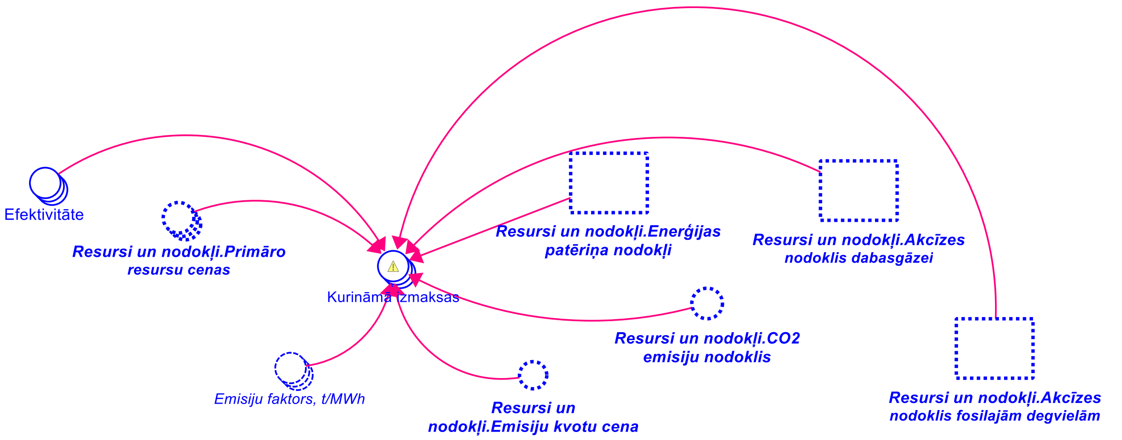


Fig. 2.4.6. Fuel cost calculation submodel

Fuel costs for ETS sector installations:

$$CK_{ETS.} = \frac{(PR_F + TX_e)}{\eta} + E_{f(MWh)} * KV_{ETS}, \tag{2.25}$$

where
CK_{ETS} - fuel costs for ETS sector installations, EUR/MWh;
PR_f – price of the primary energy resource, EUR/MWh;
TX_e – fuel excise tax, EUR/MWh;
KV_{ETS} – ETS quota price, EUR/tCO_2.

Fuel costs for non-ETS sector installations:

$$CK_{nETS} = \frac{(PR_F + TX_e)}{\eta} + E_{f(MWh)} * DRN, \tag{2.26}$$

where
CK_{nETS} – fuel costs for non-ETS sector installations, EUR/MWh;
DRN – CO_2 emissions fee set in the natural resources tax, EUR/tCO_2.

Calculation of other costs

The SD model takes into account the potential costs of the lack of experience in operating RES technologies and the various risks associated with it (Figure 2.4.7). Such risks are reduced if more energy is produced and experience in operating the technology increases.

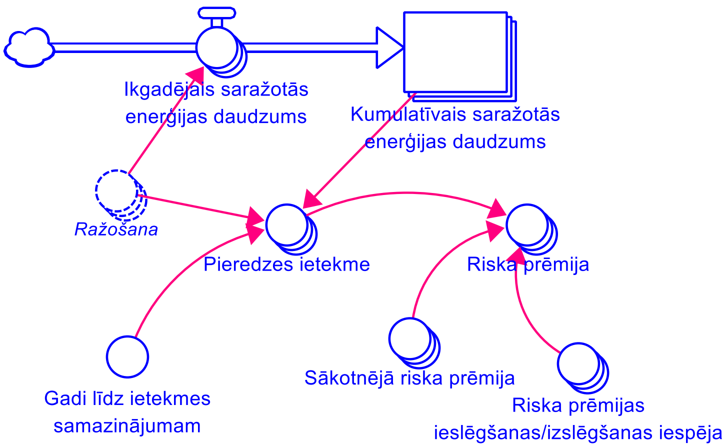


Fig. 2.4.7. Other cost calculation sub-model

Cumulative amount of energy produced from a specific technological solution:

$$KR = \int_{t_0}^{t} R\bar{A}\,(t)\,dt + KR\,(t_0), \qquad (2.27)$$

where

KR - the cumulative amount of energy produced from a particular technological solution, GWh;
RĀ - annual amount of energy produced from a specific technological solution, GWh/year.

Annual amount of energy produced from a specific technological solution:

$$R\bar{A} = P, \qquad (2.28)$$

Impact of experience on risk premium:

$$P_i = e^{-\frac{KR}{P_S * INIT(IF(P=0,1,P)}}, \qquad (2.29)$$

where

P_i – impact of experience on risk premium;
P_s – time to 63% risk reduction, years.

Risk premium:

$$RP = (SRP * P_i * RP_{off}^{on}) + SRP\,(1 - RP_{off}^{on}), \qquad (2.30)$$

where

RP - risk premium, EUR/MWh;
SRP – initial risk premium, EUR/MWh;
RP_{off}^{on} – the possibility of switching on/off the structure of the risk premium.

Total and average electricity generation tariff

The total cost of energy production consists of capital costs, operating costs, fuel costs and other costs when setting the total energy production tariff:

$$T_E = (CK + C_{O\&M} + I_K^V + RP + C_o), \qquad (2.31)$$

where

T_E – energy production tariff, EUR/MWh;
CK – fuel costs, EUR/MWh;
C_o – costs, not included in other categories, EUR/MWh;
SEN – subsidised electricity tax.

The SD model also takes into account the impact of the OIK on the electricity tariff when setting the average electricity tariff with and without the OIK component. Average electricity production tariff with OIK:

$$T_E^v = \sum_{i=1}^{n}(RD_i * T_i), \qquad (2.32)$$

where

T_E^v – average electricity generation tariff with OIK, EUR/MWh;
RDi - share of energy produced with a specific technology (also share of imports);
Ti -. electricity generation tariff with OIK for a specific technology (including import price), EUR/MWh.
Energy production tariff without OIK:

$$T_E = (CK + C_{O\&M} + I_K^V + RP + C_o) + OIK * SEN - OIK, \qquad (2.33)$$

where

T_E – energy production tariff without OIK, EUR/MWh;
CK – fuel costs, EUR/MWh;

C_o – costs not included in other categories, EUR/MWh;
SEN – subsidised electricty tax;
OIK – mandatory procurement component, EUR/MWh;

Energy production tariff with OIK:

$$\mathrm{T}_{OIK} = T_E + OIK, \tag{2.34}$$

Where
T_{OIK} – energy production tariff with OIK, EUR/MWh.

The OIK is calculated taking into account the reduction for technology development:

$$OIK = -\int_{t_0}^{t} OIK_S\,(t)\,dt + OIK\,(t_0), \tag{2.35}$$

where
OIK_S – reduction of the mandatory procurement component as a result of technological development, EUR/MWh/year;
Reduction of the mandatory procurement component (OIK) as a result of technological development,:

$$OIK_S = OIK * \mathrm{I_{SD}} * 2, \tag{2.36}$$

2.4.2. Energy consumption share

Residential sector

The household sector is based on four stocks: unrenovated buildings, renovated buildings, buildings built between 1990 and 2018, as well as buildings built after 2018 (see Figure 2.4.3). The stocks cover the heated square meters of buildings. It is assumed that the consumption of renovated buildings corresponds to the consumption of buildings built in 1990 to 2018, which is determined in the Latvian Construction Standards.

The pace of renovation depends mainly on the economic benefits, but the available capacity of builders also plays an important role. If the supply of construction companies, or the maximum possible amount of renovation, is less than the demand for the renovation of buildings, then only a part of the desired buildings will be renovated. Capacity shortfalls can have an impact on construction costs.

The household sector is divided into single-family buildings and multi-apartment buildings.

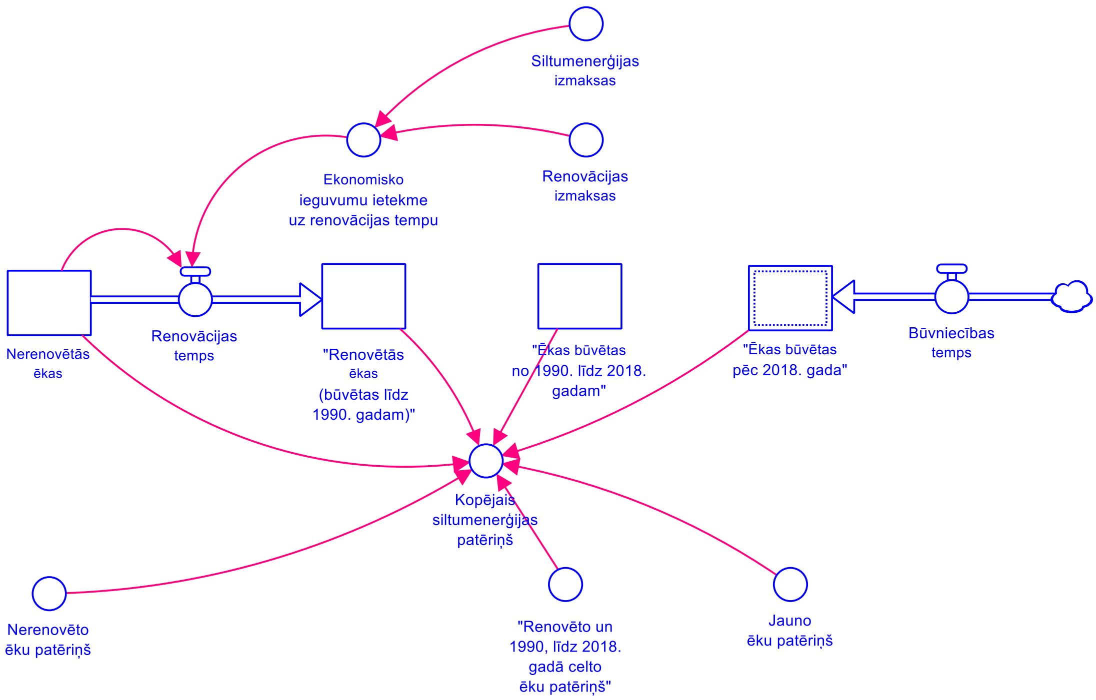


Fig. 2.4.8. Household energy consumption and renovation of buildings.

The sub-model of single-family buildings is shown in Figure 2.4.9, which takes into account the specific energy consumption indicators of different types of buildings (new buildings, insulated and uninsulated) and the area to be heated.

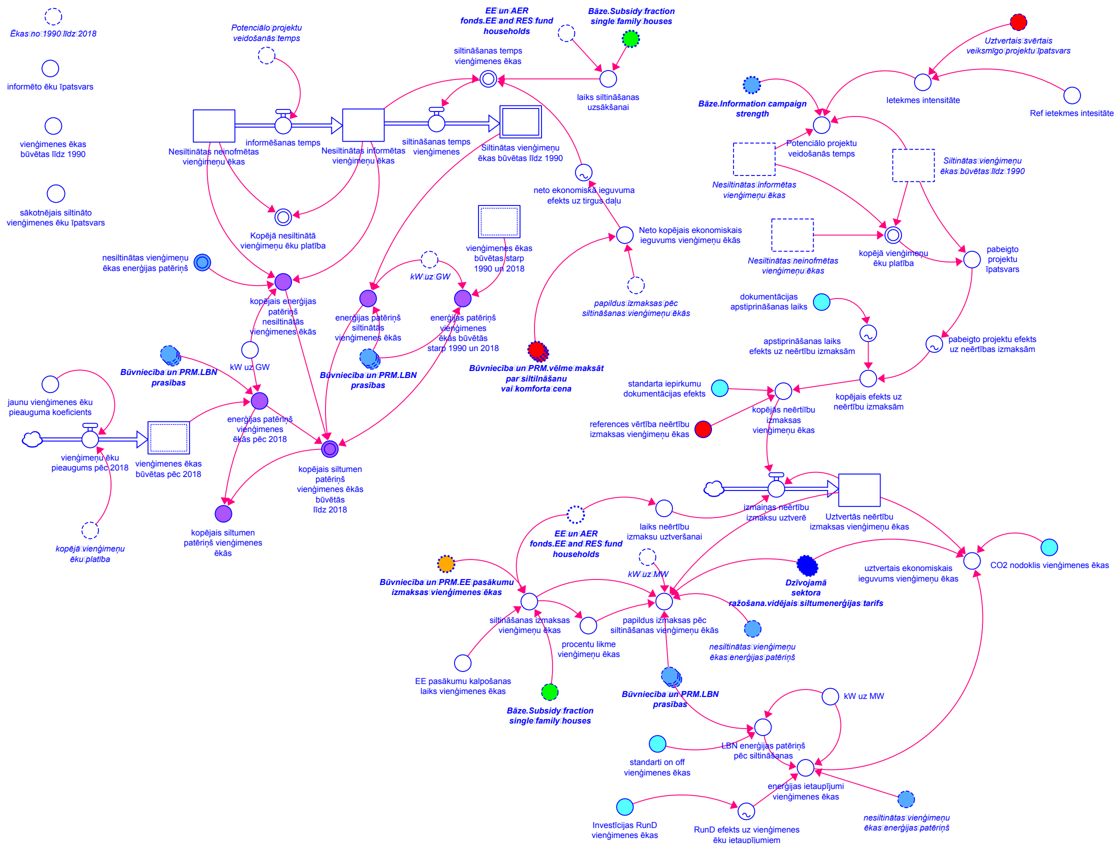


Fig. 2.4.9. Single-family building sector model

Area of uninsulated buildings whose owners are not aware of EE:

$$\mathrm{NnE} = -\int_{t_0}^{t} Inf^{likm}(t)dt + \mathrm{NnE}(t_0), \quad (2.37)$$

where

NnE – uninsulated buildings, whose owners are not informed about EE, m^2;

Inf^{likm} – the pace of information, m^2/years.

Rate of information on uninsulated buildings:

$$Inf^{likm} = PPP^{līm}, \quad (2.38)$$

where

$PPP^{līm}$ – the pace of potential project formation, m^2/year.

The area of uninsulated buildings whose owners are aware of EE is calculated as follows::

$$NNE = \int_{t_0}^{t}[Inf(t) - Silt^{ātr}(t)]\,dt + NNE(t_0), \quad (2.39)$$

where

NNE – uninsulated buildings, whose owners are informed about EE, m^2;

$Silt^{ātr}$ – the pace of insulation, m^2/year.

The pace of insulation is calculated as follows:

$$Silt^{ātr} = Silt_{VĢM}^{ātr}, \quad (2.40)$$

where

$Silt_{VĢM}^{ātr}$ – insulation rate for a single-family house, m^2/year.

The area of insulated single-family buildings, which were built until 1990, is:

$$\bar{\mathrm{E}}K_{silt}^{<1990} = \int_{t_0}^{t} Silt^{ātr}(t)dt + \bar{\mathrm{E}}K_{silt}^{<1990}(t_0), \quad (2.41)$$

where

$\bar{\mathrm{E}}K_{silt}^{<1990}$ – insulated buildings built before 1990, m^2.

The total area of uninsulated single-family buildings is calculated as follows:

$$VĢM_{nesilt}^{kopā} = \mathrm{NnE} + \mathrm{NNE}, \quad (2.42)$$

where

$VĢM_{nesilt}^{kopā}$ – uninsulated single-family buildings in total, m^2.

Energy consumption in uninsulated single-family buildings:

$$EP_{nesilt}^{VĢM} = (\mathrm{NnE} + \mathrm{NNE}) * \frac{P_{nesilt}^{VĢM}}{1000000}, \quad (2.43)$$

where

$EP_{nesilt}^{VĢM}$ – energy consumption in uninsulated buildings, GWh/year.

$P_{nesilt}^{VĢM}$ – consumption of an uninsulated building, kWh/m^2/year.

The energy consumption in newly built single-family buildings is calculated as follows::

$$EP^{jaun(VĢM)} = B\bar{u}v_{pēc\ 2018}^{VĢM} * \frac{LBN^{pras(VĢM)}}{1000000}, \quad (2.44)$$

where

$EP^{jaun(VĢM)}$ – energy consumption in newly built buildings, GWh/year.

$B\bar{u}v_{pēc\ 2018}^{VĢM}$ - single-family buildings built after 2018, m^2;

$LBN^{pras(VĢM)}$ – Latvian Construction Standards' compliant building energy consumption, kWh/m^2/year.

The area of buildings built after 2018 is calculated as follows:

$$B\bar{u}v_{p\bar{e}c\,2018}^{VĢM} = \int_{t_o}^{t} PieL_{p\bar{e}c\,2018}^{VĢM}(\mathrm{t})\mathrm{dt} + B\bar{u}v_{p\bar{e}c\,2018}^{VĢM}(t_o) \quad (2.45)$$

where

$PieL_{p\bar{e}c\,2018}^{VĢM}$ – growth rate of single-family buildings after 2018, m²/years.

Growth rate of single-family buildings after 2018 is:

$$PieL_{p\bar{e}c\,2018}^{VĢM} = (1 - DĢM_{int}) * DzP^{kop} * J\bar{E}P_{int}, \quad (2.46)$$

where

$DĢM_{int}$ – the share of multi-apartment buildings;

DzP^{kop} – total residential area, m²;

$J\bar{E}P_{int}$ – growth rate of new buildings, 1/year.

The total heat consumption is calculated as follows::

$$KSP_{VĢM} = EP_{nesilt}^{VĢM} + EP_{silt}^{VĢM} + EP^{jaun(VĢM)} + EP_{p\bar{e}c\,1990}^{VĢM}, \quad (2.47)$$

where

$KSP^{VĢM}$ – total heat consumption in single-family buildings, GWh/year;

$EP_{p\bar{e}c\,1990}^{VĢM}$ – energy consumption for single-family buildings built after 1990, GWh/year.

Total thermal energy consumption in single-family buildings before 2018:

$$KSP_{pirms\,2018}^{VĢM} = KSP_{VĢM} - EP^{jaun(VĢM)}, \quad (2.48)$$

where

$KSP_{pirms\,2018}^{VĢM}$ – total consumption of thermal energy in single-family buildings before 2018, GWh/year.

Energy consumption in insulated single-family buildings built before 1990:

$$EP_{silt}^{VĢM} = \bar{E}K_{silt}^{<1990} * \frac{LBN^{pras(VĢM)}}{1000000}, \quad (2.49)$$

Energy consumption for single-family buildings built between 1990 and 2018:

$$EP_{p\bar{e}c\,1990}^{VĢM} = B\bar{u}v_{1990-2018}^{VĢM} * \frac{LBN^{pras(VĢM)}}{1000000}, \quad (2.50)$$

where

$B\bar{u}v_{1990-2018}^{VĢM}$ – single-family buildings built in the period from 1990 to 2018, m².

Net total economic benefit in single-family buildings:

$$NKEI^{VĢM} = WTP^{EE} - PaI^{EE}, \quad (2.51)$$

where

WTP^{EE} – willingness to pay for EE measures, EUR/m²/year;

$NKEI^{VĢM}$ – net total economic benefit in single-family buildings, EUR/m²/year;

PaI^{EE} – additional costs after the implementation of EE measures, EUR/m²/year.

Insulation speed for single-family buildings:

$$Silt_{VĢM}^{\bar{a}tr} = 1150 + \frac{(\mathrm{NNE}*EII^{TD})}{T^{VĢM}}, \quad (2.52)$$

where

EII^{TD} – impact of the net total economic benefit on market share;

$T^{VĢM}$ – time to start single-family building projects per year.

Time to start single-family building projects:

$$T^{VĢM} = IF\left(F_M^{EE\&AER} > 0, IF\left(SUB_{int}^{VĢM} > 0, 1, 3\right), 3\right), \quad (2.53)$$

where

$F_M^{EE\&AER}$ – EE and RES fund in households, EUR;

$SUB_{int}^{VĢM}$ – the intensity of subsidies for single-family buildings.

Single-family buildings built in the period from 1990 to 2018:

$$Būv_{1990-2018}^{VĢM} = ĒK_{1990-2018} - Būv_{1990-2018}^{DĢM}, \quad (2.54)$$

where

$ĒK_{1990-2018}$ – buildings built in the period from 1990 to 2018, m^2;

$Būv_{1990-2018}^{DĢM}$ –multi-apartment buildings built in the period from 1990 to 2018, m^2.

The impact of the information campaign is calculated as:

$$IKS = \frac{1}{(IKS^B * 6 * (TIME - (TIME - 1)))} + \left((1 + IKS^B) * 15 * (TIME - (TIME - 1)\right), \quad (2.55)$$

where

IKS – the impact of the information campaign, 1/year;

IKS^B – reference value for the impact of the information campaign.

Pace of the potential projects:

$$PPP^{līm} = \frac{\text{NNE}}{\left(IKS^B * 6 * (TIME - (TIME - 1))\right)} + \left((1 - IKS^B) * 15 * (TIME - (TIME - 1)\right) + ĒK_{silt}^{<1990} * \left(\frac{\text{NNE}}{\text{NNE} + ĒK_{silt}^{<1990}}\right) * Iet^{stp}, \quad (2.56)$$

where

Iet^{stp} – strength of the impact, 1/year.

Strength of the impact:

$$Iet^{stp} = Iet^{at.stp} * VP^{SD}, \quad (2.57)$$

where

$Iet^{at.stp}$ – reference value of the impact, 1/year;

VP^{SD} – share of the perceived successful projects.

Total area of single-family buildings:

$$KZ^{VĢM} = \text{NnE} - \text{NNE} + ĒK_{silt}^{<1990}, \quad (2.58)$$

where

$KZ^{VĢM}$ – total area of single-family buildings, m^2.

Share of the completed projects:

$$PP_D = \frac{ĒK_{silt}^{<1990}}{KZ^{VĢM}}, \quad (2.59)$$

where

PP_D – share of the completed projects.

Overall impact on inconvenience:

$$KIet_{NĒ} = LIet_{NĒ}^{izm} * PP_{NI}^{iet}, \quad (2.60)$$

where

$KIet_{NĒ}$ – overall impact on inconvenience;

$LIet_{N\bar{E}}^{izm}$ – impact of approval time on inconvenience costs;

Impact of completed projects on uncertainty costs:

$$PP_{NI}^{iet} = ANI^{VĢM} * KIet_{N\bar{E}} * SI_{dok}^{iet}, \quad (2.61)$$

where
PP_{NI}^{iet} – impact of completed projects on uncertainty costs;
$ANI^{VĢM}$ – reference inconvenience costs, EUR/m²/year;
SI_{dok}^{iet} - impact of standardised procurement documentation.

Perceived inconvenience cost changes:

$$\text{UNI} = \frac{(PP_{NI}^{iet} - UN^{VĢM})}{L_{NU}}, \quad (2.62)$$

where
UNI – perceived inconvenience cost changes, EUR/m²/year/years;
$UN^{VĢM}$ – perceived inconvenience costs, EUR/m²/year;
L_{NU} – time of perception of inconvenience costs, per year.

Time of perception of inconvenience costs:

$$L_{NU} = IF\left(F_M^{EE\&AER} > 0{,}1{,}3\right), \quad (2.63)$$

Perceived inconvenience costs:

$$UN^{VĢM} = \int_{t_0}^{t} \text{UNI}\,(t)dt + UN^{VĢM}\,(t_0). \quad (2.64)$$

Costs of EE measures in single-family buildings:

$$I_{EE}^{VĢM} = IF\left(F_M^{EE\&AER} > 0, \left(1 - SUB_{int}^{VĢM}\right), 1\right) * \frac{I_{EE}^{VĢM(bezSUB)}}{KL_{EE}^{VĢM}}, \quad (2.65)$$

where
$I_{EE}^{VĢM}$ – EE costs in single-family buildings, EUR/m²/year;
$I_{EE}^{VĢM(bezSUB)}$ – EE costs in single-family buildings with no subsidies, EUR/m²;
$KL_{EE}^{VĢM}$ – Technical life of EE activities, years.

Interest rate in single-family buildings:

$$I^{VĢM(\%)} = I_{EE}^{VĢM}, \quad (2.66)$$

where
$I^{VĢM(\%)}$ – interest rate in single-family buildings:, EUR/m²/year.

Additional costs after the implementation of EE measures:

$$I_{EE}^{pap} = UN^{VĢM} + \frac{LBN^{pras(VĢM)} * T_v^{VĢM}}{1000} + I_{EE}^{VĢM} + I^{VĢM(\%)} - \frac{P_{nesilt}^{VĢM} * T_v^{VĢM}}{1000}, \quad (2.67)$$

where
I_{EE}^{pap} - additional costs after the implementation of EE measures, EUR/m²/year;
$T_v^{VĢM}$ – average tariff, EUR/MWh.

Requirements of Latvian Construction Standards for single-family buildings:

$$St^{VĢM} = \frac{LBN^{pras(VĢM)}}{1000} - St^{VĢM}(STEP(0.01, STARTTIME + 15) + STEP(0.01, STARTTIME + 25), \quad (2.68)$$

where
$St^{VĢM}$–requirements of Latvian Construction Standards for single-family buildings, MWh/m²/year.

Energy savings:

$$EIet_{BU}^{VĢM} = \left(\frac{P_{nesilt}^{VĢM}}{1000} - St^{VĢM}\right) * \text{P\&A}^{\text{VĢM}}, \qquad (2.69)$$

where
$EIet_{BU}^{VĢM}$ – energy savings, MWh/m²/year;
$\text{P\&A}^{\text{VĢM}}$ - the impact of R & D on the costs.

Perceived economic benefit:

$$UEI^{VĢM} = (T_v^{VĢM} + Nod_{CO_2}^{VĢM}) * (EIet_{BU}^{VĢM} - UN^{VĢM}), \qquad (2.70)$$

where
$UEI^{VĢM}$ – perceived economic benefit;
$Nod_{CO_2}^{VĢM}$ – CO_2 tax, EUR/MWh.

Figure 2.4.10 shows the structure of the model for making decisions to increase EE of buildings for the multi-apartment sector, which takes into account factors such as the costs of raising EE, the demand of construction companies, the implementation of EE projects for other successful buildings.

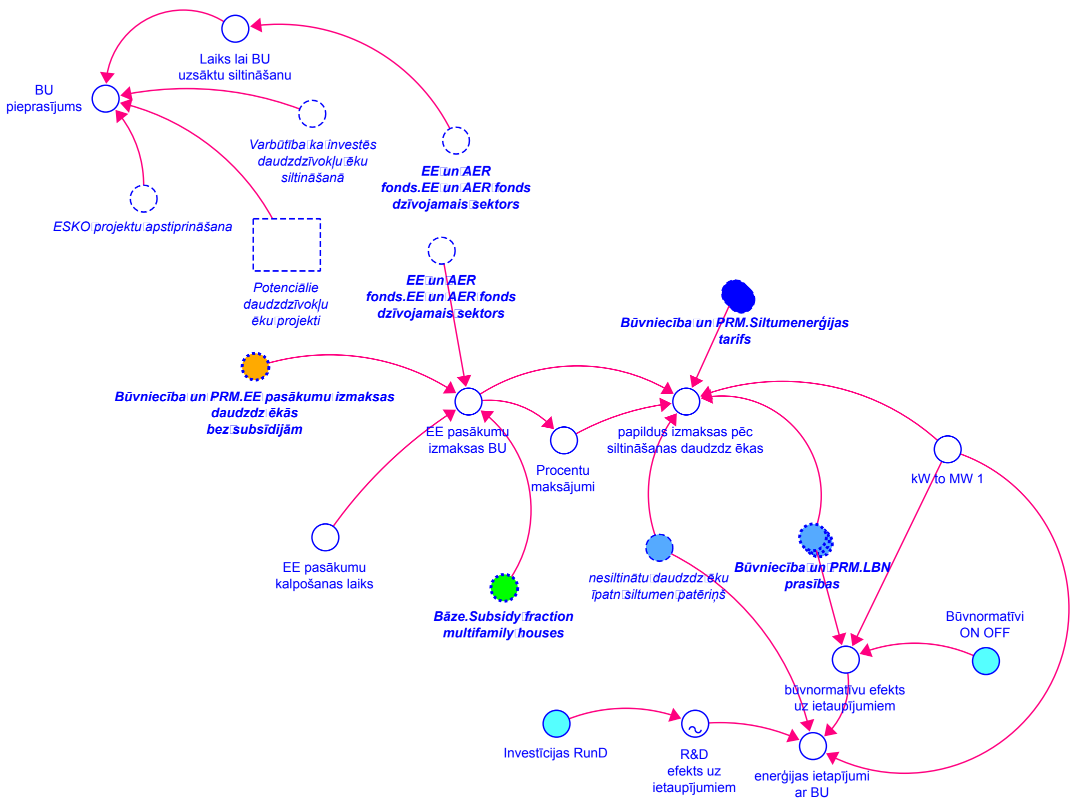


Fig. 2.4.10. Model structure for decision-making in the multi-apartment building sector

Demand for construction companies (BU):

$$PP_{BU} = MIN\left(\frac{(PP_{DÇM}*EII_{TD}^{BU})}{T^{BU}}, \left(\frac{PP_{DÇM}}{T^{BU}-EPU_{PPL}}\right)\right), \quad (2.71)$$

where

PP_{BU} – demand for BU, m2/year;

T^{BU} – time to launch BU projects, years;

EII_{TD}^{BU} – Impact of BU's economic advantage on market share.

Time to launch BU projects:

$$T^{BU} = IF\left(F_{M}^{EE\&AER} > 0{,}1{,}3\right), \quad (2.72)$$

Net perceived economic benefit:

$$NKEI^{DÇM} = IF\left(GM_{kom}^{silt} - PaI_{DÇM}^{EE}\right) > 0, \left(GM_{kom}^{silt} - PaI_{DÇM}^{EE}\right) * SVPP_{BU}, \left(GM_{kom}^{silt} - PaI_{DÇM}^{EE}\right), \quad (2.73)$$

where

$NKEI^{DÇM}$ – net perceived economic benefit in multi-apartment buildings, EUR/m2/year;

$PaI_{DÇM}^{EE}$– additional costs following the implementation of EE measures in multi-apartment buildings, EUR/m2/year;

$SVPP_{BU}$ – relatively successful completion of the BU project.

BU EE costs:

$$I_{BU}^{EE} = IF\left(F_{M}^{EE\&AER} > 0, \left(1 - SUB_{int}^{DÇM}\right), 1\right) * \frac{EE_{DÇM}^{izm}}{KL_{EE}^{DÇM}}, \quad (2.72)$$

where

I_{BU}^{EE} – BU EE costs, EUR/m2/year;

$KL_{EE}^{DÇM}$ – Technical life of EE measures in apartment buildings, years.

Additional costs after implementation of EE measures:

$$PaI_{DÇM}^{EE} = \left(UN_{BU}^{DÇM} + LBN^{pras(DÇM)}\right) * \left(\frac{T_{S}^{DÇM}}{1000} + I_{BU}^{EE} + I^{VÇM(\%)_1} - \frac{P_{nesil}^{DÇM}*T_{S}^{DÇM}}{1000}\right), \quad (2.73)$$

where

$UN_{BU}^{DÇM}$– BU perceived uncertainty in multi-apartment buildings, EUR/m2/year.

Requirements of construction standards:

$$St^{VÇM_1} = \frac{LBN^{pras(DÇM)}}{1000} - St^{DÇM} * \left(STEP(0.01, STARTTIME + 15) + STEP(0.01, STARTTIME + 25)\right), \quad (2.74)$$

where

$St^{VÇM_1}$ – requirements of construction standards (1), MWh/m2/year;

$St^{DÇM}$– requirements of construction standards, MWh/m2/year.

Similarly, the consumption of thermal energy in multi-apartment buildings is determined. Figure 2.4.11 shows the structure of the model for the sector of new multi-apartment buildings.

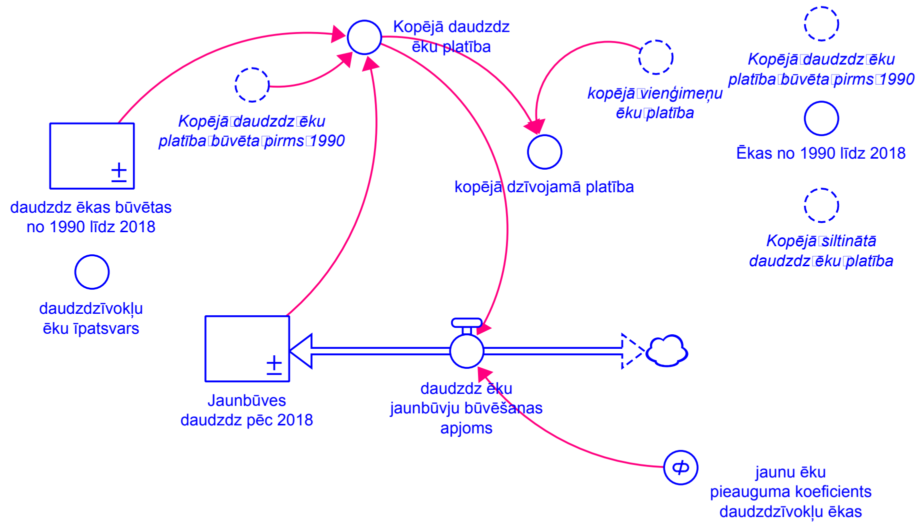


Fig. 2.4.11. Model structure for the new multi-apartment building sector

Total area of multi-apartment buildings:

$$KZ^{DĢM} = KZ^{DĢM}_{<1990} + J\bar{E}_{>2018} + B\bar{u}v^{DĢM}_{1990-2018}, \qquad (2.75)$$

where

$KZ^{DĢM}$ – total area of multi-apartment buildings, m²;

$KZ^{DĢM}_{<1990}$ – total area of multi-apartment buildings built before 1990, m²;

$J\bar{E}_{>2018}$ – new buildings, built after 2018, m².

$$B\bar{u}v^{DĢM}_{1990-2018} = \bar{E}K_{1990-2018} * DĢM_{int}. \qquad (2.76)$$

New buildings, built after 2018:

$$J\bar{E}_{>2018} = \int_{t_0}^{t} S\bar{E}K^{temp}(t)dt + J\bar{E}_{>2018}(t_0), \qquad (2.77)$$

where

$S\bar{E}K^{temp}$ – pace of construction of new buildings, m²/year.

Pace of construction of new buildings:

$$S\bar{E}K^{temp} = DzP^{kop} * J\bar{E}P_{int} * DĢM_{int}. \qquad (2.78)$$

Figure 2.4.12 shows the structure of the model for thermal energy consumption in the multi-apartment building sector.

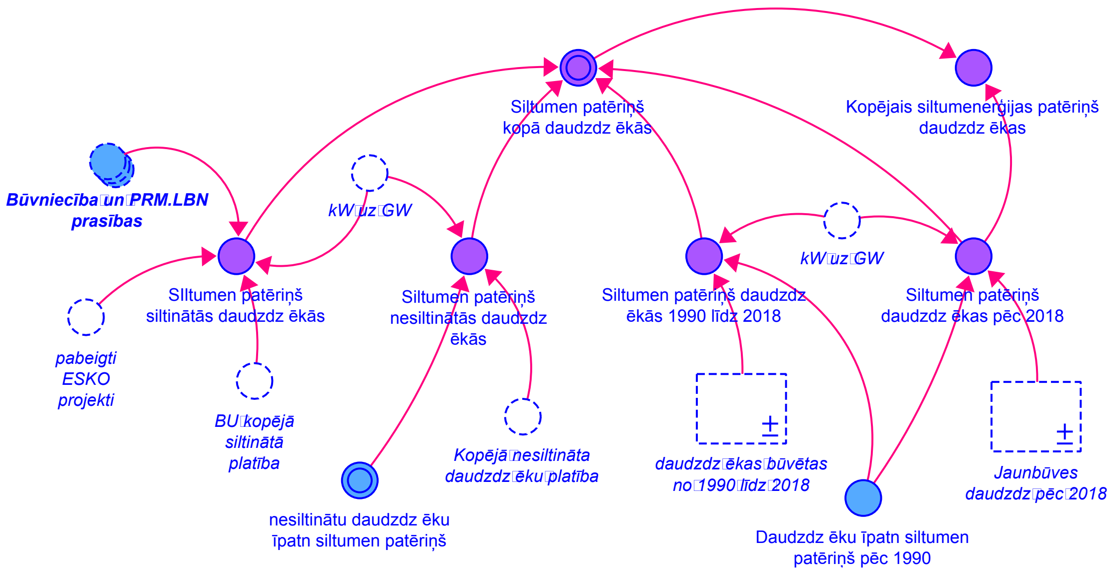


Fig. 2.4.12. Model structure for thermal energy consumption in the multi-apartment building sector

Total thermal energy consumption in multi-apartment building sector:

$$KSP_{DĢM} = P_{silt}^{DĢM} + P_{nesilt}^{DĢM} + P_{1990-2018}^{DĢM} + P_{>2018}^{DĢM}, \quad (2.79)$$

where

$KSP_{DĢM}$ - total thermal energy consumption in multi-apartment buildings, GWh/year;

$P_{silt}^{DĢM}$ – consumption in insulated multi-apartment buildings, GWh/year;

$P_{nesilt}^{DĢM}$ – consumption in uninsulated multi-apartment buildings, GWh/year;

$P_{1990-2018}^{DĢM}$ – consumption in multi-apartment buildings built in the period from 1990 to 2018, GWh/year;

$P_{>2018}^{DĢM}$ – consumption in multi-apartment buildings built after 2018, GWh/year.

Consumption in insulated multi-apartment buildings:

$$P_{silt}^{DĢM} = \left(Plat_{silt}^{BU} + VPP_{BU}^{UD}\right) * \frac{LBN^{pras(DĢM)}}{1000}, \quad (2.80)$$

Consumption in uninsulated multi-apartment buildings:

$$P_{nesilt}^{DĢM} = KP_{nesilt}^{DĢM} * \frac{P_{nesil}^{DĢM}}{1000}, \quad (2.81)$$

where

$KP_{nesilt}^{DĢM}$ – total uninsulated area in multi-apartment buildings, GWh/year.

Consumption in multi-apartment buildings built in the period from 1990 to 2018:

$$P_{1990-2018}^{DĢM} = Būv_{1990-2018}^{DĢM} * \frac{P^{>1990}}{1000000}, \quad (2.82)$$

where

$P^{>1990}$ – consumption in multi-apartment buildings built after 1990, GWh/gadā.

consumption in multi-apartment buildings built after 2018:

$$P_{>2018}^{DĢM} = JĒ_{>2018} * \frac{P^{>1990}}{1000000}, \quad (2.83)$$

Total thermal energy consumption in multi-apartment buildings before 2018:

$$KSP_{<2018}^{DĢM} = KSP_{DĢM} - P_{>2018}^{DĢM}, \qquad (2.84)$$

where

$KSP_{<2018}^{DĢM}$ – total thermal energy consumption in multi-apartment buildings before 2018, GWh/year.

Electricity consumption in the residential sector is modelled on key economic indicators, EE promotion measures as well as the integration of heat pumps (see Figure 2.4.13)

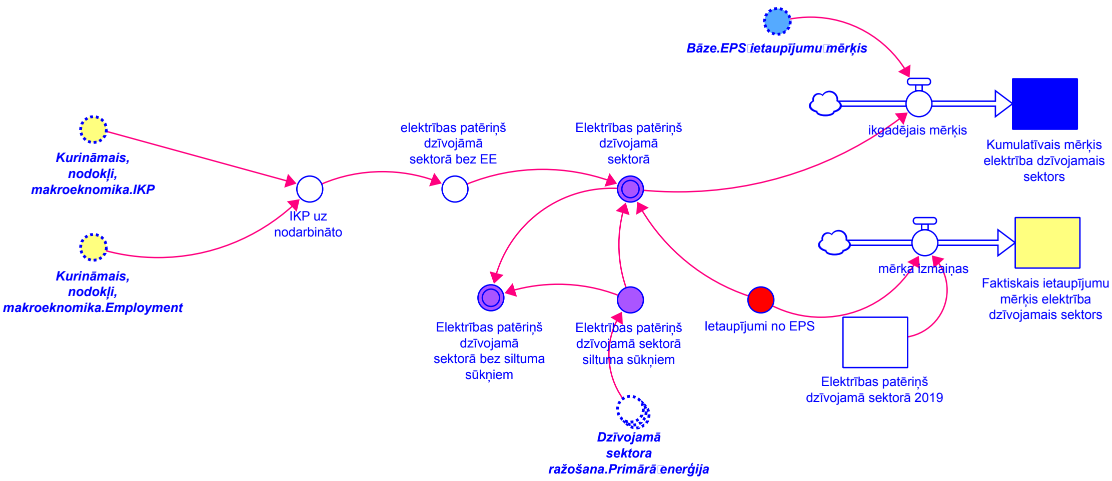


Fig. 2.4.13. Model structure for electricity consumption in the residential sector

Electricity consumption in households without EE measures:

$$EP_M^{bez(EE)} = -0.017 * (IKP_{nod.per.} + 2243.1) * Unit_{non}, \qquad (2.85)$$

where

$IKP_{nod.per.}$ - GDP per person employed, EUR/person;

$EP_M^{bez(EE)}$ – electricity consumption in households without EE measures, GWh/year;

$Unit_{non}$ – unit removal, GWh/year/(EUR/person).

Electricity consumption in households without heat pumps:

$$EP_M^{bez(SS)} = EP_M - MP_{SS}, \qquad (2.86)$$

where

$EP_M^{bez(SS)}$ – electricity consumption in households without heat pumps, GWh/year;

EP_M – electricity consumption in households, GWh/year;

MP_{SS} – household demand from heat pumps, GWh/year.

Primary energy for heat pumps:

$$MP_{SS} = E_{VĢM}^{SS} + E_{DĢM}^{SS}, \qquad (2.87)$$

where

$E_{VĢM}^{SS}$ – primary energy (heat pump – VĢM), GWh/year;

$E_{DĢM}^{SS}$ – primary energy (heat pump in multi-apartment buildings), GWh/year.

Electricity consumption in households:

$$EP_M = MP_{SS} + EP_M^{bez(EE)} - Iet_M^{ESS}, \qquad (2.88)$$

where

Iet_M^{ESS} – savings in households from heat pumps, GWh/year.

Industrial and commercial services sector

In the industrial and service sectors, the main stocks describe not the amount of square meters, but the number of enterprises, since in these sectors, unlike households, part of the premises are unheated, as well as part of the energy resources are used not only for the production of heat for space heating, but also for the provision of technological processes (see Figure 2.4.14).

Unlike in households, in industry and services, not only the renovation of buildings to reduce thermal energy consumption is considered, but also other EE measures, including to increase the efficiency of production processes.

Enterprises are divided into large enterprises and large electricity consumers, as well as small enterprises. This distinction is used because of the significant specific difference in energy consumption between large companies and other companies.

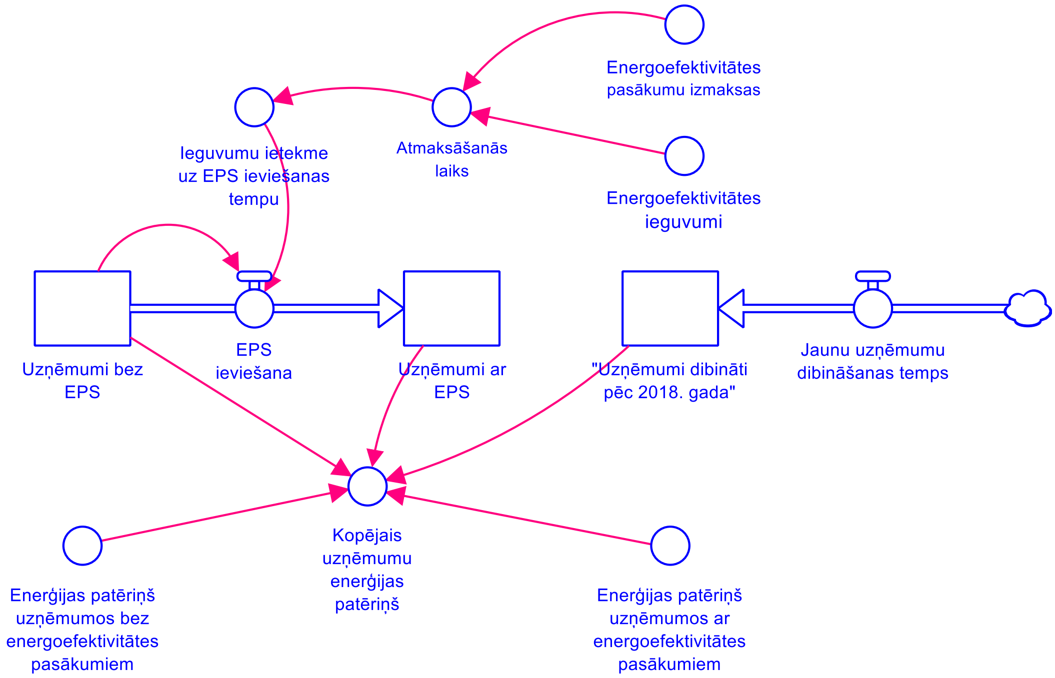


Fig. 2.4.14. Energy consumption of enterprises and taking EE measures.

The structure of the industrial model is shown in Figure 2.4.15

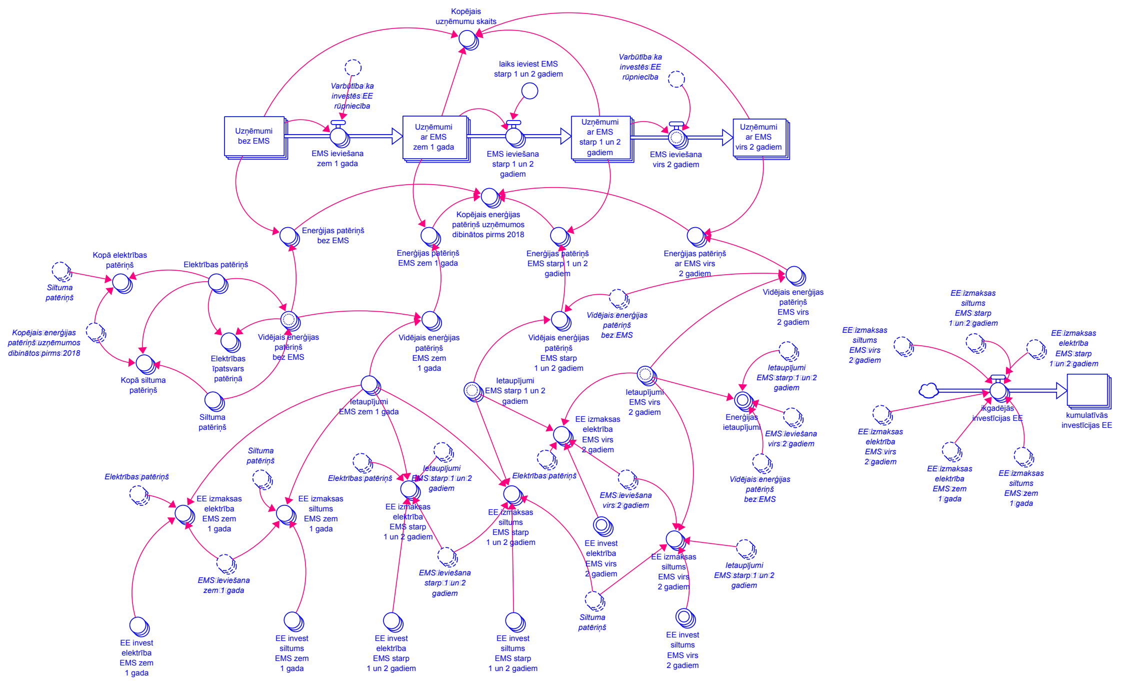


Fig. 2.4.15. Structure of the industrial model

Companies without EMS divided into large and small enterprises under the legislation:

$$uzņ. = -\int_{t_0}^{t} EMS_{<1}(t)dt + uzņ.(t_0), \qquad (2.89)$$

where

$uzņ.$ – companies without EMS, pieces;

$EMS_{<1}$ – transition to EMU up to 1 year, pieces/year.

New companies:

$$uzņ._{jaun.} = \frac{(SPD*n_{uzņ.}*SPD)+(1-n_{uzņ.})*SPD*n_{uzņ.}}{10}, \qquad (2.90)$$

where

$uzņ._{jaun.}$ – new companies, pieces/year;

SPD - initial growth share, 1/year.

Initial growth share:

$$\mathrm{SPD} = \mathrm{IF}\left(\mathrm{TIME} < 2021, 0.01423, \mathrm{IF}\left(\mathrm{TIME} > 2030, -0.0081, -0.00116\right)\right) \qquad (2.91)$$

Total electricity consumption in enterprises established after 2018:

$$KEP_{uzņ._{>2018.}} = uzņ._{>2018.} * EP^{VPS}_{uzņ._{>2}}, \qquad (2.92)$$

where

$KEP_{uzņ._{>2018.}}$ -total electricity consumption in enterprises established after 2018, GWh/year;

$EP^{VPS}_{uzņ._{>2}}$ – average energy consumption with EMS over 2 years, GWh/pc/year.

Total electricity consumption in the enterprises:

$$KEP_{uzņ.} = KEP_{uzņ._{<2018.}} + KEP_{uzņ._{>2018.}}, \qquad (2.93)$$

where

$KEP_{uzņ.}$ – total electricity consumption in the enterprises, GWh/year;

$KEP_{uzņ._{<2018.}}$ total electricity consumption in enterprises established before 2018, GWh/year.

Total heat consumption in all enterprises:

$$KSP_{uzņ.}^{visos} = KEP_{uzņ.} - KEP_{uzņ.}^{visos}, \quad (2.94)$$

where

$KSP_{uzņ.}^{visos}$– total heat consumption in all enterprises, GWh/year;

$KEP_{uzņ.}^{visos}$ – total electricity consumption in all enterprises, GWh/year.

Total electricity consumption in all enterprises:

$$KEP_{uzņ.}^{visos} = KEP_{uzņ.} * EP_D, \quad (2.95)$$

where

EP_D – share of electricity in consumption.

Total electricity consumption in enterprises established before 2018:

$$KEP_{uzņ.<2018.} = EP + EP_{VPS_{<1}} + EP_{VPS_{1-2}} + EP_{VPS_{>2}}, \quad (2.96)$$

where

EP – energy consumption without EMS implementation, GWh/year;

$EP_{EMS_{<1}}$ – energy consumption with EMU up to 1 year, GWh/year;

$EP_{EMS_{1-2}}$ – energy consumption with EMS from 1 to 2 years, GWh/year;

$EP_{EMS_{>2}}$ – energy consumption with EMU longer than 2 years, GWh/year

Average energy consumption without EMS implementation:

$$EP^{vid} = EP * SP, \quad (2.97)$$

where -

EP – electricity consumption, GWh/piece/year;

SP – heat consumption, GWh/piece/year.

Total electricity consumption:

$$KEP = \frac{KEP_{uzņ.<2018.} * EP}{(EP+SP)}, \quad (2.98)$$

where

KEP – total electricity consumption, GWh/year.

Total heat consumption:

$$KSP = \frac{KEP_{uzņ.<2018.} * SP}{(EP+SP)}, \quad (2.99)$$

where

KSP – total heat consumption, GWh/year.

Electricity savings:

$$Iet._E = VPS_{>2} * EP^{vid} * \left(Iet._{EMS_{>2}} - Iet._{EMS_{1-2}}\right) * (TIME - (TIME - 1)), \quad (2.100)$$

where

$Iet._E$ – electricity savings, GWh/year;

$Iet._{EMS_{>2}}$ – savings with EMS longer than 2 years;

$Iet._{EMS_{1-2}}$ – savings with EMS from 1 to 2 years.

EE's costs for electricity in year 1:

$$EE_{E_{1.g}}^{izm} = I_{E_{1.g}}^{EE} * EP * VPS_{<1} * Iet._{EMS_{<1}} * \left(TIME - (TIME - 1)\right), \quad (2.101)$$

where

$EE^{izm}_{E_{1.g}}$ – EE's costs for electricity in year 1, EUR/year;
$I^{EE}_{E_{1.g}}$ – investment costs in EE's electricity measures in year 1, EUR/GWh.

EE's costs for heat in year 1:

$$EE^{izm}_{S_{1.g}} = I^{EE}_{S_{1.g}} * SP * EMS_{<1} * \ Iet._{EMS_{<1}} * \left(TIME - (TIME - 1)\right), \quad (2.102)$$

where
$EE^{izm}_{S_{1.g}}$ – EE's costs for heat in year 1, EUR/year;
$I^{EE}_{S_{1.g}}$ – investment costs in EE's heat measures in year 1, EUR/GWh.

EE measurable costs for electricity for years 1 to 2:

$$EE^{izm}_{E_{1-2}} = I^{EE}_{E_{1-2}} * EP * EMS_{1-2} * \left(Iet._{EMS_{1-2}} - Iet._{VPS_{<1}}\right) * \left(TIME - (TIME - 1)\right), \quad (2.103)$$

where
$EE^{izm}_{E_{1-2}}$ – EE measurable costs for electricity for years 1 to 2:, EUR/year;
$I^{EE}_{E_{1-2}}$ –investment costs in EE's electricity measures for years 1 to 2, EUR/GWh.

EE measurable costs for heat for years 1 to 2::

$$EE^{izm}_{S_{1-2}} = I^{EE}_{E_{1-2}} * SP * EMS_{1-2} * \left(Iet._{EMS_{1-2}} - Iet._{VPS_{<1}}\right) * \left(TIME(TIME - 1)\right), \quad (2.104)$$

where
$EE^{izm}_{S_{1-2}}$ – EE measurable costs for heat for years 1 to 2:, EUR/gadā;
$I^{EE}_{E_{1-2}}$ – investment costs in EE's heat measures for years 1 to 2, EUR/GWh.

Annual investments in EE measures:

$$II^{EE} = EE^{izm}_{S_{>2}} + EE^{izm}_{E_{>2}} + EE^{izm}_{S_{1-2}} + EE^{izm}_{E_{1-2}} + EE^{izm}_{S_{1.g}} + EE^{izm}_{E_{1.g}}, \quad (2.105)$$

where
II^{EE} – annual investments in EE measures, EUR/year;
$EE^{izm}_{S_{>2}}$ – EE measurable heat costs after year 2, EUR/year;
$EE^{izm}_{E_{>2}}$ – EE's measurable electricity costs after year 2, EUR/year.

Cumulative investments in EE measures:

$$KI^{EE} = \int_{t_0}^{t} II^{EE}(t)dt + KI^{EE}(t_0), \quad (2.106)$$

where
KI^{EE} – cumulative investments in EE measures, EUR.

Figure 2.4.16 shows the structure of the industrial sector payback time module.

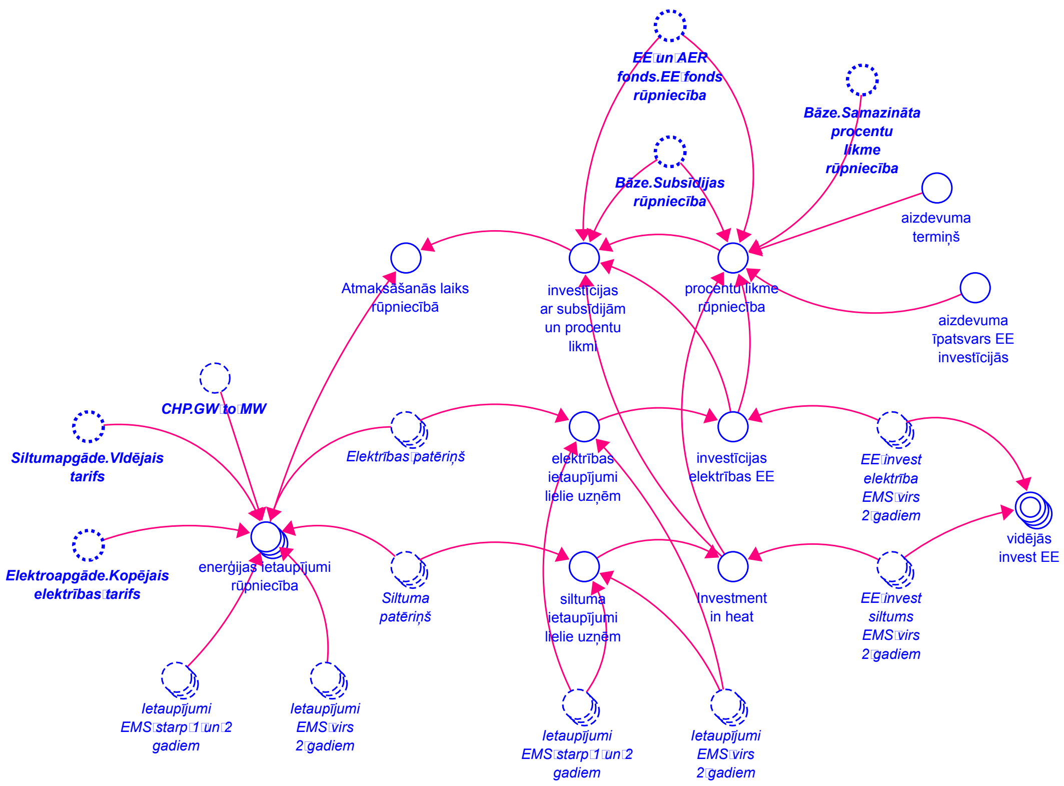


Fig. 2.4.16.The structure of the industrial sector payback time module

Heat savings in the large enterprises:

$$S_{iet(L)} = (Iet._{VPS_{>2}} - Iet._{VPS_{1-2}}) * SP, \quad (2.107)$$

where

$S_{iet(L)}$ – heat saved in the large enterprises, GWh/piece/year.

Investments to reduce thermal energy consumption:

$$I_S = I^{EE}_{S_{>2}} * S_{iet(L)} * (TIME - (TIME - 1)), \quad (2.108)$$

where

I_S – investments to reduce thermal energy consumption, EUR/piece;

$I^{EE}_{S_{>2}}$ – EE investments to reduce heat with EMS after 2 years, EUR/GWh.

Electricity saved in the large enterprises:

$$E_{iet(L)} = ((Iet._{VPS_{>2}} - Iet._{VPS_{1-2}}) * EP, \quad (2.109)$$

where

$E_{iet(L)}$ – electricity saved in the large enterprises, GWh/piece/year.

Investments to reduce electricity consumption:

$$I_E = I^{EE}_{E_{>2}} * E_{iet(L)} * (TIME - (TIME - 1)), \quad (2.110)$$

where

I_E – investments to reduce electricity consumption, EUR/piece.

Payback time:

$$AL = \frac{I^{proc}_{sub}}{EEE_R}, \quad (2.111)$$

where

AL – payback time, per year.

Investments with subsidies and interest rates:

$$I_{sub}^{proc} = IF\ (F_R^{EE} > 0, (1 - SUB_{int}^R), 1 * (I_E + I_S) + r^*), \qquad (2.112)$$

where

F_R^{EE} – EE fund in industry, EUR;

SUB_{int}^R - subsidy intensity in the industrial sector.

Reduced interest rate:

$$r^* = AD_{ieg} * (I_E + I_S) * IF\ (F_R^{EE} > 0, (1 - SUB_{int}^R), 1) * \frac{(r_{AN}^* * AL_{kr} * 0{,}5\ )}{(TIME - (TIME - 1))}, \quad (2.113)$$

where

r_{AN}^* - reduced interest rate in industry.

The public sector

Total electricity consumption in the public sector is calculated taking into account the electricity consumption of heat pumps:

$$KEP^{SS} = KEP^{bez(SS)} + E_{piep}^{SS}, \qquad (2.114)$$

where

$KEP^{bez(SS)}$ – total electricity consumption without heat pumps, GWh/year.

Electricity consumption of the heat pumps:

$$E_{piep}^{SS} = E^{SS}, \qquad (2.115)$$

where

E^{SS} – primary energy (heat pump), GWh/year.

Figure 2.4.17 shows the structure of the model for the consumption of thermal energy and electricity without heat pumps in the public sector.

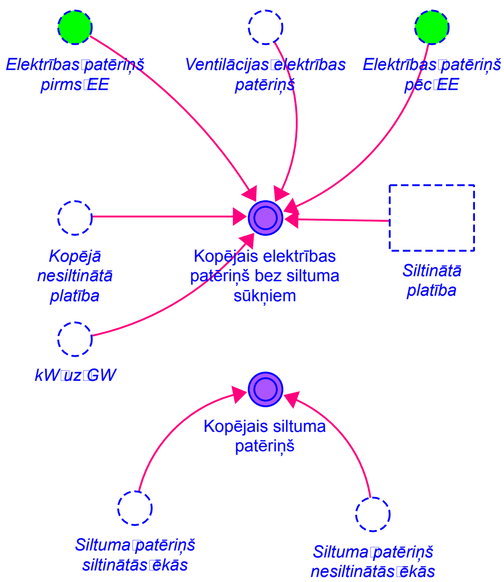


Fig. 2.4.17. Model structure for consumption of heat and electricity without heat pumps in the public sector

Total electricity consumption without heat pumps:

$$KEP^{bez(SS)} = EP^{pirms(EE)} * \frac{Plat_{nesilt}^{kop}}{1000000} + \left(EP^{pēc(EE)} + EP^{vent}\right) * \frac{Plat_{silt}^{kop}}{1000000}, \quad (2.116)$$

where

$EP^{pirms(EE)}$ – electricity consumption before EE introduction, kWh/m²/year;

$Plat_{nesilt}^{kop}$ – total uninsulated area, m²;

$EP^{pēc(EE)}$ – electricity consumption after EE introduction, kWh/m²/year;

EP^{vent} - electricity consumption for ventilation, kWh/m²/year;

$Plat_{silt}^{kop}$ – total insulated area, m².

Total heat consumption:

$$KSP = SP_{silt} + SP_{nesilt}, \quad (2.117)$$

where

SP_{silt} – heat consumption in insulated buildings, GWh/year;

SP_{nesilt} – heat consumption in uninsulated buildings, GWh/year.

Figure 2.4.18 shows the structure of the model for the introduction of EE in the public sector.

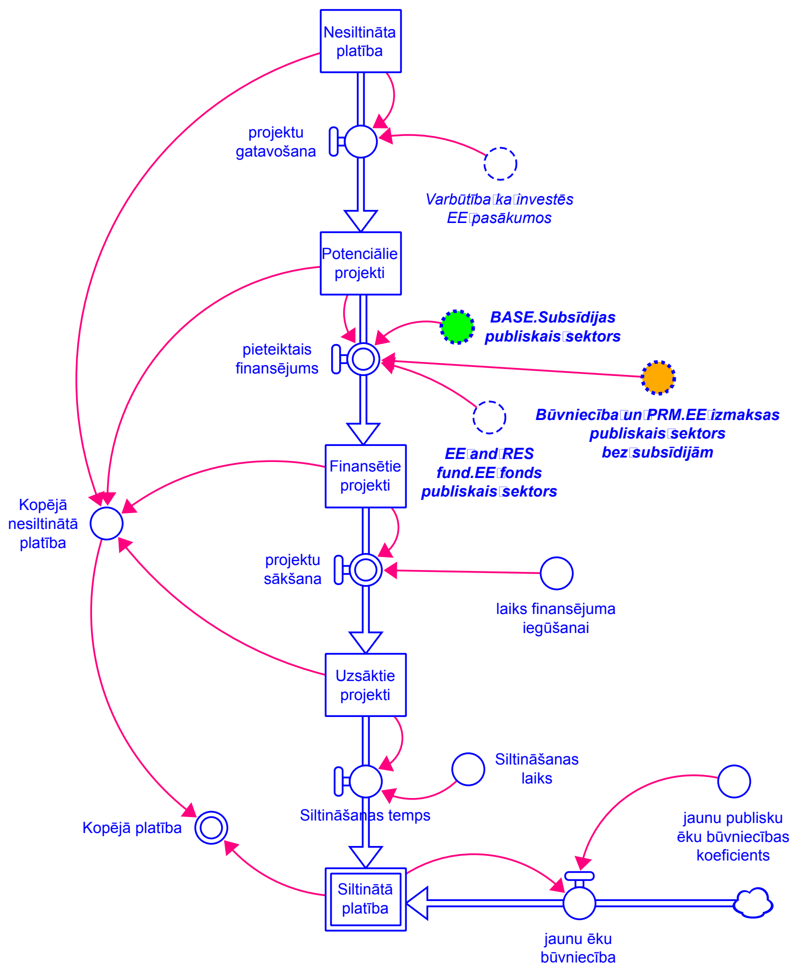


Fig. 2.4.18. Model structure for EE introduction I the public sector

Area of uninsulated public buildings:

$$Z_{nesilt} = -\int_{t_0}^{t} Pl\_1_{16}\,(t)dt + Z_{nesilt}\,(t_0), \tag{2.118}$$

where

Pl_1_{16} – pace of project launching, m^2/years.

Project start rate:

$$Pl\_1_{16} = IF(Z_{nesilt} > 0, V_{EE}, 0). \tag{2.119}$$

where

V_{EE} – probability of investing in EE measures.

The potential projects:

$$PP = \int_{t_0}^{t} [Pl_{1_{16}}(t) - GF(t)]\,dt + PP\,(t_0), \tag{2.120}$$

where

PP – the potential projects, m^2;

GF – funding raised, m^2/years.

Funding raised:

$$GF = IF\left(PP > 0, IF\left(F_{pub}^{EE\&AER} > 0, IF\,\frac{\left(SUB_{int}^{P\bar{E}} * EE_{P\bar{E}}^{izm} = 0,0, F_{pub}^{EE\&AER}\right)}{\left(SUB_{int}^{P\bar{E}} * EE_{P\bar{E}}^{izm} * (TIME-(TIME-1)\right)}\right), 0,0\right), \tag{2.121}$$

where

$F_{pub}^{EE\&AER}$ – EE public fund (EE and EAR fund), EUR/year;

$SUB_{int}^{P\bar{E}}$ - intensity of subsidies in public buildings;

$EE_{P\bar{E}}^{izm}$ - EE costs in public buildings without subsidies, EUR/m^2.

The funded projects:

$$FP = \int_{t_0}^{t} [GF\,(t) - P_{SL}(\mathrm{t})]\mathrm{dt} + \mathrm{FP}\,(t_0), \tag{2.122}$$

where

FP – funded projects, m^2;

P_{SL} – the pace of project launch, m^2/years.

The pace of project launch:

$$P_{SL} = \frac{FP}{F_{IeL}}, \tag{2.123}$$

where

F_{IeL} – financial acquisition time, per year.

Started projects:

$$P_{s\bar{a}kt} = \int_{t_0}^{t} [\,P_{SL}\,(t) - Silt_{\bar{a}tr}(t)]\,dt + P_{s\bar{a}kt}, \tag{2.124}$$

where

$P_{s\bar{a}kt}$ – started projects, m^2;

$Silt_{\bar{a}tr}$ – insulation speed, m^2/years.

Total insulated area:

$$KZ_{silt} = \int_{t_0}^{t} [\,Silt_{\bar{a}tr}\,(t) + \bar{E}K_{jaun}(t)]\,dt + KZ_{silt}\,(t_0), \tag{2.125}$$

where

KZ_{silt} – total insulated area, m^2;

$\bar{E}K_{jaun}$ – new buildings, m2/years.

New buildings:

$$\bar{E}K_{jaun} = KZ_{silt} * S\bar{E}K_{jaun}^{temp}, \tag{2.126}$$

where

$S\bar{E}K_{jaun}^{temp}$ – the pace of construction of new public buildings, 1/year.

Total uninsulated area:

$$KZ_{nesilt} = Z_{nesilt} + PP + FP + P_{s\bar{a}kt}, \tag{2.127}$$

where

KZ_{nesilt} – total uninsulated area, m2.

Total area:

$$KZ = KZ_{nesilt} + KZ_{silt}, \tag{2.128}$$

where

KZ – total area, m2.

Figure 2.4.19 shows the structure of the model for energy consumption in the public sector.

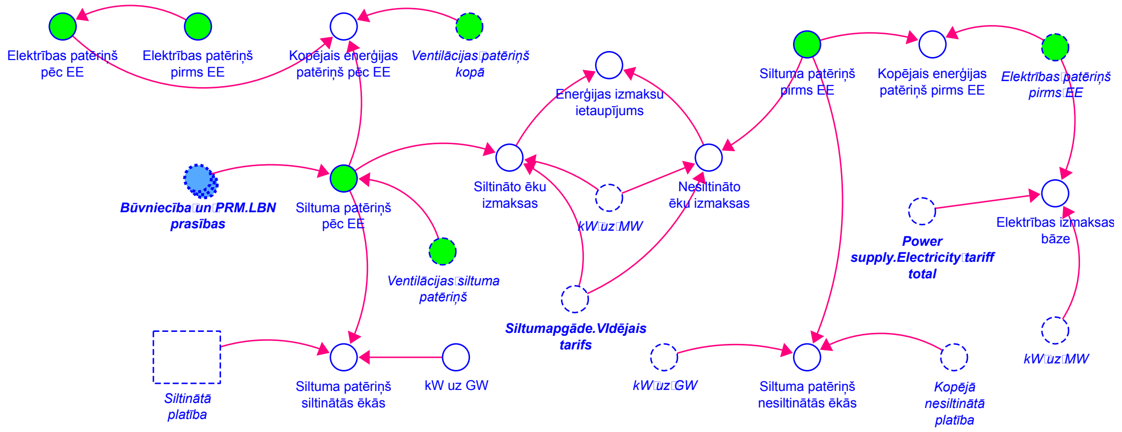


Fig. 2.4.19. Structure of the model for energy consumption in the public sector.

Electricity consumption after EE:

$$EP^{p\bar{e}cEE} = EP^{pirmsEE} * 0.8, \tag{2.129}$$

where

$EP^{p\bar{e}cEE}$ – electricity consumption after EE, kWh/m2/year;

$EP^{pirmsEE}$ – electricity consumption before EE, kWh/m2/year.

Total electricity consumption after EE:

$$KEP^{p\bar{e}cEE} = SP^{p\bar{e}cEE} + KV + EP^{p\bar{e}cEE}, \tag{2.130}$$

where

$KEP^{p\bar{e}cEE}$ – total electricity consumption after EE, kWh/m2/year;

KV – total ventilation, kWh/m2/year.

Specific heat consumption after EE:

$$SP^{p\bar{e}cEE} = LBN^{pras(DĢM)} + SP^{vent}, \tag{2.131}$$

where

$LBN^{pras(DĢM)}$ – Requirements of Latvia's Construction Standards, kWh/m2/year;
SP^{vent} - heat consumption for ventilation, kWh/m2/year.

Total heat consumption after EE:

$$SP_{silt} = SP^{pēcEE} * \frac{Plat_{izol}^{kop}}{1000000}. \quad (2.132)$$

Costs of an insulated building:

$$I^{silt.ēk} = T_S^v * \frac{SP^{pēcEE}}{1000}, \quad (2.133)$$

where
$I^{silt.ēk}$ – costs of an insulated building, EUR/m2/year.

Cost savings:

$$\text{EII} = I^{nesilt.ēk} - I^{silt.ēk}, \quad (2.134)$$

where
$I^{nesilt.ēk}$ – costs of an uninsulated building, EUR/m2/year.

Costs of an uninsulated building:

$$I^{nesilt.ēk} = T_S^v * \frac{SP^{pirmsEE}}{1000}. \quad (2.135)$$

Total heat consumption before EE:

$$SP_{nesilt} = SP^{pirmsEE} * \frac{Plat_{neiz}^{kop}}{1000000}. \quad (2.136)$$

Total energy consumption before EE:

$$KEnP^{pirmsEE} = EP^{pirms(EE)} + SP^{pirms(EE)}, \quad (2.137)$$

where
$KEnP^{pirmsEE}$ – total energy consumption before EE, kWh/m2/year.

Electricity costs for self- consumption:

$$I^{E(ppat)} = T_{kop}^{E} * \frac{EP^{pirms(EE)}}{1000}, \quad (2.138)$$

where
$I^{E(ppat)}$ – Electricity costs for self- consumption, EUR/m2/year.

2.4.3. Sub-model of the linkage of individual energy production and consumption shares

In order to link individual energy consumption and heating solution sections, a linking sub-model has been created, which takes into account the choice of heating solutions, the energy consumption of buildings and the share of individual energy consumption (see Figure 2.4.20).

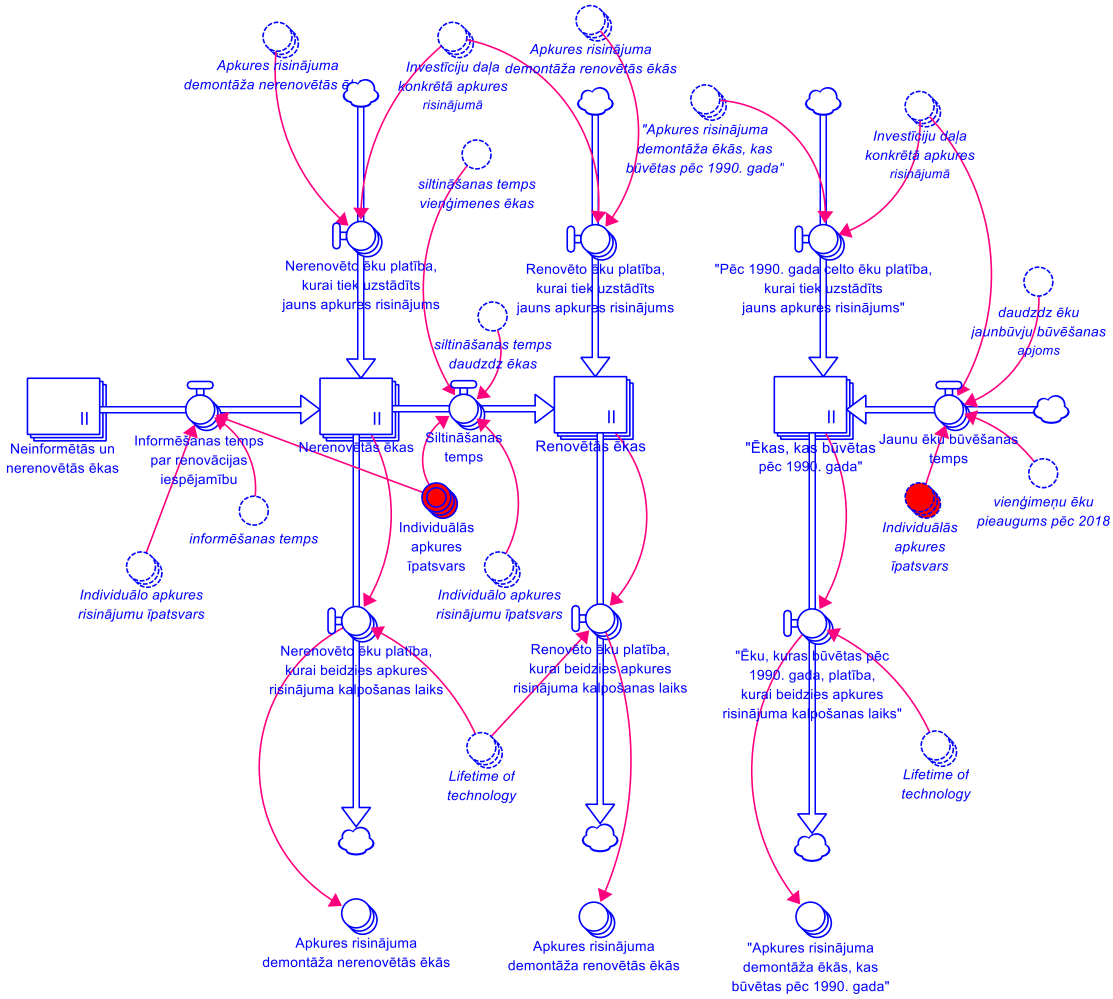


Fig. 2.4.20. Structure of the interlinking sub-model for individual energy production and consumption shares

Area of unrenovated and uninformed buildings for a specific heating solution:

$$\bar{E}k_{NN} = \int_{t_0}^{t} [-InfT\ (\mathrm{t})]dt + \bar{E}k_{NN}\ (t_0), \qquad (2.139)$$

where

$\bar{E}k_{NN}$ – area of unrenovated and uninformed buildings for a specific heating solution, m^2;
InfT – the pace of information on the possibility of renovation for a particular heating solution, m^2/year.

Area of unrenovated buildings for a specific heating solution:

$$\bar{E}k_{N} = \int_{t_0}^{t} [InfT + ApU_N - ApN_N - RenT\ (\mathrm{t})]dt + \bar{E}k_{N}\ (t_0), \qquad (2.140)$$

where

$\bar{E}k_{N}$ – area of unrenovated buildings for a specific heating solution, m^2;
RenT – the pace of renovation for a specific heating solution, m^2/year;
ApU_N – the pace of installation of a new heating solution for unrenovated buildings, m^2/year;
ApN_N – rate of dismantling of an outdated heating solution for unrenovated buildings, m^2/year.

Area of renovated buildings for a specific heating solution:

$$\bar{E}k_R = \int_{t_0}^{t} [RenT + ApU_R - ApN_R\ (t)]dt + \bar{E}k_R\ (t_0), \tag{2.141}$$

where

$\bar{E}k_R$ – area of renovated buildings for a specific heating solution, m^2;

ApU_R – the pace of installation of a new heating solution for renovated buildings, m^2/year;

ApN_R – the pace of dismantling of an outdated heating solution for renovated buildings, m^2/year.

Area of buildings built after 1990 for a specific heating solution:

$$\bar{E}k_{1990} = \int_{t_0}^{t} [B\bar{u}vT + ApU_{1990} - ApN_{1990}\ (t)]dt + \bar{E}k_{1990}\ (t_0), \tag{2.142}$$

where

$\bar{E}k_{1990}$ – area of buildings built after 1990 for a specific heating solution, m^2;

BūvT – the pace of construction of new buildings with a specific heating solution, m^2/year;

ApU_{1990} – the pace of installation of a new heating solution for buildings built after 1990, m^2/year;

ApN_{1990} – the pace of dismantling of an outdated heating solution for buildings built after 1990, m^2/year.

Information rate on the possibility of renovation for a particular heating solution:

$$InfT = Inf^{likm} * InSH * InAP, \tag{2.143}$$

where

InSH – share of individual heating in buildings (single-family and multi-apartment);

InAP – share of individual heating solutions in buildings (single-family and multi-apartment);

Renovation rate for a specific heating solution:

$$RenT = Silt^{\bar{a}tr} * InSH * InAP, \tag{2.144}$$

where

$Silt^{\bar{a}tr}$ – renovation rate in buildings (single-family and multi-apartment), m^2/year.

Renovation rate for a specific heating solution:

$$B\bar{u}vT = S\bar{E}K^{temp} * InSH * InvAP, \tag{2.145}$$

where

$S\bar{E}K^{temp}$ – the pace of construction of new buildings (single-family and multi-apartment), m^2/year;

InvAP – investment part of a particular heating solution.

The pace of dismantling an outdated heating solution for unrenovated buildings:

$$ApN_N = \frac{\bar{E}k_N}{ApLT}, \tag{2.146}$$

where

ApLT – lifespan of heating solutions, years.

The pace of dismantling of an outdated heating solution for renovated buildings:

$$ApN_R = \frac{\bar{E}k_R}{ApLT}, \tag{2.147}$$

The pace of dismantling of an outdated heating solution for buildings built after 1990:

$$ApN_{1990} = \frac{\bar{E}k_{1990}}{ApLT}, \tag{2.148}$$

Total area of unrenovated buildings dismantling outdated heating solutions:

$$TOTApN_N = \sum_{i=1}^{n} ApN_{Ni}, \quad (2.149)$$

where

$TOTApN_N$ – total area of unrenovated buildings dismantling outdated heating solutions (single-family and multi-apartment), m^2/year.

Total area of renovated buildings dismantling outdated heating solutions:

$$TOTApN_R = \sum_{i=1}^{n} ApN_{Ri}, \quad (2.150)$$

where

$TOTApN_R$ – total area of renovated buildings dismantling outdated heating solutions (single-family and multi-apartment), m^2/year.

Total area of buildings built after 1990 dismantling outdated heating solutions:

$$TOTApN_{1990} = \sum_{i=1}^{n} ApN_{1990i}, \quad (2.151)$$

where

$TOTApN_{1990}$ – the total area of buildings built after 1990 dismantling outdated heating solutions (single-family and multi-apartment), m^2/year.

Installation rate of a new heating solution for unrenovated buildings:

$$ApU_N = TOTApN_N * InvAP, \quad (2.152)$$

Installation rate of a new heating solution for renovated buildings:

$$ApU_R = TOTApN_R * InvAP, \quad (2.153)$$

The pace of installation of a new heating solution for buildings built after 1990:

$$ApU_{1990} = TOTApN_{1990} * InvAP, \quad (2.154)$$

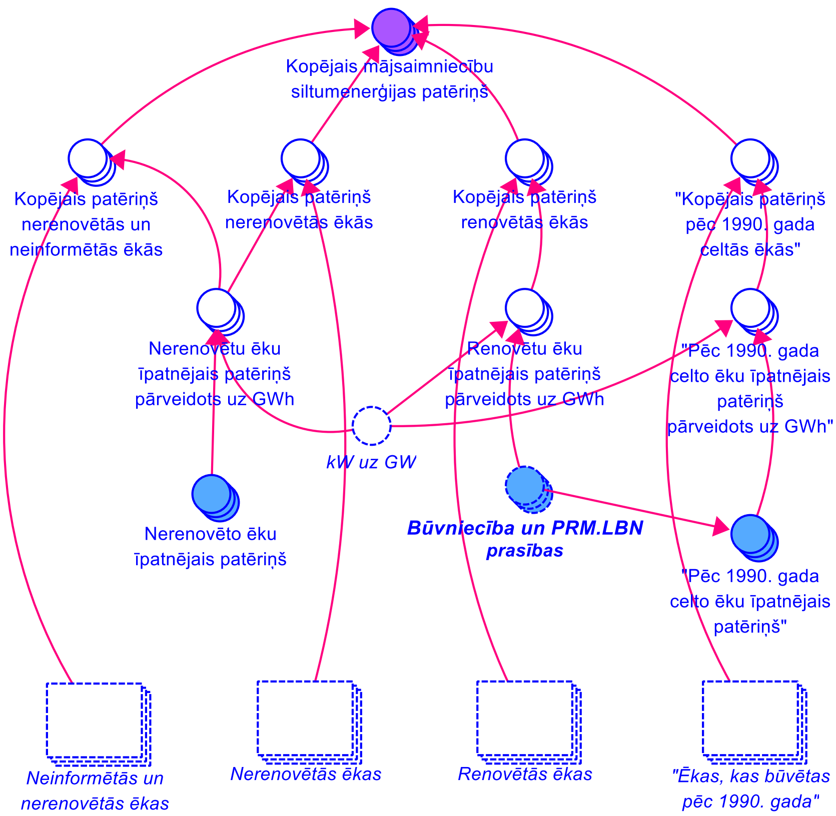


Fig. 2.4.21. Structure of modelling of total thermal energy consumption

Specific consumption of unrenovated buildings converted to GWh (single-family and multi-apartment buildings):

$$\bar{I}pPat_R^{GWh} = \frac{\bar{I}pPat_R}{1000000}, \quad (2.155)$$

where

$\bar{I}pPat_N^{GWh}$ – the specific consumption of unrenovated buildings converted to GWh (single-family and multi-apartment buildings),GWh/m^2/year;

$\bar{I}pPat_N$ – specific consumption of unrenovated buildings (for single-family and multi-apartment buildings), kWh/m^2/year.

Specific consumption of renovated buildings converted to GWh (single-family and multi-apartment buildings):

$$\bar{I}pPat_R^{GWh} = \frac{\bar{I}pPat_R}{1000000}, \quad (2.156)$$

where

$\bar{I}pPat_R^{GWh}$ – specific consumption of renovated buildings converted to GWh (single-family and multi-apartment buildings):, GWh/m^2/year;

$\bar{I}pPat_R$ – specific consumption of renovated buildings (for single-family and multi-apartment buildings), kWh/m$_2$/year.

Specific consumption of buildings built after 1990 converted to GWh (single and multi-apartment buildings):

$$\bar{I}pPat_{1990}^{GWh} = \frac{\bar{I}pPat_{1990}}{1000000}, \quad (2.157)$$

where

$\bar{I}pPat_{1990}^{GWh}$ – specific consumption of buildings built after 1990 converted to GWh (single and multi-apartment buildings), GWh/m^2/year;

$\bar{I}pPat_{1990}$ – specific consumption of buildings built after 1990 (single and multi-apartment buildings), kWh/m^2/year.

Total thermal energy consumption in unrenovated and uninformed buildings with a specific heating solution:

$$TOTPat_{NN} = \bar{E}k_{NN} * \bar{I}pPat_N^{GWh}, \quad (2.158)$$

where

TOTPatNN – total thermal energy consumption in unrenovated and uninformed buildings with a specific heating solution, GWh/year.

Total heat consumption in unrenovated buildings with a specific heating solution:

$$TOTPat_N = \bar{E}k_N * \bar{I}pPat_N^{GWh}, \quad (2.159)$$

where

$TOTPat_N$ – total heat consumption in unrenovated buildings with a specific heating solution, GWh/year.

Total heat consumption in renovated buildings with a specific heating solution:

$$TOTPat_R = \bar{E}k_R * \bar{I}pPat_R^{GWh}, \quad (2.160)$$

where

$TOTPat_R$ – Total heat consumption in renovated buildings with a specific heating solution, GWh/year.

Total thermal energy consumption in buildings built after 1990 with a specific heating solution:

$$TOTPat_{1990} = \bar{E}k_{1990} * \bar{I}pPat_{1990}^{GWh}, \quad (2.161)$$

where

$TOTPat_{1990}$ – total thermal energy consumption in buildings built after 1990 with a specific heating solution, GWh/year.

Total household thermal energy consumption with a specific heating solution:

$$TOTPat = TOTPat_{NN} + TOTPat_{N} + TOTPat_{R} + TOTPat_{1990}, \quad (2.162)$$

where

TOTPat – total household thermal energy consumption with a specific heating solution, GWh/year.

2.4.4. Structure of electricity demand and supply

This sub-model determines the total energy demand from different sectors, taking into account the factors affecting this demand. The SD model includes the overall structure of the electricity market, taking into account electricity imports and the transmission system.

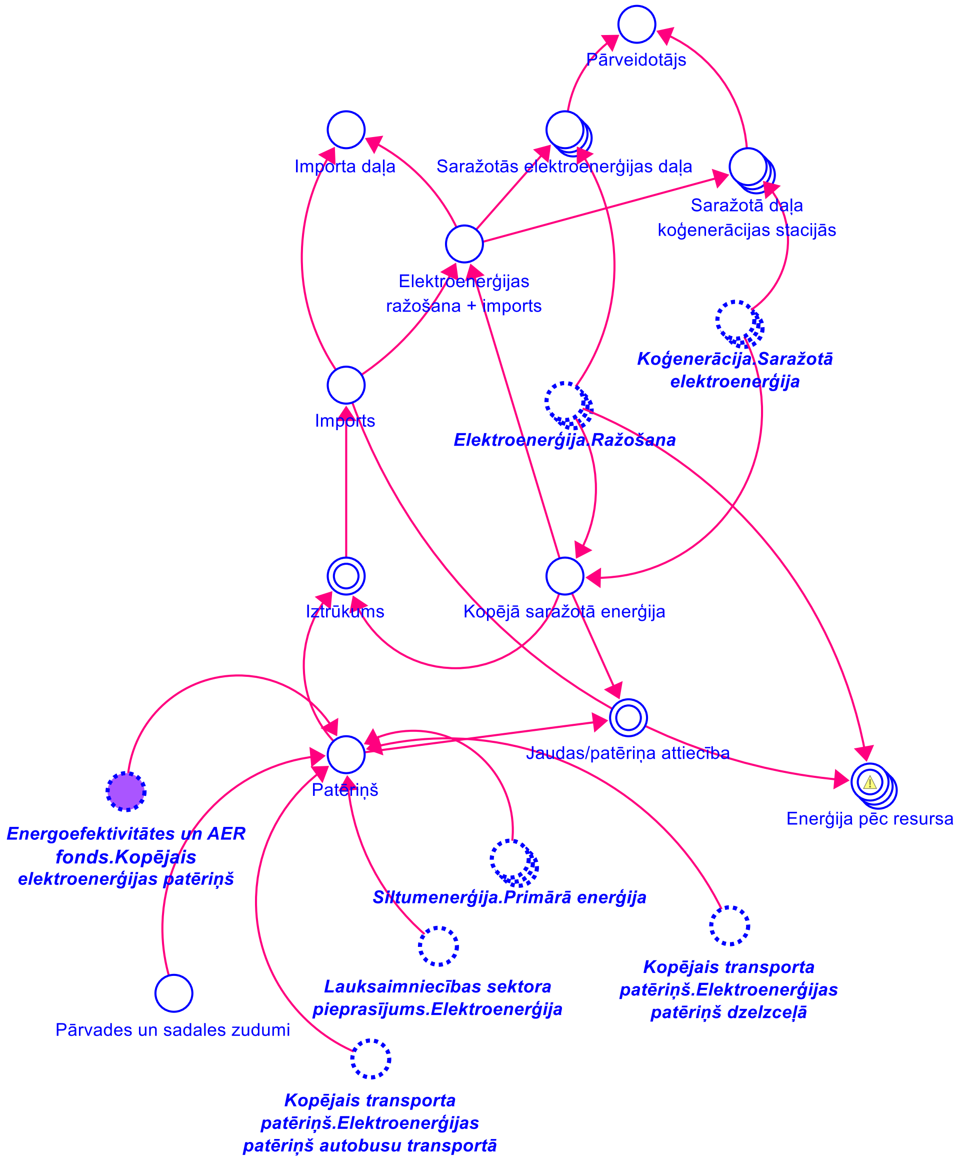


Fig. 2.4.22. Structure of the model matching the demand and supply

Total amount of electricity produced from all installations:

$$P_{EL} = \sum_{i=1}^{n} P_i \,, \tag{2.163}$$

where

P_{EL} – total amount of electricity produced from all installations, GWh/year;
P_i – amount of energy produced by specific technologies, GWh/year.

Total demand of all the sectors:

$$DEM_{EL} = (\sum_{i=1}^{n} DEM_i) * (1 + TDL) \,, \tag{2.164}$$

where

DEM_{EL} – total demand of all the sectors, GWh/year;
DEM_i – electricity demand from individual sectors, GWh/year;
TDL – share of electricity transmission and distribution losses.

Ratio of demand for electricity to electricity produced:

$$JPA_{EL} = \frac{P_{EL}}{DEM_{EL}} \,, \tag{2.165}$$

where

JPA_{EL} – ratio of demand for electricity to electricity produced.

Electricity shortage:

$$IT_{EL} = IF((DEM_{EL} - P_{EL}) < 0, 0, (DEM_{EL} - P_{EL})), \tag{2.166}$$

where

IT_{EL} – electricity shortage (equal to imports), GWh/year.

Total amount of electricity provided:

$$PTOT_{EL} = P_{EL} + IT_{EL} \,, \tag{2.167}$$

where

$PTOT_{EL}$ – total amount of electricity provided, GWh/year.

Share of energy produced by a specific technology (including share of imports):

$$RD_i = \frac{P_{EL}}{PTOT_{EL}} \,, \tag{2.168}$$

where

RD_i – share of energy produced by a specific technology (including share of imports).

Exponential function for the determination of the import price weight:

$$\mathrm{EXP}_{IMP} = e^{-\alpha * T_{IMP}}. \tag{2.169}$$

where

EXP_{IMP} – exponential function for the determination of the import price weight;
α – coefficient, which characterises the behaviour of decision-makers in choosing one of the solutions, depending on the energy tariff;
T_{IMP} – price of imported electricity, EUR/MWh;

Exponential function for determining the tariff weight of various technological solutions:

$$\mathrm{EXP}_i = e^{-\alpha * T_i}. \tag{2.170}$$

where

EXP_i – exponential function for determining the tariff weight of various technological solutions.

Value of exponential functions depending on the use of the technology in the model:

$$EXPin_i = IF\ (TEH_i = 1, \mathrm{EXP}_i \,, 0), \tag{2.171}$$

where
$EXPin_i$ – value of exponential functions depending on the use of the technology in the model.

Sum of individual exponential functions:

$$EXP_{SUM} = IF(INS_{IMP} = 1, EXP_{IMP}, 0) + \sum_{i=1}^{n} EXPin_i, \qquad (2.172)$$

where
EXP_{SUM} – Sum of individual exponential functions;
INS_{IMP} – including electricity imports in the model.

Investment decision in one of the power generation technologies:

$$INV_i = IF\left(TEH_i = 1, \frac{\mathrm{EXP}_i}{\mathrm{EXP}_{SUM}}, 0\right), \qquad (2.173)$$

where
INV_i – investment decision in one of the power generation technologies;

Decision on the import of electricity, additional production capacity at the place of installation:

$$FR_{IMP} = IF\left(INS_{IMP} = 1, \frac{\mathrm{EXP}_{IMP}}{\mathrm{EXP}_{SUM}}, 0\right), \qquad (2.174)$$

where
FR_{IMP} – Decision on the import of electricity, additional production capacity at the place of installation

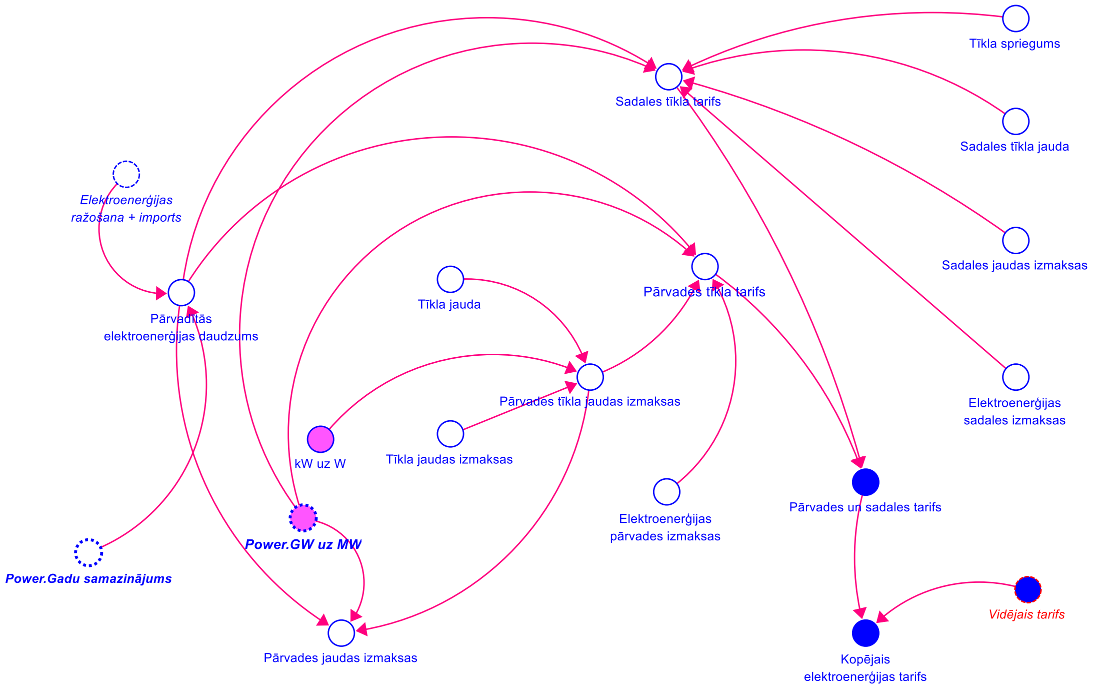


Fig. 2.4.23. Structure of the electricity distribution system

Distribution network tariff:

$$T_{ST} = \frac{(I_{ST} * J_{ST})}{U * (E_{nod} * 1000)} + I_{ES}, \qquad (2.175)$$

where
T_{ST} - Distribution network tariff, EUR/MWh;
I_{ST} - distribution capacity costs, EUR/A;
J_{ST} - distribution network capacity, VA;
U – network voltage, V;

E_{nod} - amount of electricity transmitted, GWh;
I_{ES} - electricity distribution costs, EUR/MWh.

Amount of electricity transmitted:

$$E_{nod} = PTOT_{EL}, \quad (2.176)$$

where
E_{nod} – amount of electricity transmitted, GWh.

Transmission network capacity costs:

$$I_{PTJ} = \left(\frac{I_{TJ}}{1000}\right) * J_{PT}, \quad (2.177)$$

where
I_{PTJ} – transmission network capacity costs, EUR;
I_{TJ} - distribution capacity costs, EUR/kW;
J_{PT} - transmission network capacity, VA.

Transmission network tariff:

$$T_{PT} = \frac{I_{TJ}}{E_{nod}*1000} + I_{EP}, \quad (2.178)$$

where
T_{PT} - transmission network tariff:, EUR/MWh;
I_{EP} – electricity transmission costs, EUR/MWh.

$$T_{P\&ST} = T_{PT} + T_{ST}, \quad (2.179)$$

where
$T_{P\&ST}$ - transmission and distribution tariff, EUR/MWh.

$$T_{kop}^{E} = T_{P\&ST} + T_{e}^{v}, \quad (2.180)$$

where
T_{kop}^{E} – elektroenerģijas tarifs gala lietotājiem, EUR/MWh.

2.4.5. RES share calculation

The SD model determines the share of RES in total energy consumption, taking into account the total amount of energy produced and the amount produced from RES in all sectors (see Figure 2.4.24).

The share of RES is defined as the ratio between total RES consumption and total primary energy consumption.

$$RES_{KP} = \frac{KP^{AER}}{E_{KP}}, \quad (2.181)$$

where
RES_{KP} – total RES share;
KP^{AER} – renewable energy sources, GWh/year;
E_{KP} – total energy, GWh/year.

$$AER_{sil(ind)} = AER_{R} + AER_{P+P} + AER_{M}, \quad (2.182)$$

where
$AER_{sil(ind)}$ – RES in individual heating, GWh/year;
AER_{R} – RES in industry, GWh/year;
AER_{P+P} – RES in the services and the public sector, GWh/year;
AER_{M} – RES in households, GWh/year.

$$AER_{sil} = AER_{R} + AER_{P+P} + AER_{CSA} + AER_{M}, \quad (2.183)$$

where
AER_{sil} – RES in heating, GWh/year;
AER_{CSA} – RES in district heating, GWh/year.

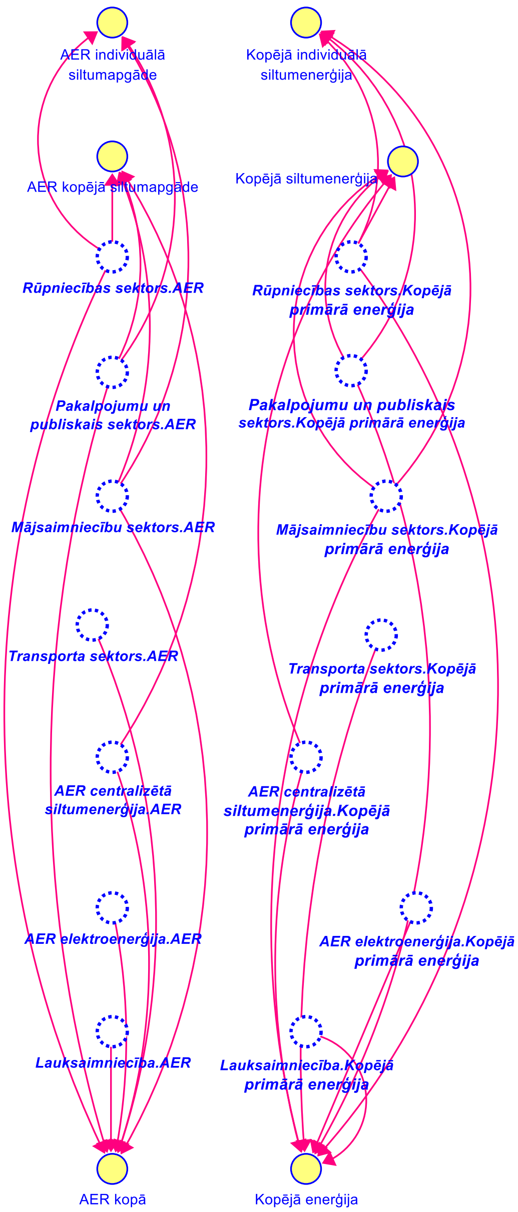


Fig. 2.4.24.att. Calculation structure of RES share

The total RES consumption is determined as the sum of RES consumption in different sectors:

$$AER = AER_R + AER_{P+P} + AER_J + AER_{CSA} + AER_{Tr} + AER_M + AER_L \text{ , (2.184)}$$

where
AER_J – RES capacity, GWh/year;
AER_{Tr} – RES in transport sector, GWh/year;
AER_L – RES in agriculture, GWh/year.

2.4.6. Transport sector

In the transport sector, the different types of vehicles, their electricity consumption and various factors affecting the reduction in consumption and the transition to RES are analysed in detail.

Transport demand

Transport demand is modelled separately for public transport, passenger transport and freight transport. The model integrates various elements to incorporate policy instruments for the transition of citizens from light to public transport.

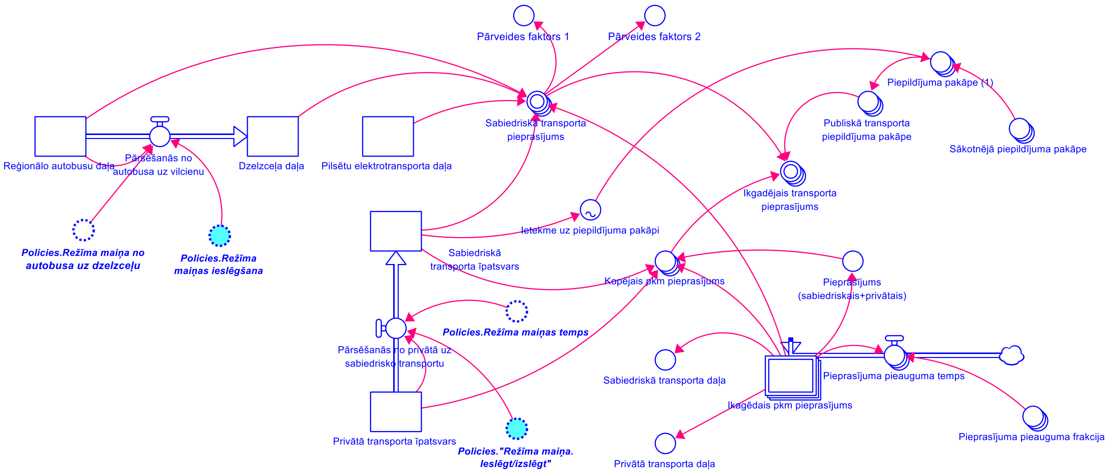


Fig. 2.4.25.. Structure of transport demand

Regional bus share in public transport demand:

$$RA_D = -\int_{t_0}^{t} Pār_V^A\,(t)dt + RA_D\,(t_0), \qquad (2.185)$$

where
RA_D – regional bus share in public transport demand;
$Pār_V^A$ – change of mode - transition from buses to trains, 1/year.

Change of mode - transition from buses to trains:

$$Pār_V^A = IF\,(RPP_V^A = 0, 0, RA_D * RP_V^A), \qquad (2.186)$$

where
RPP_V^A – the possibility of switching on the mode change promotion policy instrument (from bus to train);
RP_V^A – mode change speed – transfer from buses to trains, 1/year.

Share of trains in public transport demand:

$$V_D = \int_{t_0}^{t} Pār_V^A\,(t)dt + V_D\,(t_0), \qquad (2.187)$$

where
V_D – share of trains in public transport demand.

Share of public transport in the total amount of passenger-kilometres (pkm):

$$S_D = \int_{t_0}^{t} RP\,(t)dt + S_D\,(t_0), \qquad (2.188)$$

where
S_D – share of public transport in the total amount of pkm;
RP – regime change - transition from private transport to public, 1/year.

Regime change - transition from private transport to public:

$$RP = IF\ (RPP = 0, 0, Pr_D * RP_{\bar{a}tr}\ ), \tag{2.189}$$

where

RPP – the possibility of switching on the mode change promotion policy instrument (from private to public);

Pr_D – share of private transport in the total amount of pkm;

$RP_{\bar{a}tr}$ – mode change rate – transfer from private to public transport, 1/year.

Share of private transport in the total amount of pkm:

$$Pr_D = -\int_{t_0}^{t} RP\ (t)dt + Pr_D\ (t_0), \tag{2.190}$$

Total pkm demand from private and public transport:

$$PP_{Pr+S} = GPP_{\mathrm{Pr}\ (p-km)} + GPP_{\mathrm{S}\ (p-km)}, \tag{2.191}$$

where

PP_{Pr+S} – total pkm demand from private and public transport, pkm/year;

$GPP_{\mathrm{Pr}\ (p-km)}$– annual pkm demand (private), pkm/year;

$GPP_{\mathrm{S}\ (p-km)}$– annual pkm demand (public), pkm/year.

Annual pkm demand for a particular transport regime (private, public, air):

$$GPP_{(p-km)i} = \int_{t_0}^{t} PPT_{(pkm)i}\ (t)dt + GPP_{(p-km)i}\ (t_0), \tag{2.192}$$

where

$GPP_{(p-km)i}$ – annual pkm demand for a particular transport regime (private, public, air), pkm/year;

$PPT_{(pkm)i}$ – pkm demand growth rate for a particular transport mode (private, public, air), pkm/year/year.

Pkm demand growth rate for a particular transport mode (private, public, air)::

$$PPT_{(pkm)i} = GPP_{(p-km)i} * PP\bar{I}_i, \tag{2.193}$$

where

$PP\bar{I}_i$ – pkm demand growth fraction for a particular transport mode (private, public, air), 1/year.

Degree of filling of public transport:

$$OCC_{publ} = INIT(OCC_{publ}) * Eff_{publ}, \tag{2.194}$$

where

OCC_{publ} – Degree of filling of public transport, person/vehicle;

Eff_{publ} – impact of the share of public transport on the degree of filling of public transport, the person/vehicle.

Impact of the share of public transport on the degree of filling of public transport, the person/vehicle:

$$Eff_{publ} = GRAPH(S_D)$$

(2.195)

Degree of filling of private transport:

$$OCC_{priv} = INIT(OCC_{priv}), \tag{2.196}$$

where

OCC_{priv} – degree of occupation of private transport, person/vehicle.

Degree of filling of air transport:

$$OCC_{avio} = INIT(OCC_{avio}), \quad (2.196)$$

where

OCC_{avio} – degree of filling of air transport, person/vehicle.

Average annual mileage of a given mode of transport (private, public, air):

$$PN\bar{A}_i = \int_{t_0}^{t} \mathrm{NPieaug}_i(\mathrm{t})dt + PN\bar{A}_i(t_0), \quad (2.197)$$

where

$PN\bar{A}_i$ – average annual mileage of a given mode of transport (private, public, air), km/year;
$NPieaug_i$ – annual mileage growth rate of a given mode of transport (private, public, air), km/year/year.

Annual mileage growth rate of a given mode of transport (private, public, air):

$$\mathrm{NPieaug}_i = PN\bar{A}_i * \mathrm{NPieaug}_{Di}. \quad (2.198)$$

where

$\mathrm{NPieaug}_{Di}$ – annual mileage growth fraction for a particular mode of transport (private, public, air), 1/year.

Demand for numbers of trucks:

$$\mathrm{GPP}_{KP} = \frac{GPP_{\mathrm{Pr}\,(t-km)}}{KFK*KN}, \quad (2.199)$$

where

GPP_{KP} - demand for numbers of trucks, vehicle;
$GPP_{\mathrm{Pr}\,(t-km)}$ – annual tkm demand for road transport, tkm/year;
KFK - load capacity of trucks, tons/vehicle;
CN — freight mileage, km/year.

Annual tonne-kilometre (tkm) demand for a specific mode of transport (road, rail):

$$GPP_{Pr(t-km)i} = \int_{t_0}^{t} PPT_{(tkm)i}\,(t)dt + GPP_{Pr(t-km)i}\,(t_0), \quad (2.200)$$

where

$GPP_{Pr(t-km)i}$ – Annual tonne-kilometre (tkm) demand for a specific mode of transport (road, rail):, tkm/year;
$PPT_{(tkm)i}$ – tkm growth rate of demand for a particular mode of transport (road, rail), tkm/year/year.

The growth rate of tkm demand for a particular mode of transport (road, rail):

$$PPT_{(tkm)i} = GPP_{Pr(t-km)i} * PP\bar{I}_{(tkm)i}, \quad (2.201)$$

where

$PP\bar{I}_{(tkm)i}$ – tkm demand growth fraction for a particular mode of transport (road, rail), 1/year.

Sub-model for modelling the age structure of vehicles (by fuel type))

The SD model models the age structure of vehicles to better measure fuel consumption and the impact of the different policies implemented.

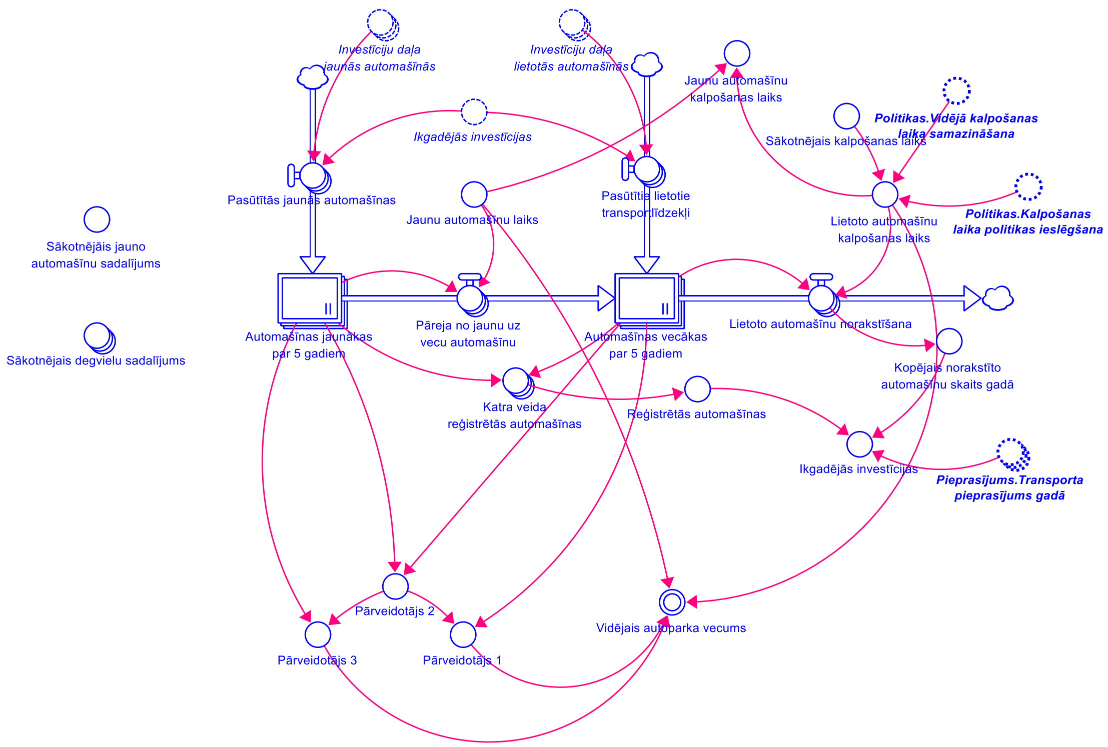


Fig. 2.4.26.. Vehicle age modelling structures

Purchased new vehicles:

$$IeTr_{jaun} = IF\left(IegG * Ieg_{D.jaun} > 0, IegG * Ieg_{D.jaun}, 0\right), \quad (2.202)$$

where

$IeTr_{jaun}$ – purchased new vehicles, vehicle/year;

IegG – total annual number of cars purchased, vehicle/year;

$Ieg_{D.jaun}$ – share of investments in new (<5 years) vehicles.

Fleet under 5 years:

$$AuP_{<5} = \int_{t_0}^{t} [IeTr_{jaun} - P\bar{a}r_{vTr}^{jTr}](t)dt + AuP_{<5}(t_0), \quad (2.203)$$

where

$AuP_{<5}$ – fleet under 5 years, vehicle;

$P\bar{a}r_{vTr}^{jTr}$ – vehicle ageing (changeover to car stock over 5 years), vehicle/year.

Original fleet under 5 years of age:

$$INIT(AuP_{<5}) = AuP_{<5}^{SD} * INIT\left(GPP_{Tr(P)}\right), \quad (2.204)$$

where

$AuP_{<5}^{SD}$ – initial share of fleet under 5 years of age;

$GPP_{Tr(P)}$ – annual demand for vehicles (private), vehicle.

Vehicle ageing (transition to car stock over 5 years):

$$P\bar{a}r_{vTr}^{jTr} = \frac{AuP_{<5}}{JTr_{DzI}}, \quad (2.205)$$

where

JTr_{DzI} – ageing time of the new vehicles, years.

Fleet older than 5 years:

$$AuP_{>5} = \int_{t_0}^{t} [P\bar{a}r_{vTr}^{jTr} + IeTr_{liel} - LTr_{KMD}](t)dt + AuP_{>5}(t_0), \quad (2.206)$$

where
$AuP_{>5}$ – fleet older than 5 years, vehicle;
$IeTr_{liel}$ – purchase of used vehicles, vehicle/year;
LTr_{KMD} – disposal of second-hand vehicles, vehicle/year.

Original fleet older than 5 years:

$$INIT(AuP_{>5}) = (1 - AuP_{<5}^{SD}) * INIT\left(GPP_{Tr(P)}\right), \quad (2.207)$$

Quantity of the purchased second-hand vehicles:

$$IeTr_{liel} = IF\ (\text{IegG} * Ieg_{D.liet} > 0, \text{IegG} * Ieg_{D.liet}, 0), \quad (2.208)$$

where
$Ieg_{D.liet}$ – share of investments in used (>5 years) vehicles.

Removal of used vehicles from the register:

$$LTr_{KMD} = \frac{AuP_{>5}}{LTr_{DzI}}, \quad (2.209)$$

where
LTr_{DzI} – life expectancy of used vehicles, years.

Total number of cars registered:

$$RD_{tip} = AuP_{<5} + AuP_{>5}, \quad (2.210)$$

where
RD_{tip} – total number of cars registered, vehicle.

Total number of registered cars by all fuel types:

$$RD = \sum RD_{(tip)i}, \quad (2.211)$$

where
RD – total number of registered cars by all fuel types, vehicle;
$RD_{(tip)i}$ – total number of registered cars by fuel type, vehicle.

Total number of cars removed from the register by all fuel types:

$$KMD = \sum LTr_{(KMD)i}, \quad (2.212)$$

where
KMD – total number of cars removed from the register by all fuel types, vehicle/year;
$LTr_{(KMD)i}$ – total number of cars removed from the register by fuel type, vehicle/year.

Total annual number of cars purchased:

$$IegG = KMD + \frac{GPP_{Tr(P)} - RD}{DT}, \quad (2.213)$$

Decision-making sub-model

A decision-making sub-model has been created in the SD model, which evaluates the user's choice for the purchase of a vehicle of a certain age and fuel type.

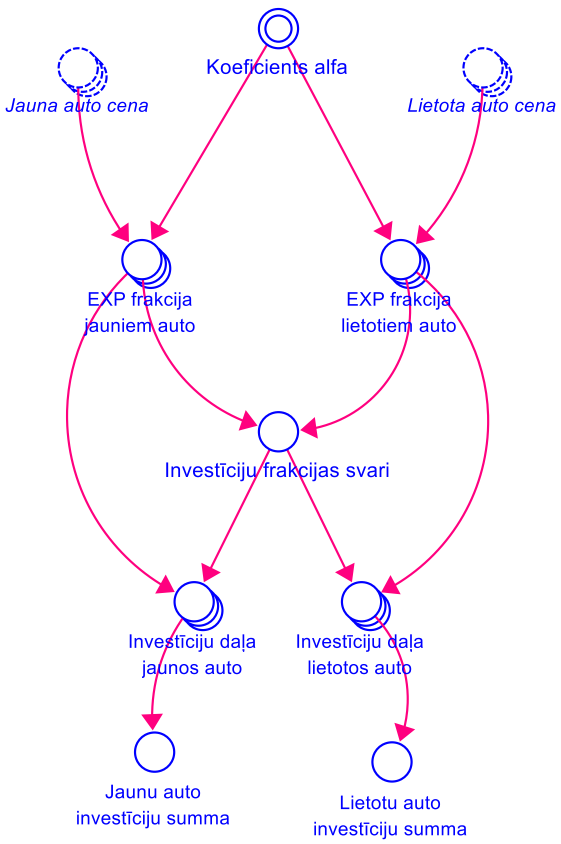


Fig. 2.4.27. Structure of the decision-making sub-model

The exponential function for determining the cost weight of new vehicles (by type of fuel):

$$EXPD_{(j)i} = e^{-\alpha_{Tr} * I_{(jTr)i}}, \quad (2.214)$$

where

$EXPD_{(j)i}$ – the exponential function for determining the cost weight of new vehicles (by type of fuel);

$I_{(jTr)i}$ – costs of new vehicles (by fuel type), EUR/km;

α_{Tr} – a coefficient characterising the behaviour of decision-makers in choosing one of the solutions, depending on the;

The exponential function for determining the cost weight of second-hand vehicles (by type of fuel):

$$EXP\ LTr_{(D)i} = e^{-\alpha_{Tr} * I_{(lTr)i}}, \quad (2.215)$$

where

$EXP\ LTr_{(D)i}$ – the exponential function for determining the cost weight of second-hand vehicles (by type of fuel);

$I_{(lTr)i}$ – costs of second-hand vehicles, EUR/km.

Sum of individual exponential functions:

$$I_{DS} = \sum_{i=1}^{n} EXPD_{(j)i} + \sum_{i=1}^{n} EXP\ LTr_{(D)i} \quad (2.216)$$

where

I_{DS} – sum of individual exponential functions for vehicles.

$$Ieg_{(D.jaun)i} = \frac{EXPD_{(j)i}}{I_{DS}}, \qquad (2.217)$$

where

$Ieg_{(D.jaun)i}$ – share of investment in new (<5 years) vehicles by type of fuel.

$$Ieg_{(D.liet)i} = \frac{EXP\ LTr_{(D)i}}{I_{DS}}, \qquad (2.218)$$

where

$Ieg_{(D.liet)i}$ – share of investments in used (>5 years) vehicles by type of fuel.

Calculation of vehicle costs (by fuel type)

An example is given for the calculation of the costs of used vehicles (age > 5 years), while an analogous approach is also used to calculate the cost of new (age < 5 years) vehicles.

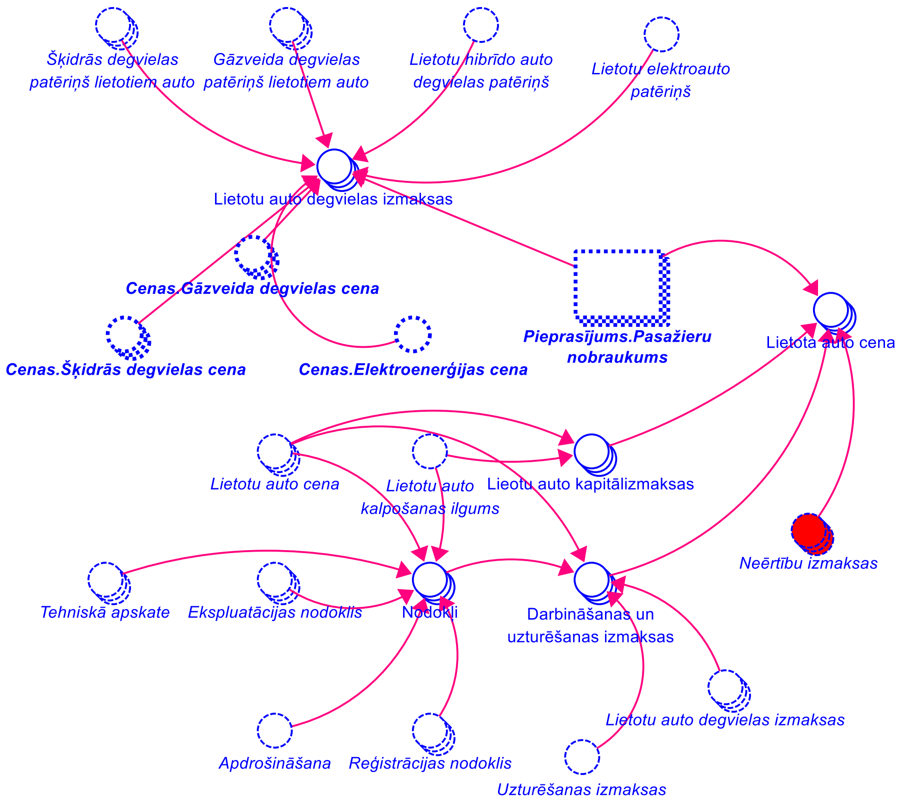


Fig. 2.4.28. Structure of second-hand vehicle costs

The taxes for a used vehicle:

$$No_l = TA + C_l * ApD + No_{eksp}\ \frac{Ma_{reģ}}{LTr_{DzI}}, \qquad (2.219)$$

where

No_l – The taxes for a used vehicle, EUR/year;

TA – technical inspection, EUR/year;

C_l – price of used vehicles, EUR/year;

ApD – insurance, 1/year;

No_{eksp} – operating tax, EUR/year;

$Ma_{reģ}$ – registration fee, EUR.

Operating and maintenance costs for second-hand vehicles:

$$C^l_{O\&M} = No_l + C_l * I_{uzt} + I_{Dl}, \quad (2.220)$$

where

$C^l_{O\&M}$ – Operating and maintenance costs for second-hand vehicles, EUR/year;
I_{uzt} – maintenance costs, 1/year;
I_{Dl} – fuel costs for the second-hand vehicles, EUR/year.

Capital costs for second-hand vehicles:

$$KI_l = \frac{C_l}{LTr_{DzI}}, \quad (2.221)$$

where

KI_l – capital costs for second-hand vehicles, EUR/year.

$$I_{lTr} = \frac{KI_l + C^l_{O\&M}}{PN\bar{A}} + I_N, \quad (2.222)$$

where

I_N – inconvenience costs, EUR/km.

Vehicle price sub-model

This sub-model is used to model the prices of vehicles of all fuel types.

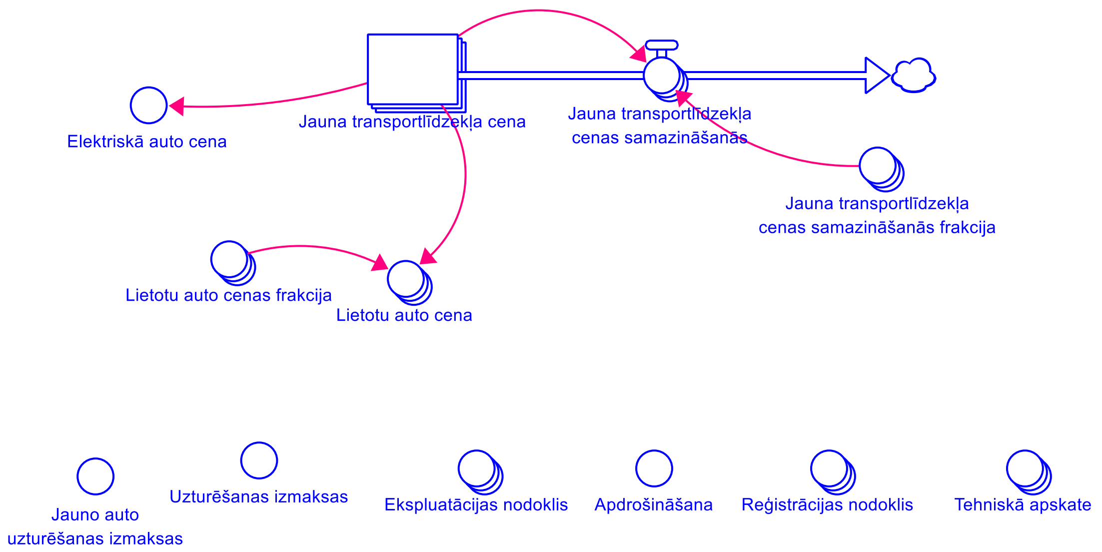


Fig. 2.4.29.. Structure of the vehicle pricing sub-model

Price of a new vehicle:

$$C_{jTr} = -\int_{t_0}^{t} CPL_{jTr}(t)dt + C_{jTr}(t_0), \quad (2.223)$$

where

C_{jTr} price of a new vehicle, EUR;
CPL_{jTr} – the rate of decline in the price of new vehicles, EUR/year.

The rate of decline in the price of new vehicles, EUR/year.:

$$CPL_{jTr} = C_{jTr} * Csd_{jTr}, \quad (2.224)$$

where

Csd_{jTr} – fraction of the reduction in the price of a new vehicle.

Price of the second-hand vehicles:

$$C_l = C_{jTr} * CPL_{lTr}, \quad (2.225)$$

where

CPL_{lTr} – price fraction of second-hand vehicles, EUR/year.

Inconvenience cost calculation sub-model

This sub-model takes into account all inconveniences arising from lack of infrastructure, vehicle prices, lack of information. There are elements embedded in the model to analyse the impact of different policies on inconvenience costs.

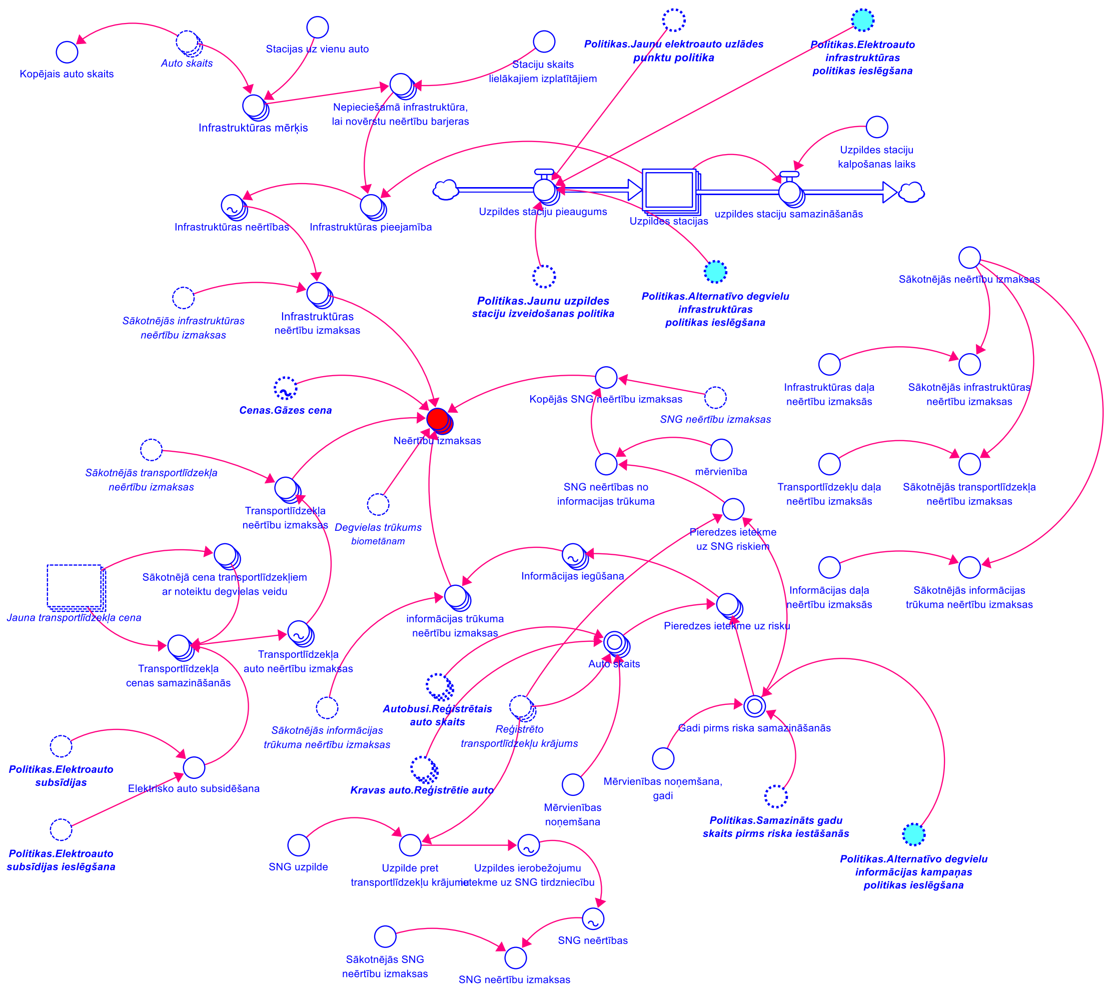


Fig. 2.4.30.. The structure of calculating inconveniences

Saturation target of refuelling infrastructure for a specific type of fuel:

$$InM_i = RD_{(tip)i} * Sta_{(kr)i}, \quad (2.226)$$

where

InM_i – saturation target of refuelling infrastructure for a specific type of fuel, stations;

$Sta_{(kr)i}$ – number of filling stations per car for a given type of fuel, station/vehicle.

Infrastructure needed to overcome inconveniences caused by the lack of refuelling infrastructure:

$$NIn_N = IF\ (InM > SSsk_{LI} * 0.3, InM, SSsk_{LI} * 0.3), \quad (2.227)$$

where

NIn_N – Infrastructure needed to overcome inconveniences caused by the lack of refuelling infrastructure, station;
$SSsk_{LI}$ – number of filling stations for the major fuel distributors, station.

Availability of refuelling infrastructure:

$$In_{(pie)i} = IF\left(((UzS_i = UzS_{dTr})\ OR\ (UzS_i = UzS_{gTr})\ OR\ (UzS_i = UzS_{LPGTr})\ OR\ (UzS_i = UzS_{hiTr})), 1, (\ IF\left(\frac{UzS_i}{NIn_N}\right) < 1, \left(\frac{UzS_i}{NIn_N}\right), 1)\right), \quad (2.228)$$

where
$In_{(pie)i}$ – availability of refuelling infrastructure for a specific type of fuel;
UzS_i – number of filling stations for a particular type of fuel, stations;
UzS_{dTr} – filling stations for diesel vehicles, stations;
UzS_{gTr} – filling stations for petrol vehicles, stations;
UzS_{LPGTr} – filling stations for LPG vehicles, stations;
UzS_{hiTr} – filling stations for hybrid vehicles, stations.

Numbers of filling stations for a certain type of fuel:

$$UzS_i = \int_{t_0}^{t}[UzS_{P\bar{A}} - UzS_{N\bar{A}}]\,(t)dt + UzS_i\,(t_0), \quad (2.229)$$

where
$UzS_{P\bar{A}}$ – the rate of emergence of new filling stations, stations/year;
$UzS_{N\bar{A}}$ – the pace of disposal of old filling stations, stations/year.

The pace of disposal of old filling stations:

$$UzS_{N\bar{A}} = IF\left((UzS_i = UzS_{dTr})\ OR\ (UzS_i = UzS_{gTr})\ OR\ (UzS_i = UzS_{LPGTr})\ OR\ (\ UzS_i = UzS_{hiTr}), 0, \frac{UzS_i}{UzS_{DL}}\right), \quad (2.230)$$

where
UzS_{DL} – duration of operation of the filling stations, years.

Impact of lack of infrastructure on inconvenience costs:

$$InA_i = GRAPH\left(In_{(pie)i}\right), \quad (2.231)$$

where
InA_i – Impact of lack of infrastructure on inconvenience costs, EUR/km.

Costs of infrastructure shortage inconvenience:

$$I_{(InA)i} = InA_i * INIT\left(I_{(InA)i}\right), \quad (2.232)$$

where
$I_{(InA)i}$ – infrastructure shortage inconveniences for a particular type of fuel, EUR/km.

Vehicle price reduction fraction for a given type of fuel:

$$CSa_{(Tr)i} = IF\left(\frac{SC_{(Tr)i} - C_{(jTr)i}}{SC_{(Tr)i}} > 0, \frac{SC_{(Tr)i} - C_{(jTr)i}}{SC_{(Tr)i}}, 0\right), \quad (2.233)$$

where
$CSa_{(Tr)i}$ – vehicle price reduction fraction for a given type of fuel;
$SC_{(Tr)i}$ – initial price for vehicles with a certain type of fuel, EUR;
C_{jTr} – price of a new vehicle for a given fuel type, EUR.

Initial price for vehicles with a certain type of fuel:

$$SC_{(Tr)i} = INIT\left(C_{(jTr)i}\right). \quad (2.234)$$

Impact of vehicle price on inconvenience costs:

$$CA_{(Tr)i} = GRAPH\left(CSa_{(Tr)i}\right), \quad (2.235)$$

where

$CA_{(Tr)i}$ – Impact of vehicle price on inconvenience costs.

Inconvenience costs due to vehicle price:

$$CAIz_{(Tr)i} = CA_{(Tr)i} * INIT\left(CAIz_{(Tr)i}\right), \quad (2.236)$$

where

$CAIz_{(Tr)i}$ – inconvenience costs caused by vehicle price, EUR/km.

Total stock of vehicles by fuel type:

$$Tr_{(kr)i} = \left(RK^{AP}_{(Tr)i} + RK^{SMP}_{(Tr)i} + RD_{(tip)i}\right), \quad (2.237)$$

where

$Tr_{(kr)i}$ – Total stock of vehicles by fuel type, vehicles;

$RK^{AP}_{(Tr)i}$ – registered size of bus parks, vehicles;

$RK^{SMP}_{(Tr)i}$ – registered size of the lorry fleet, vehicles;

Impact of experience on reducing the risk of vehicle use for a particular fuel type:

$$PI_{(R)i} = IF((Tr_{(kr)i} = Tr_{krD})\ OR\ (Tr_{(kr)i} = Tr_{krG}), 0, e^{\left(\frac{-Tr_{(kr)i}}{INIT\left(Tr_{(kr)i}\right)*IS_{GP}}\right)}), \quad (2.238)$$

where

$PI_{(R)i}$ – impact of experience on reducing the risk of vehicle use for a particular fuel type:;

DTr_{kr} – stocks of diesel vehicles, vehicles;

GTr_{kr} – stocks of gas vehicles, vehicles;

IS_{GP} – time needed to reduce the risk, years.

Impact of the information and experience on the cost of inconvenience for a particular type of fuel:

$$\mathrm{IPAi} = GRAPH\left(PI_{(R)i}\right), \quad (2.239)$$

where

IPA_i – impact of the information and experience on the cost of inconvenience for a particular type of fuel.

Inconvenience costs of the lack of information and experience by certain fuel type:

$$I_{(IPA)i} = IPA_i * INIT\left(I_{(IPA)i}\right), \quad (2.240)$$

where

$I_{(IPA)i}$ – Inconvenience costs of the lack of information and experience by certain fuel type, EUR/km.

Total inconvenience costs for a particular type of fuel:

$$I_{(N)i} = I_{(IPA)i} + CAIz_{(Tr)i} + I_{(InA)i}, \quad (2.241)$$

where

$I_{(N)i}$ – total inconvenience costs for a particular type of fuel, EUR/km.

Consumption of transport fuels

The total transport consumption is determined by summing up the consumption of railway, bus and passenger vehicles.

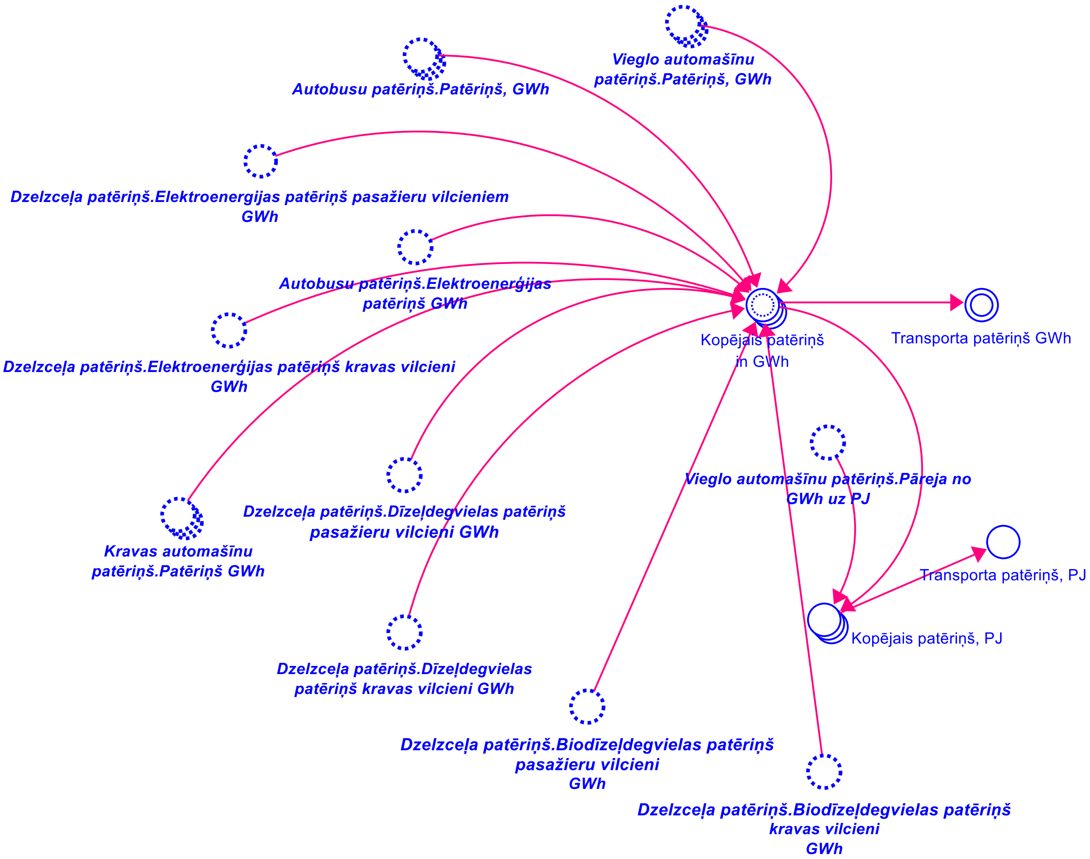


Fig. 2.4.31. Structure for determining total transport consumption

In the model, the consumption of private transport is determined as the sum of the consumption of different vehicles, taking into account their age structure and the types of fuel consumed. Fuel consumption is converted into unified units, taking into account the density and conversion factors of each fuel type.

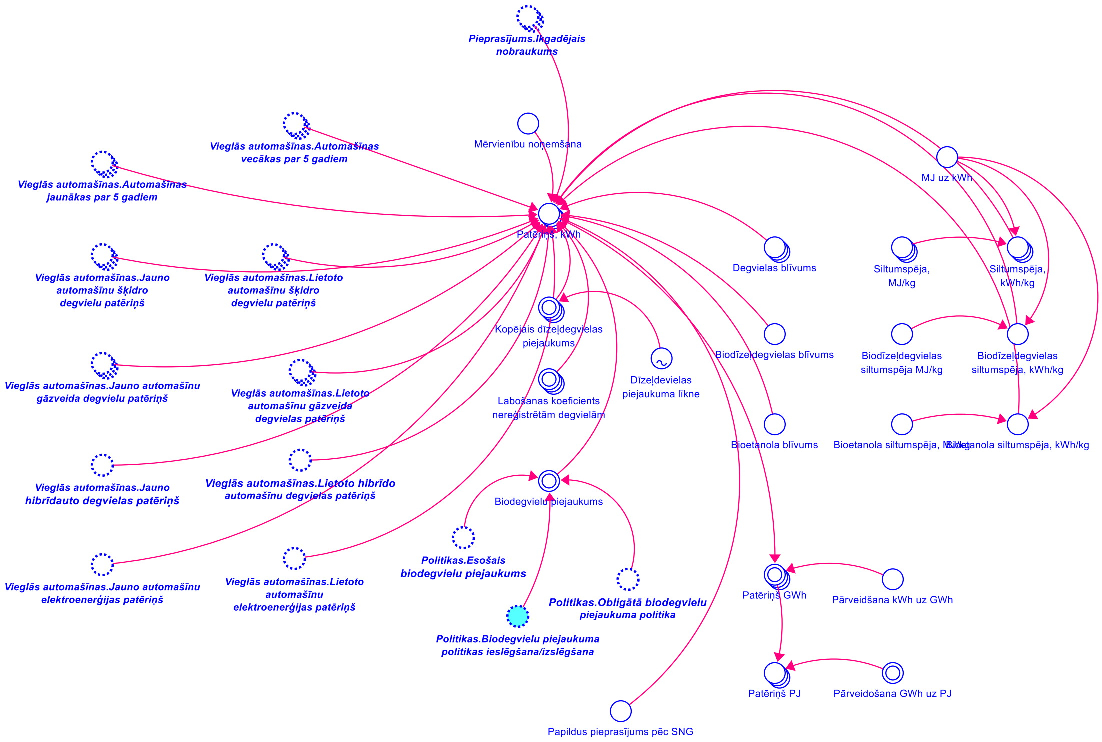


Fig. 2.4.32. Structure for determining the total fuel consumption of car transport

The model sums the liquid fuel, gaseous fuel and electricity consumption of new and used vehicles. In addition, the consumption of biofuels under specific biofuel blending policies is taken into account.

$$BIOd_{jaukt} = IF\left(BIOd_{jaukt(P)} = 0, INIT\ BIOd_{jaukt}, IF\left(TIME2021, INIT\ BIOd_{jaukt}, BIOd_{OPP}\right)\right), \quad (2.242)$$

where

$BIOd_{jaukt}$ - blended biofuel;

$BIOd_{jaukt(P)}$ - biofuel blending policy;

$INIT\ BIOd_{jaukt}$ – initial biofuel admixes;

$BIOd_{OPP}$ – policy of the mandatory blending of biofuels.

In the SD model, the energy consumption of the railway is determined by taking into account the proportion of electric and diesel trains for the carriage of passengers and cargo. Sub-model incorporates elements for policy scenarios to promote rail electrification.

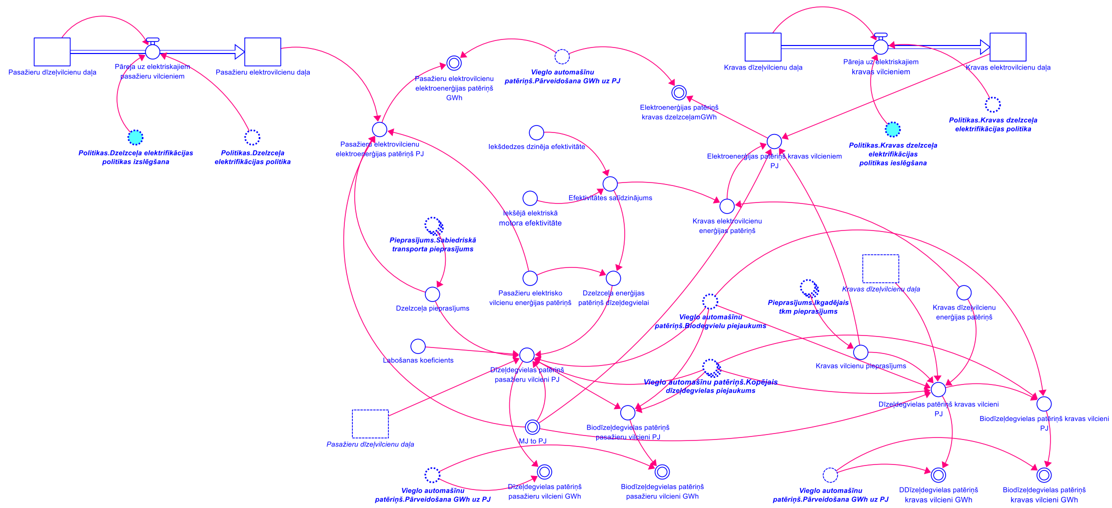


Fig. 2.4.33. Structure for determining the railway energy consumption

The energy consumption of passenger trains is calculated as the sum of the energy consumption of electric and diesel trains:

$$ElP_{PJ}^{V} = \frac{EP_{E}^{PV} * PP_{Dz} * ElP_{D}}{1000000}, \quad (2.243)$$

where

ElP_{PJ}^{V} – electricity consumption for a passenger train, PJ/year;

EP_{E}^{PV} – specific electricity consumption of passenger trains, MJ/pkm;

PP_{Dz} – demand for passenger trains, pkm/year.

The model includes a shift from diesel to electric trains for freight and passenger transport, taking into account the electrification policy. Below is an example of the transition from passenger diesel trains to electric trains, which is also modelled in the same way for freight trains.

$$DiP_{D} = -\int_{t_0}^{t} Pār_{ele}(t)dt + DiP_{D}(t_0), \quad (2.244)$$

where

DiP_{D} – share of passenger diesel trains;

$Pār_{ele}$ – switch to electric train use, 1/year.

$$Pār_{ele} = IF\ (DzEl_{P} = 0, 0, DiP_{D} * DzEl_{PLP}), \quad (2.245)$$

where

$DzEl_{P}$ – rail electrification policy;

$DzEl_{PLP}$ – rate of increase of railway electrification policy, 1/year.

$$ElP_{D} = \int_{t_0}^{t} Pār_{ele}(t)dt + ElP_{D}(t_0), \quad (2.246)$$

where

ElP_{D} – share of electric passenger trains.

The total energy consumption of diesel trains takes into account the blending of biodiesel.

$$DiP_{PJ}^{V} = \left(\frac{EP_{Di}^{PV} * PP_{Dz} * DiP_{D}}{1000000}\right) * \left(1 - BIOd_{jaukt}\right) * SV_{DīT}, \quad (2.247)$$

where

DiP_{PJ}^{V} – diesel consumption for a passenger train, PJ/year;

EP_{Di}^{PV} – specific diesel consumption of passenger trains, MJ/pkm;

$SV_{DīT}$ – biodiesel admixes.

When determining the total fuel consumption of passenger and freight diesel trains, the blending of biofuels is also taken into account

$$BIOdiP_{PJ}^{V} = DiP_{PJ}^{V} * \left(\frac{BIOd_{jaukt} * SV_{DīT}}{(1 - BIOd_{jaukt}) * SV_{DīT}}\right), \tag{2.248}$$

The total diesel consumption of passenger trains is determined taking into account the efficiency of internal combustion engines and electric motors to take into account fuel consumption on electric trains.

$$EP_{Di}^{PV} = EP_{E}^{PV} * \frac{IEM_{\eta}}{IDz_{\eta}}, \tag{2.249}$$

where

IEM_{η} – efficiency of an internal combustion electric engine;

IDz_{η} – efficiency of an internal combustion engine.

The electricity consumption of freight trains is determined by taking into account freight demand, consumption of electric train parts and electric trains.

$$ElP_{PJ}^{KV} = \frac{DzEP_{KE} * PP_{KV} * ElVK_{D}}{1000000}, \tag{2.250}$$

where

ElP_{PJ}^{KV} – electricity consumption of freight trains, PJ/year;

PP_{KV} – the demand for freight trains, tkm/year;

$ElVK_{D}$ – share of electric freight trains.

Vehicle fuel consumption sub-model

The fuel consumption structure shown in this sub-model is used to model the fuel consumption of all types of fuel. The only difference is in the use of units of measurement – liters are used for liquid fuels, kilograms of gaseous fuels are used, and kilowatt hours are used for electricity.

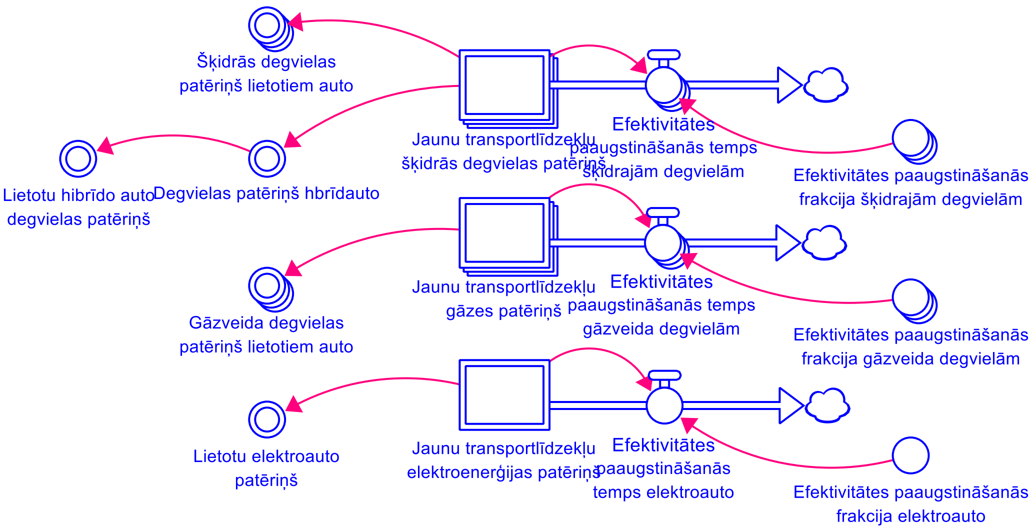


Fig. 2.4.34. Vehicle fuel consumption sub-model

Fuel consumption of the new vehicles:

$$DP_{jTr} = -\int_{t_0}^{t} Ef_{PĀ}(t)dt + DP_{jTr}(t_0), \tag{2.251}$$

where

DP_{jTr} – fuel consumption of the new vehicles, l/km;
$Ef_{P\bar{A}}$ – rate of increase in fuel efficiency, l/km/years.

Rate of increase in fuel efficiency, l/km/years:

$$Ef_{P\bar{A}} = DP_{jTr} * Ef_{UZ}, \quad (2.252)$$

where
Ef_{UZ} – efficiency improvement fraction, 1/year.

Fuel consumption of the second-hand vehicles:

$$DP_{lTr} = DP_{jTr} * Coef_l, \quad (2.253)$$

where
DP_{lTr} – fuel consumption of the second-hand vehicles, l/km;
$Coef_l$ – second-hand car fuel consumption ratio.

Fuel prices

Fuel prices in the model are determined separately for each type of fuel, determining the potential rate of price increase under various factors.

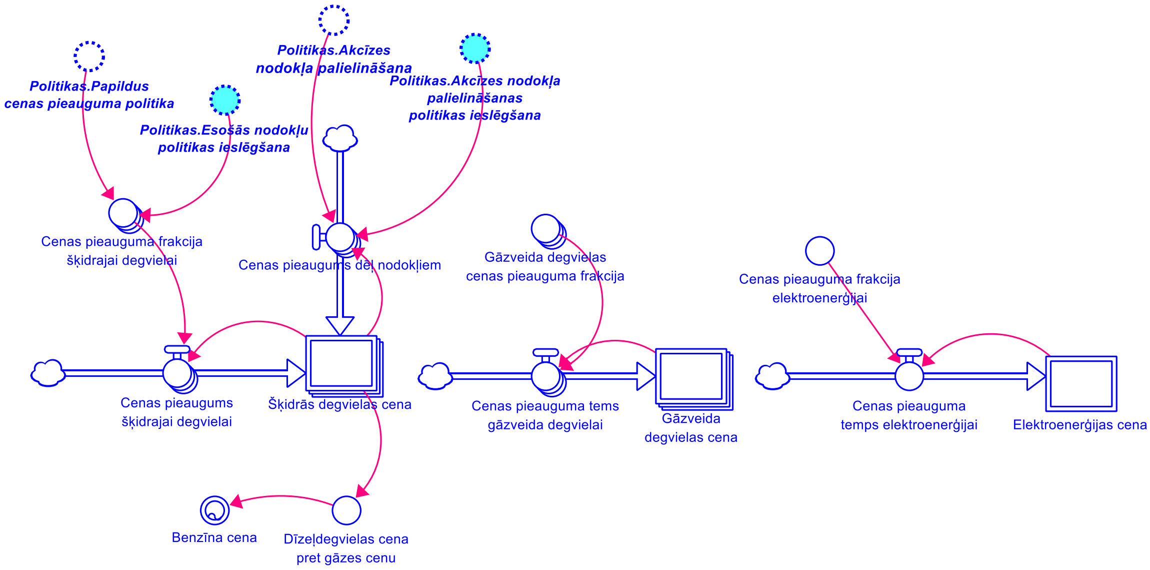


Fig. 2.4.35. Structure of the fuel pricing sub-model

A potential price increase is determined for each of the fuels. Below is an example of diesel fuel. Diesel price:

$$FuelC_{Diesel} = \int_{t_0}^{t} [CPT_{Diesel} + CPT_{AN}]dt + FuelC_{Diesel}\,(t_0), \quad (2.254)$$

where
$FuelC_{Diesel}$ – diesel price, EUR/l;
CPT_{Diesel} – rate of change in diesel price (fuel share), (EUR/l)/year;
CPT_{AN} – rate of change in diesel price (excise tax share), (EUR/l)/year

Rate of change in diesel price (fuel share):

$$CPT_{Diesel} = FuelC_{Diesel} * FrP_{Diesel}, \quad (2.255)$$

where
FrP_{Diesel} – diesel price change rate fraction, 1/year.

Rate of change in the price of diesel fuel (part of excise duty):

$$CPT_{AN} = FuelC_{Diesel} * FrP_{AN}, \quad (2.256)$$

where

FrP_{AN} – rate fraction of the rate of change in excise duty, 1/year.

Calculation of the RES share in the transport sector

The share of RES in the transport sector is determined taking into account the consumption of electricity and biofuels in each of the sub-sectors.

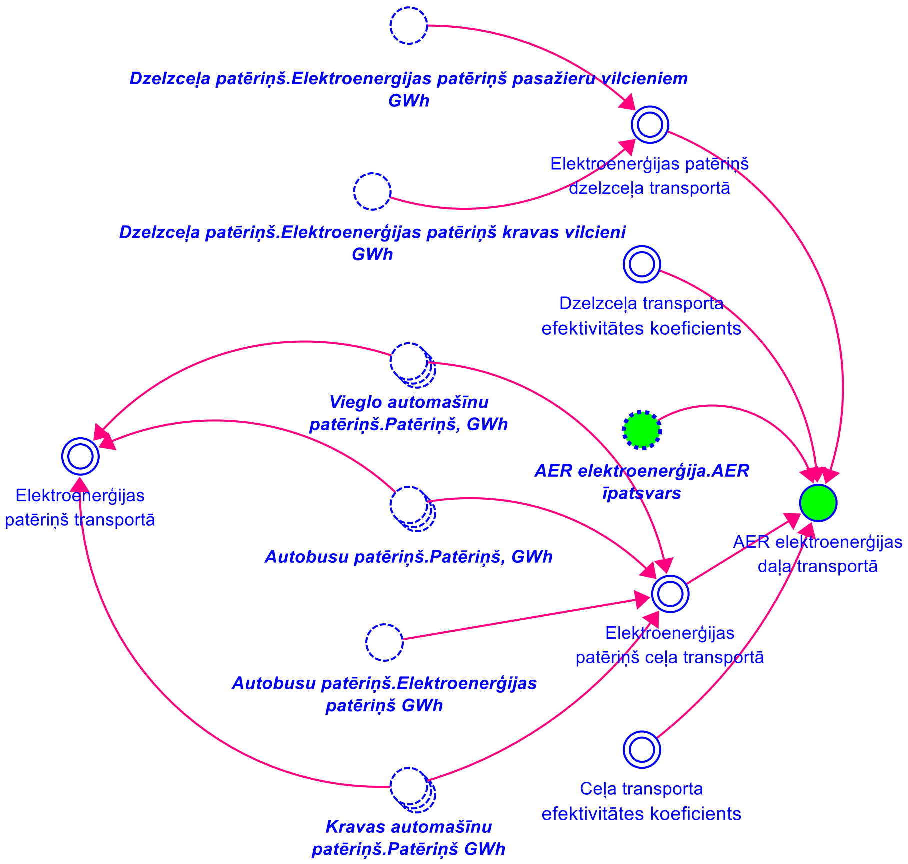


Fig. 2.4.36. Structure for determining the share of RES electricity

Electricity consumption for road transport:

$$ElP_{Tr} = P^{ElM}_{GWh} + P^{ElA}_{GWh} + P^{ElSM}_{GWh} + ElP^{P}_{GWh}, \quad (2.257)$$

where

ElP_{Tr} – electricity consumption for road transport, GWh/year;

P^{ElM}_{GWh} – consumption of the private electric transport, GWh/year;

P^{ElA}_{GWh} – consumption of electric buses, GWh/year;

P^{ElSM}_{GWh} - electric freight transport consumption, GWh/year;

ElP^{P}_{GWh} – electricity consumption for urban public transport, GWh/year.

Electricity consumption for rail transport:

$$ElP_{DzTr} = ElP^{PV}_{GWh} + ElP^{KV}_{GWh}, \quad (2.258)$$

where

ElP_{DzTr} – electricity consumption for rail transport, GWh/year;

ElP^{KV}_{GWh} – electricity consumption for freight trains, GWh/year;

ElP^{PV}_{GWh} – electricity consumption for passenger trains, GWh/year.

Coefficient to be used for the calculation of RES for electricity in road transport:

$$kEl_{CTr} = IF\ (TIME < 2021, 5, 4), \tag{2.259}$$

where

kEl_{CTr} – coefficient to be used for the calculation of RES for electricity in road transport.

Coefficient to be used for the calculation of RES for electricity in rail transport:

$$kEl_{DzTr} = IF\ (TIME < 2021, 2.5, 1.5), \tag{2.260}$$

where

kEl_{DzTr} – coefficient to be used for the calculation of RES for electricity in rail transport.

Total RES electricity consumption in transport:

$$ElP_{Tr}^{AER} = RES_{pwr} * (ElP_{Tr} * kEl_{CTr} + ElP_{DzTr} * kEl_{DzTr}), \tag{2.261}$$

where

ElP_{Tr}^{AER} – total RES electricity consumption in transport, GWh/year;

RES_{pwr} – the share of RES in electricity production.

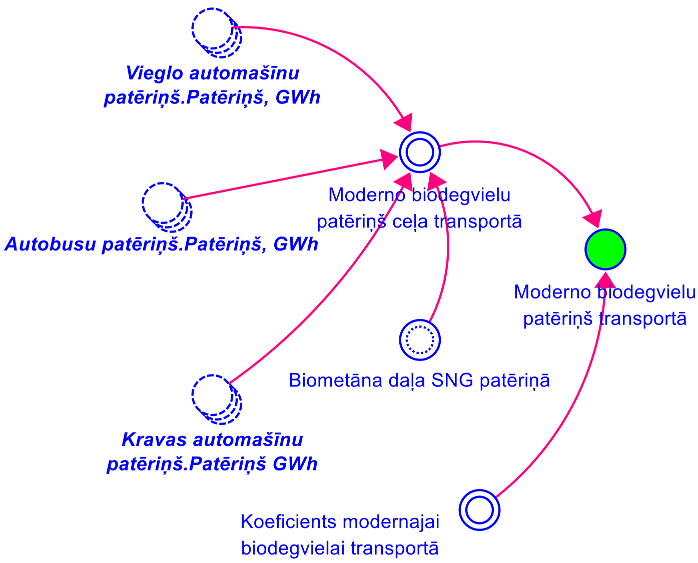


Fig. 2.4.37. Structure for the determination of the share of advanced biofuels

Consumption of advanced biofuels in road transport:

$$BIOdP_{CTr}^{uzl} = BIOdPM_{GWh}^{uzl} + BIOdPA_{GWh}^{uzl} + BIOdPSM_{GWh}^{uzl} + +(PM_{GWh}^{CNG} + PA_{GWh}^{CNG} + PSM_{GWh}^{CNG}) * BIOmet_{CNG}^{D}, \tag{2.262}$$

where

$BIOdP_{CTr}^{uzl}$ – consumption of advanced biofuels in road transport, GWh/year;

$BIOdPM_{GWh}^{uzl}$ - consumption for private transport (advanced biofuels), GWh/year;

$BIOdPA_{GWh}^{uzl}$ – consumption for buses (advanced biofuel), GWh/year;

$BIOdPSM_{GWh}^{uzl}$ - consumption for freight transport (advanced biofuels), GWh/year;

PM_{GWh}^{CNG} - consumption for private transport (CNG), GWh/year;

PA_{GWh}^{CNG} – consumption for buses (CNG), GWh/year;

PSM_{GWh}^{CNG} - consumption for freight transport (CNG), GWh/year;

$BIOmet_{CNG}^{D}$ – biomethane share in CNG fuel.

Coefficient to be used for the calculation of RES for advanced biofuels in transport:

$$kUBIOd_{Tr} = IF\ (TIME < 2021, 2, 2), \qquad (2.263)$$

where

$kUBIOd_{Tr}$ – coefficient to be used for the calculation of RES for advanced biofuels in transport.

Total consumption of RES in advanced biofuels in transport:

$$PUBIOd_{Tr}^{AER} = BIOdP_{CTr}^{uzl} * kUBIOd_{Tr}, \qquad (2.264)$$

where

$PUBIOd_{Tr}^{AER}$ – total consumption of RES in advanced biofuels in transport, GWh/year.

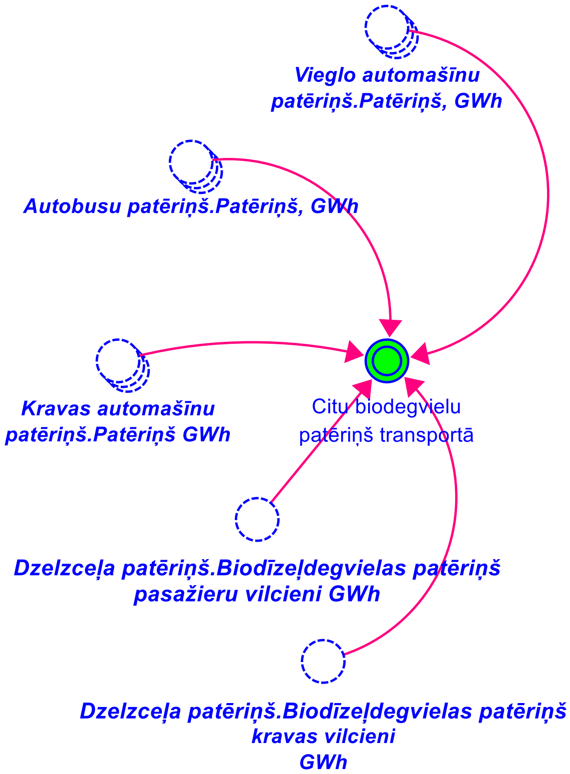


Fig. 2.4.38. Structure for determining the consumption of other biofuels

Total biofuel consumption in transport:

$$PcBIOd_{Tr}^{AER} = PM_{GWh}^{BIOd\bar{\imath}} + PM_{GWh}^{BIOet} + PA_{GWh}^{BIOd\bar{\imath}} + PA_{GWh}^{BIOet} + PSM_{GWh}^{BIOd\bar{\imath}} + PSM_{GWh}^{BIOet} + PV_{GWh}^{BIOd\bar{\imath}} + PV_{GWh}^{BIOet}, \qquad (2.265)$$

where

$PcBIOd_{Tr}^{AER}$ – total biofuel consumption in transport, GWh/year;

$PM_{GWh}^{BIOd\bar{\imath}}$ – consumption for private transport (biodiesel), GWh/year;

PM_{GWh}^{BIOet} – consumption for private transport (bioethanol), GWh/year;

$PA_{GWh}^{BIOd\bar{\imath}}$ – consumption for buses (biodiesel), GWh/year;

PA_{GWh}^{BIOet} – consumption for buses (bioethanol), GWh/year;

$PSM_{GWh}^{BIOd\bar{\imath}}$ – consumption for freight transport (biodiesel), GWh/year;

PSM_{GWh}^{BIOet} – consumption for freight transport (bioethanol), GWh/year;

$PVfr_{GWh}^{BIOd\bar{\imath}}$ – consumption for freight trains (biodiesel), GWh/year;

$PVpas_{GWh}^{BIOd\bar{\imath}}$ – consumption for passenger trains (biodiesel), GWh/year.

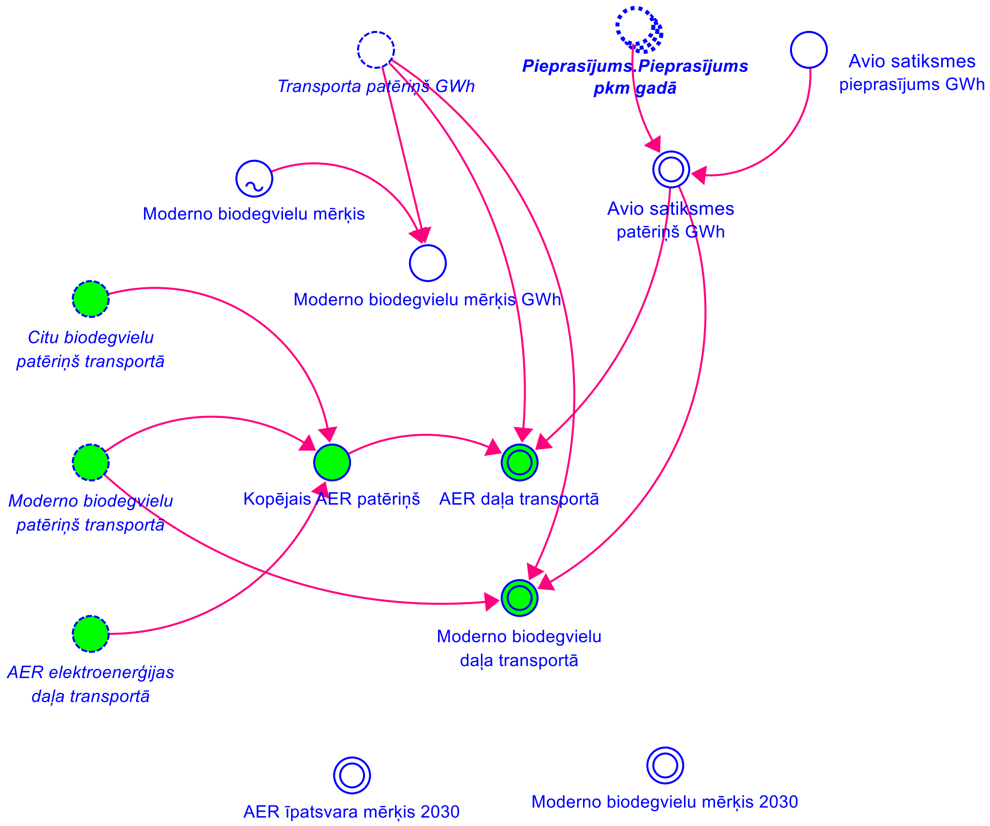


Fig. 2.4.39. Structure for determining the overall share of RES

Aviation fuel consumption GWh:

$$AvDP_{GWh} = GPP_{(p-km)av} * AvP_{\mathrm{GWh}}, \quad (2.266)$$

where
$AvDP_{GWh}$ - aviation fuel consumption, GWh/year;
$GPP_{(p-km)av}$ – annual pkm demand for aviation, pkm/year;
AvP_{GWh} – energy consumption per pkm (air), GWh/pkm.

Total RES consumption in transport:

$$KP_{Tr}^{AER} = PcBIOd_{Tr}^{AER} + PUBIOd_{Tr}^{AER} + ElP_{Tr}^{AER}, \quad (2.267)$$

where
KP_{Tr}^{AER}– total RES consumption in transport, GWh/year.

The share of RES in transport:

$$RES_{Tr} = \frac{KP_{Tr}^{AER}}{\sum TrP_{\mathrm{GWh}} + AvDP_{GWh}}, \quad (2.268)$$

where
RES_{Tr} – the share of RES in transport.

The share of advanced biofuels in transport:

$$RESbio_{Tr} = \frac{PUBIOd_{Tr}^{AER}}{\sum TrP_{\mathrm{GWh}} + AvDP_{GWh}}, \quad (2.269)$$

where
$RESbio_{Tr}$ – the share of advanced biofuels in transport.

3. SD MODEL INPUT DATA

This chapter summarises the main input parameters used for modelling the potential of RES in different sectors and planning regions according to the breakdown according to cabinet regulation No. 391 "Regulations regarding territories of planning regions" (Noteikumi Par Plānošanas Reģionu Teritorijām, 2009).

3.1. Centralised electricity production and transmission infrastructure

On electricity production, data in different planning regions were taken from the Ministry of Economics' (EM) reports on the amount of electricity purchased and the amounts paid out under the mandatory procurement.

3.1.1. Input data on electricity generation technologies and fuel consumption

Table 3.1.1. summarises information on the electricity production capacities installed in 2017 according to the fuel consumed. The table below contains information on CHP plants, wind plants and hydropower plants in different planning regions.

TABLE 3.1.1. INSTALLED ELECTRIC CAPACITY BY TYPE of energy resources used in 2017 (Ekonomikas ministrija, 2020)

	Installed capacity, MW				
	Kurzeme	Vidzeme	Latgale	Zemgale	Rīga
Natural gas	8.16	5.97	33.64	37.11	1080.13
Biomass	10.52	19.43	6.65	12.62	21.14
Biogas	10.43	10.35	7.16	15.44	18.14
Wind	63.72	0.00	0.00	0.50	0.00
Hydro	4.16	9.47	5.80	914.28	644.49

Information on the amount of electricity produced in the largest cogeneration plants with a capacity exceeding 20MW, which receive the payment of the installed capacity of the OIK, is compiled from the publicly available annual reports (Latvenergo, 2020), emission and fuel consumption reports. It can be seen that the amount of electricity produced in the largest stations has decreased significantly in 2017 and has increased in 2018.

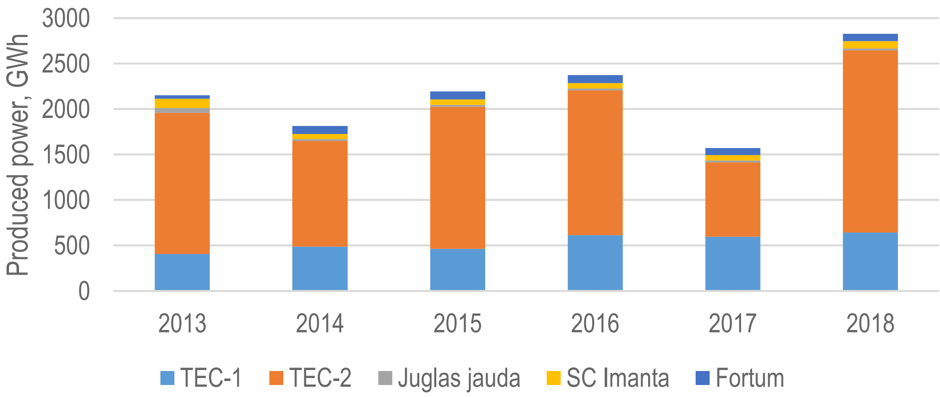


Fig. 3.1.1. Electricity produced in high capacity plants (>20 MW).

The amount of electricity produced in the remaining plants is compiled from the OIK reports. Information on the amount of electricity produced by the largest hydropower stations is compiled from the publicly available annual reports. The data obtained by region are summarised in Table 3.1.2.

TABLE 3.1.2. AMOUNT OF ELECTRICITY PURCHASED WITHIN THE FRAMEWORK OF MANDATORY PROCUREMENT IN 2017 (EKONOMIKAS MINISTRIJA, 2020)

	Purchased amount, GWh/year				
	Kurzeme	**Vidzeme**	**Latgale**	**Zemgale**	**Rīga**
Natural gas	50.83	20.51	208.14	69.26	2511.77
Biomass	65.93	118.76	31.90	71.09	108.95
Biogas	54.90	54.13	37.47	115.26	103.08
Wind	134.87	0.00	0.00	0.33	0.00
Hydro	9.44	34.32	21.54	2451.35	1849.42

Separately, data on installed solar power plants obtained from solar panel installation permits issued by the EM in the period from 2014 to 2018 have been compiled (Regulations On Permits for Increasing Electricity Production Capacities Or For The Introduction of New Production Equipment, 2020). It is assumed that all installed stations for which permits have been issued are installed in the year following receipt of the permit. The table shows that the highest installed solar panel capacity is in Riga region. More solar panels have been installed in the services sector.

TABLE 3.1.3. SOLAR PANEL INSTALLATION PERMITS (MW) FOR THE PERIOD FROM 2014 TO 2018

	Agricultural enterprises	Manufacturing companies	Services sector	Centralised energy sector	Households
Rīga	0.2	0.3	5.5	4.0	1.2
Kurzeme	0.4	0.0	0.5	0.0	0.5
Latgale	0.1	1.1	1.6	0.0	0.2
Vidzeme	0.0	0.2	0.0	0.0	0.2
Zemgale	0.0	0.0	0.0	0.0	0.2
In total	0.7	1.6	7.6	4.1	2.1

3.1.2.Electricity transmission infrastructure

From the information available to JSC Augstsprieguma tīkls (AST, 2020) on Latvian electricity transmission networks, which can be seen in Figure 3.1.2, the necessary information on the power supply capacity between regions of Latvia was read out. The power of electricity grids between Kurzeme, Zemgale, Riga, Vidzeme and Latgale regions was examined. The electricity grid connections were read as a section where the electricity grid crosses the border of other regions and marked as a link between two substations located in two different regions.

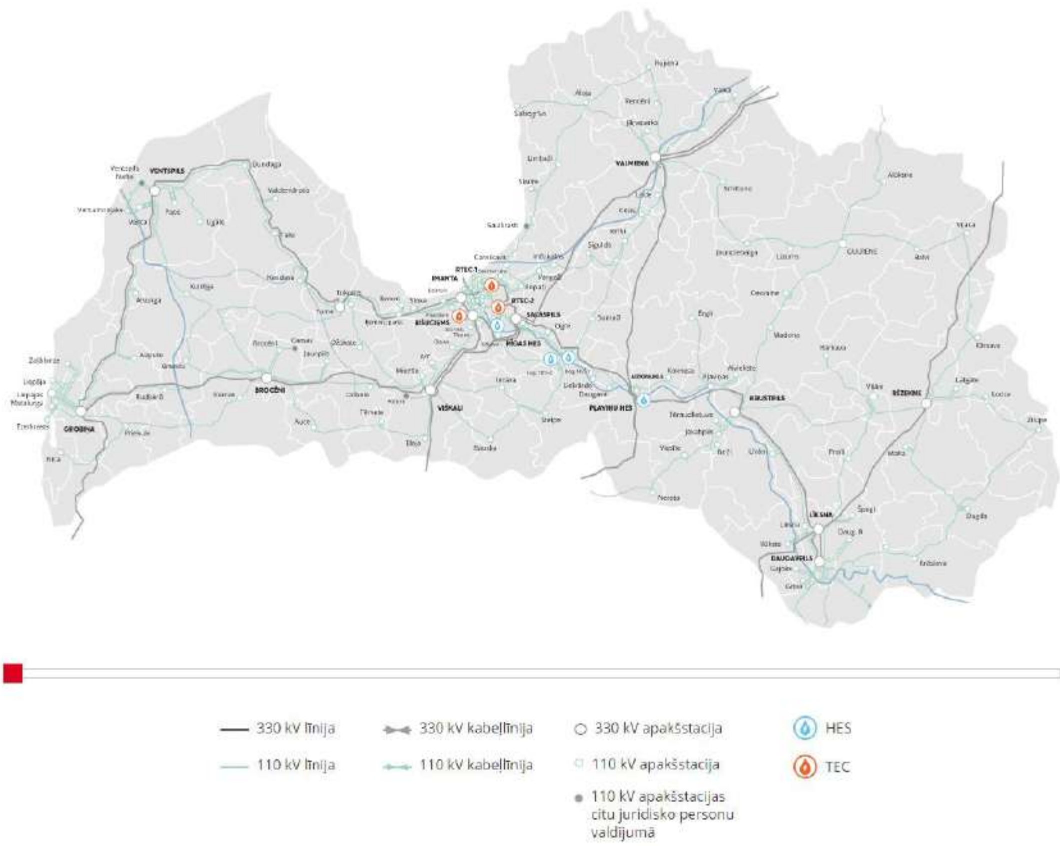


Fig. 3.1.2. Latvian electricity 330 kV and 110 kV electrical network scheme (AST, 2020).

The power supply capacity of 110 kV between regions of Latvia is summarised in Table 3.1.4. Network connection between Kurzeme and Zemgale region is formed from Brocēni-Auce electricity grid and Brocēni-Jaunpils electricity grid connection. Kurzeme region and Riga region are connected by the network Kandava-Tukums and Brocēni-Tukums. The largest number of 110 kV network connections are between Zemgale and Riga region and there are three connections – Viskaļi-Tukums, Viskaļi-Riga and Pļaviņas-Riga. Riga and Vidzeme regions are connected by the networks Riga-Rūjiena and Riga-Cesis. Vidzeme and Latgale regions are connected by Gulbene-Balvi and Barkava-Viļāni. The electricity grid connection is also formed between Latgale and Zemgale regions and these are the electricity grids of Daugavpils-Ilūkste and Viļāni-Krustpils. A total of 13 electricity grid connections with a capacity of 110 kV are formed between regions of Latvia.

TABLE 3.1.4.

110 KV ELECTRICAL NETWORK CONNECTIONS BETWEEN REGIONS OF LATVIA

Kurzeme region	2	Zemgale region
Kurzeme region	2	Riga region
Zemgale region	3	Riga region
Riga region	2	Vidzeme region
Vidzeme region	2	Latgale region
Latgale region	2	Zemgale region

The 330 kV electricity grid connections between regions are shown in Table 3.1.5 and form 6 connections between regions. Brocēni-Viskaļi forms the connection of electricity networks between Kurzeme and Zemgale region and Ventspils-Tukums forms a connection between

Kurzeme and Riga region. The largest number of electricity grid connections is formed between Zemgale and Riga region and they are two 330 kV network connections – Viskaļi-Riga and Krustpils-Riga. The connection between Riga and Vidzeme region was formed from the electricity grid Riga-Valmiera. Riga region and Latgale region are connected to the network Riga-Liksna.

TABLE 3.1.5.

330 KV ELECTRICAL NETWORK CONNECTIONS BETWEEN REGIONS OF LATVIA

Kurzeme region	1	Zemgale region
Kurzeme region	1	Riga region
Zemgale region	2	Riga region
Riga region	1	Vidzeme region
Riga region	1	Latgale region

Information on electricity grid connections will be taken into account as a limiting factor for the transmission of excess electricity between different regions.

3.2. Centralised thermal energy production

The amount of thermal energy produced in district heating and transferred to users in different regions, as well as the installed thermal energy capacities are taken from the central Statistical Bureau (CSP) database ENG160 (Centrālā Statistikas pārvalde, 2020d). Figure 3.2.1 shows changes in the amount of thermal energy produced over a 10-year period in different regions. In the model, introductory data on Riga and Pierīga (Riga suburbs) region are viewed together.

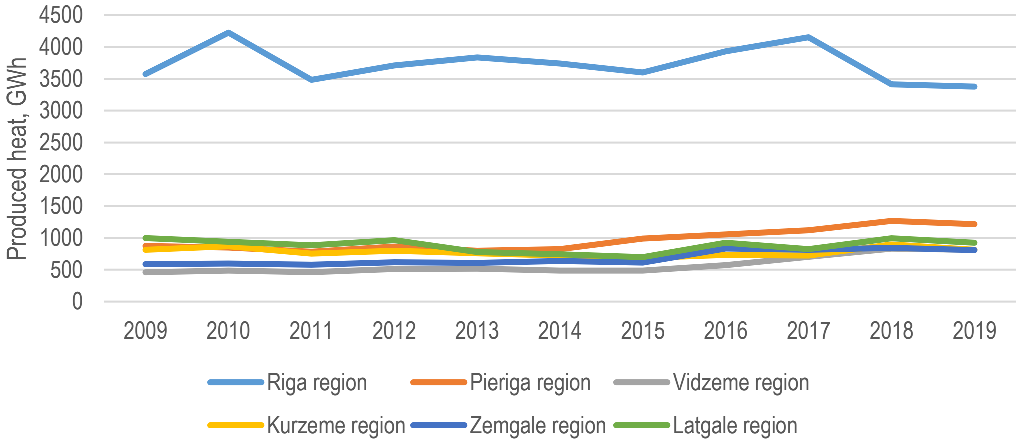


Fig. 3.2.1. Changes in heat produced in the statistical regions.

As can be seen in Figure 3.2.2, most or 50% of thermal energy is produced in Riga, but together with Pierīga region it accounts for 63% of all heat produced.

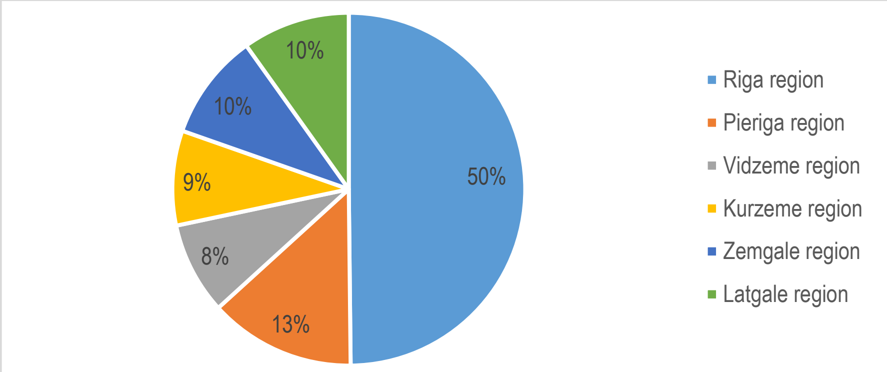


Fig. 3.2.2. Percentage breakdown of heat produced in 2017.

3.2.1. Input data on DH heat production technologies and fuel consumption

Figure 3.2.3 summarises changes in the installed capacity of boiler houses in the last 10 years (Central Statistical Bureau, 2020d). It can be seen that in all regions the installed capacity of boiler houses decreases, which is explained by the increase in the capacity of CHP plants.

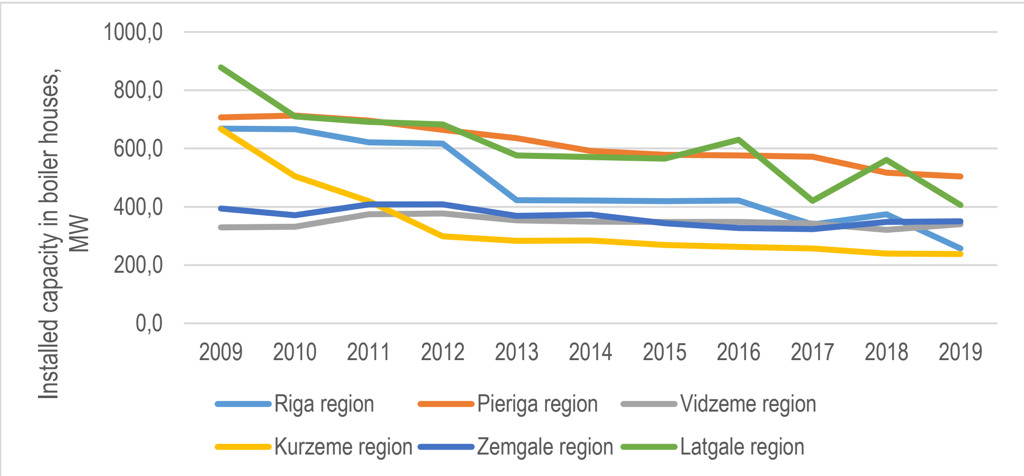


Fig. 3.2.3. Changes in the capacity installed in boiler houses.

The majority (82%) of the capacity of cogeneration plants is located in Riga. The distribution of other regions of Latvia according to the capacity of cogeneration plants is similar and varies from 3-5% of the total installed cogeneration capacity.

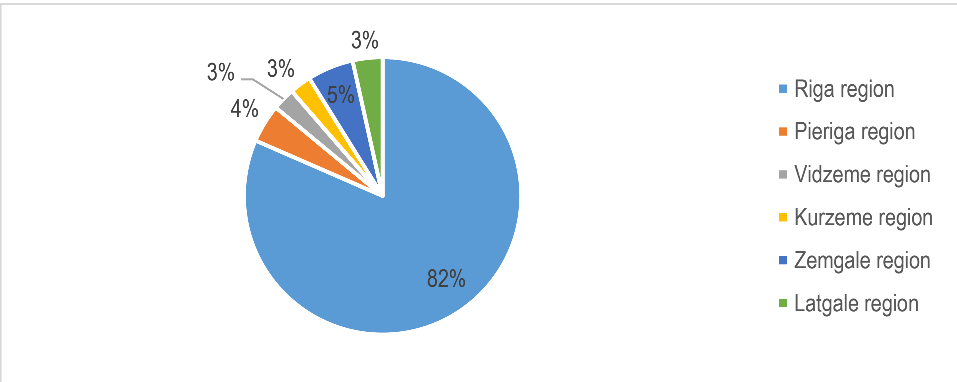


Fig. 3.2.4. Distribution of installed capacity of cogeneration plants in 2017.

The distribution of used resources for the production of heat by fuel type and technology is taken from the State Ltd "Latvian Environment, Geology and Meteorology Centre" 2-Air reporting database (LVĢMC, 2020b) and is recalculated to GWh using assumptions about the calorific values of different fuels and the average combustion efficiency of boiler equipment.

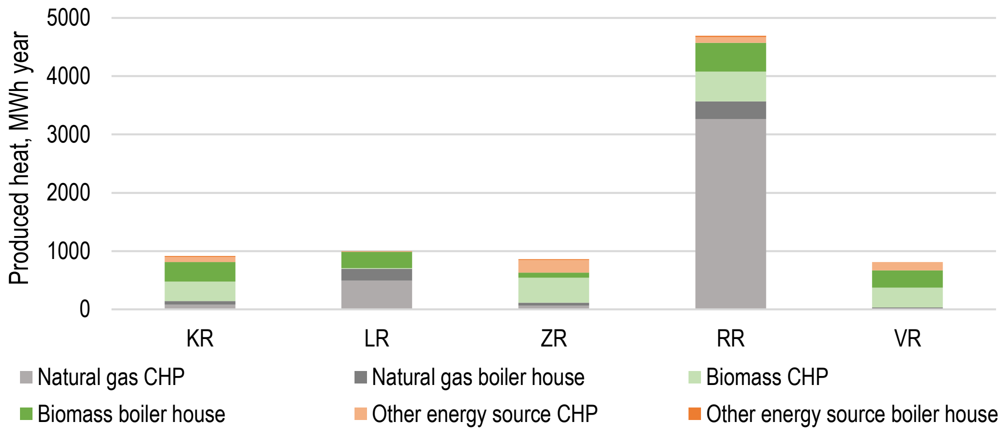


Fig. 3.2.5. Produced thermal energy by fuel types and technologies in 2017 in different planning regions.

Figure 3.2.5 summarises the amount of heat produced by fuel type and different technologies in different regions. It can be seen that the use of biomass dominates Kurzeme (KR), Zemgale (ZR) and Vidzeme (VR) region, but natural gas is mainly used in Riga (RR) and Latgale (LR) region. The use of other fuels (e.g. biogas) also accounts for a small part.

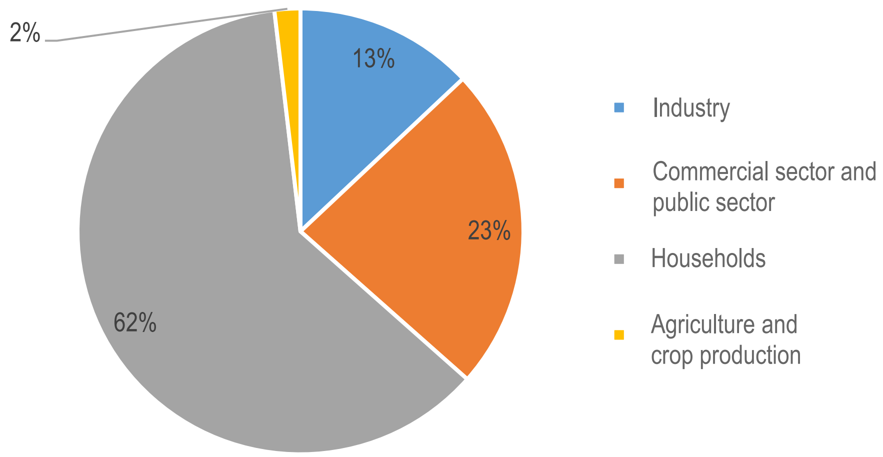


Fig. 3.2.6. Distribution of heat supplied by DH by sub-sector.

The distribution of final consumers of centralised thermal energy can be seen in Figure 3.2.6, which is in accordance with the Energy Balance of Latvia (Central Statistical Bureau, 2020c). The majority or 62% of thermal energy consumption is in households, but 23% in the commercial sector and public sector. Distribution of final consumption of district heat is assumed to be the same in all regions.

3.2.2. Input data for DH networks

In order to model the raw data of heating networks, a DH reference system has been established, using generic data from statistical databases, surveys and analysis of available literature, including previous DH studies covering total national heating. Taking into account the available information on heating supply networks in Latvia, three different models of transmission systems have been defined as the analysed system scale:

- Model 1 - large-scale system (more than 100 thousand inhabitants)
- Model 2 - medium-scale system (from 25 to 100 thousand inhabitants)
- Model 3 - small-scale system (less than 25 thousand inhabitants)

In order to determine the total length of heating networks, a regression analysis method was used, which analysed the correlation between the total population in specific cities and the length of heating networks (see Figure 3.2.7). Figure 3.2.7 of the regression analysis shows that the regression coefficient is high in both cases and the empirical equation obtained can be used to determine the length of the heating network using the number of inhabitants in a particular populated area. Using the available information on heat network lengths (Ekodoma, 2015) and results of regression models, the total length of heating networks in Riga has been determined – 756 km (Rīgas Siltums, 2018), in cities under state jurisdiction – 460 km, in other counties and municipality centres – 593 km.

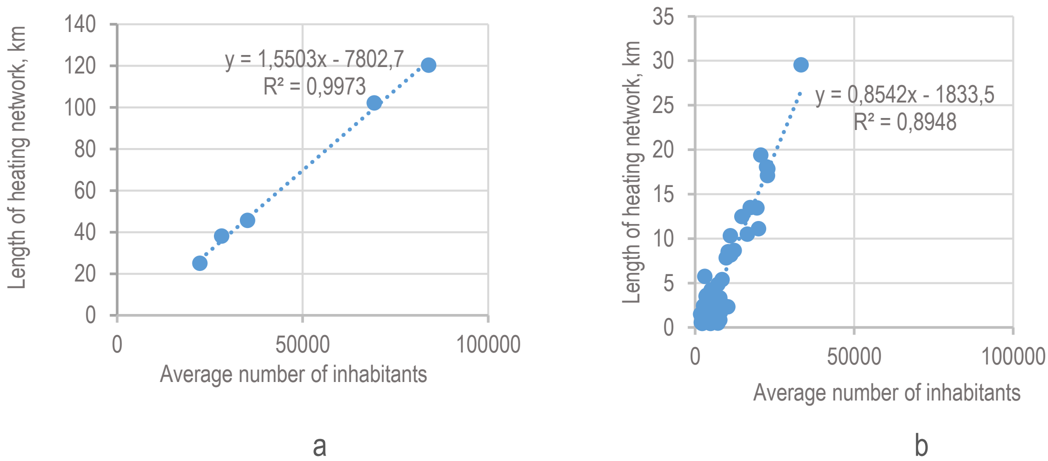


Fig. 3.2.7. Regression analysis models for determining the lengths of heating networks in cities under state jurisdiction (a) and other counties and their centres (b)(Rīgas Siltums, 2018).

Heat loss varies significantly depending on the diameter of the heat route deployed. For the creation of a reference system, the length distributions of heating networks by diameters for a specific region analysed are determined. Figure 3.2.8 shows the distribution of pipelines according to the diameters of the old and new heating mains of Riga. It can be seen that the internal diameter of most of the located heating networks is from 65 mm to 200 mm. The internal diameter of the main pipelines reaches up to 1200 mm.

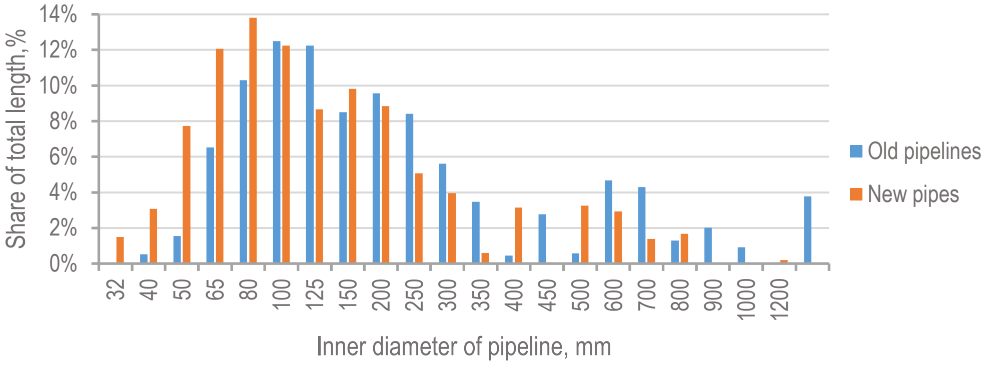
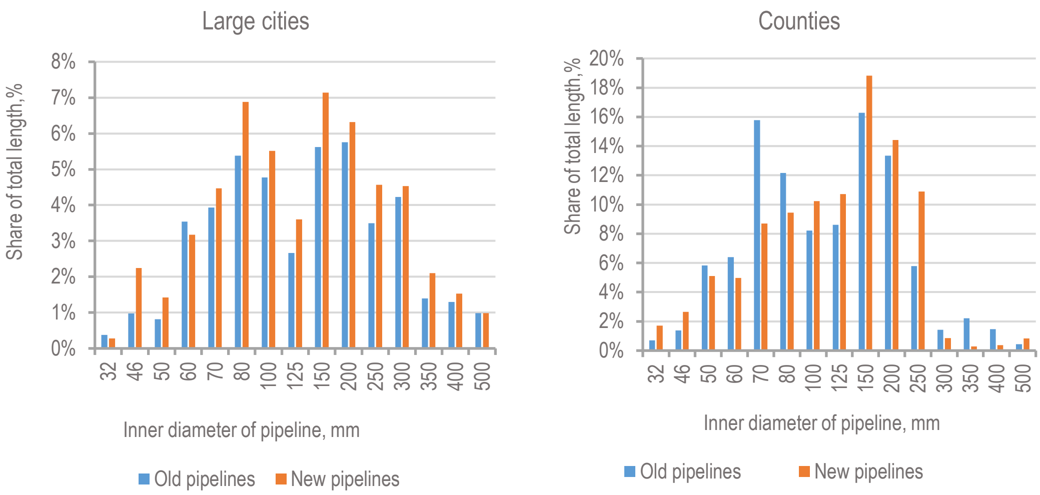


Fig. 3.2.8. Distribution of heating networks according to the diameters of the pipelines located for the new and old heating mains of Riga.

Figure 3.2.9 shows the distribution of pipelines by diameters in Daugavpils, Jurmala and Rezekne, as well as the average indicator in the municipality. The breakdown is determined according to the previous study of SIA "Ekodoma". It can be seen that the largest share in counties consists of pipelines with internal diameter 80 mm, but in cities under state jurisdiction - 110, 200 and 250 mm.



a b

Fig. 3.2.9. Distribution of total heating networks by diameters of the pipelines located. Model 2 in cities under state jurisdiction (a) and model 3 average in counties(b).

An important factor affecting heat transfer losses is the technical condition of the pipes of heating networks and the parameters of thermal insulation. These factors are different for new, industrially insulated pipelines and older heating lines. Therefore, the calculation of heat losses is carried out separately for old and new heating lines. Transmission loss models use both available information on the age of heat pipelines and assumptions about the distribution of old and new heat pipelines. It is assumed that in Model 2, 47% of the total heating network consists of old heating pipelines and 53% are new heating pipelines. In Model 3, outdated pipelines are 26% and 62% are new pipelines. Pipeline distribution is determined by previous survey of DH operators (Ekodoma, 2015).

The calculation of heat loss was carried out according to equation (3.1) (Ziemele et al., 2016), taking into account the available information on diameters, lengths and condition of heat pipes:

$$\sum q_{i,n} = \frac{(t_{sup}+t_{ret}-2t_{gr})}{R_{pipe\ i,n}+R_{insul\ i,n}+R_{shell\ i,n}+R_{ground\ i,n}+R_{inter\ i,n}} \quad (3.1.)$$

where
q - linear density of the pipeline i and tube n;
t_{sup}, t_{ret}- forward and return water temperature;
t_{gr}- average ground temperature;
R_{pipe},R_{insul},R_{shell},R_{ground},R_{inter}- linear resistance of internal pipes, insulation, housing, ground and pipes.

Linear resistance coefficients for different types of pipes are calculated according to the described methodology (Ziemele et al., 2016). Table 3.2.1 summarises the main calculation assumptions.

TABLE 3.2.1.

ASSUMPTIONS MADE FOR DETERMINATION OF LINEAR HEAT TRANSITION COEFFICIENT

Assumption	Value
Ground temperature	+8 ^{0}C
Thermal conduction coefficient of the pipe wall	50 W/(mK)
Heat conduction coefficient of the tube sheath	0.43 W/(mK)
Heat conduction coefficient for insulation of new heating mains	0.03 W/(m K)
Heat conduction coefficient for insulation of old heating mains	0.45 W/(m K)
Pipeline laying depth	1.5 m
Distance between pipes	0.15 m

The linear density of heat flow is determined at different forward and return temperatures depending on the outdoor air temperature. The total heat loss Q (Wh) is calculated with formula 3.2:

$$Q = q_L LT \quad (3.2.)$$

where
L – total length of heating mains, m;
T – number of heating hours, h.

In order to determine the total heat loss, the average heat carrier temperature regime of 95/75 (maximum forward temperature 95°C and return temperature 75 °C, adjusted to the actual outdoor temperature) is assumed in the calculations. The average number of hours at different outdoor air temperatures is used (LVĢMC, 2020a). In the calculations, it is assumed that thermal energy of Models 1 and 2 is used both for heating and heating hot water. Therefore, heat is supplied to consumers throughout the year (8760 hours). As Model 3 has fewer consumers, it is assumed that the DH provides heat mainly for space heating, so the operating period is shorter (approximately 8000 hours).

The input data values used in the SD model are summarised in Table 3.2.2.

TABLE 3.2.2. OVERVIEW OF INPUT VALUES FOR THE SD MODEL

Parameter	Riga	Cities under the state jurisdiction	Other cities and counties
Mains older than 2000			
Length, km	501,9	208,0	153,0
Average diameter of pipelines, mm	244	165	128
Linear thermal conductivity coefficient of pipelines, W/(mK)	0.82	1.36	1.23
Operating hours	8760	8760	7929
Heat loss, GWh/year	365	251	151
Mains younger than 2000			
Length, m	254,9	251,7	364,6
Average diameter of pipelines, mm	177	202	127
Linear thermal conductivity coefficient of pipelines, W/(mK)	0.32	0.34	0.27
Operating hours	8760	8760	7929
Heat loss, GWh/year	72	77	78
Total heat loss, GWh/year	437	328	229

As can be seen from Figure 3.2.10, where the simulated losses and real losses are compared, the real losses are of very similar values to the simulated losses.

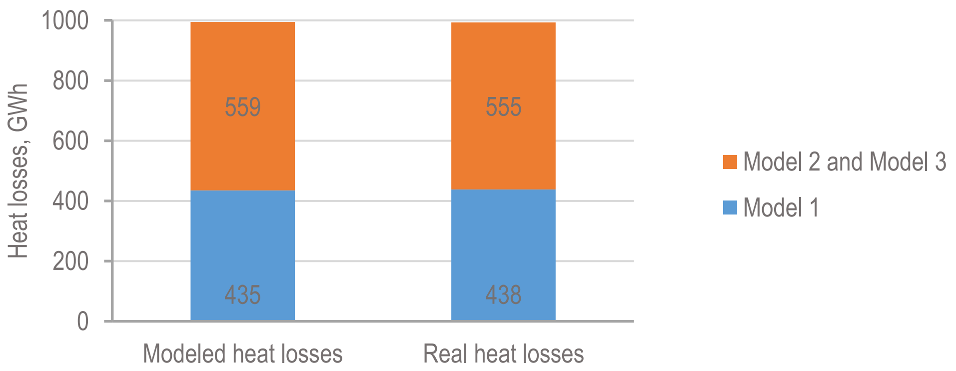


Fig. 3.2.10. Results of validation of the transmission loss model.

The total heat loss obtained from transmission loss models has been compared with the available data on thermal energy losses in 2017 (Ministry of Economics of the Republic of Latvia, 2013) (see Figure 3.2.10). Due to the lack of data, the results of Models 2 and 3 are not compared separately. The main assumptions about the linear heat transfer coefficient of the pipelines were adjusted to correspond to the actual situation. Therefore, the difference between calculated and actual heat losses is negligible and developed heat loss models can be used to model EE scenarios.

Within the SD model, it is assumed that the rate of replacement of heating networks depends on the economic benefit. The heating system operator makes a decision before replacing the pipelines, considering the potential benefits of replacing outdated pipelines with new ones. To determine the Empirical equation shown in Figure 3.2.11, it is used to determine the specific costs of heating pipelines

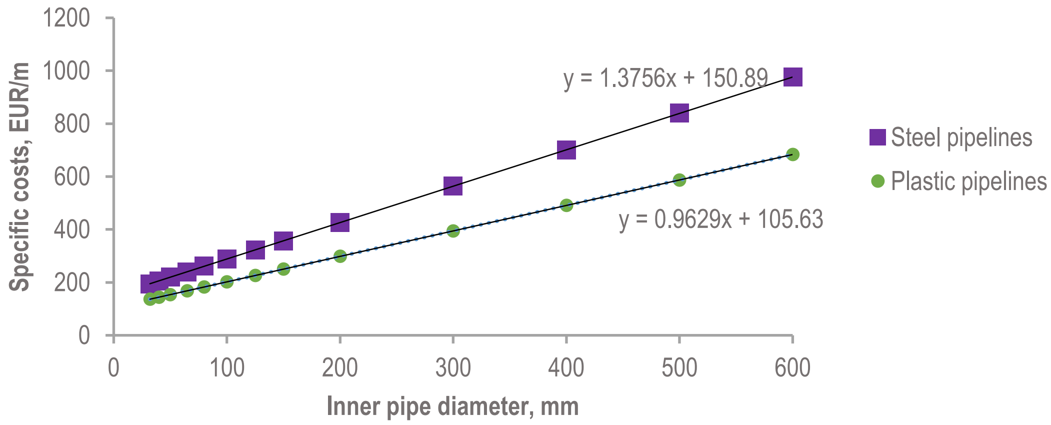


Fig. 3.2.11. Specific costs of steel and plastic pipelines (Nielsen & Möller, 2013).

Taking into account the heating tariff, an economic benefit is determined, which is compared with the planned renovation costs. In the event that the planned costs are greater than the economic benefits and the payback time is long, the proportion of replacement of the pipeline will be low and only the damaged pipes will replace. When payback time decreases, interest in replacing the pipeline is greater. At national level, the level of replacement of heating networks can be increased by granting aid to heating enterprises.

The SD model takes into account that the system can switch to low-temperature mode, but this can only happen if there are renovated buildings in the DH network, where it is possible to ensure comfortable temperatures during the winter months with a low-temperature heat carrier. The model assumes that there is no linear relationship between the transition to low-temperature heating and the renovation of the building, and, for example, the proportion of 20% of renovated buildings does not mean that 20% of the DH system can switch to low temperatures. Such considerations are based on the location of the renovated buildings - between unrenovated buildings, between different types of buildings or between renovated buildings. Switching can only occur if there is a high proportion of renovated buildings in certain parts of the system. Switching to a low-temperature mode allows you to replace metal pipes with plastic pipes, which reduces the cost of replacing the heating network, as described in the previous sections. Therefore, the transition to low-temperature heat supply also has a positive effect on the replacement of heating networks, as it reduces costs and the payback time of investments. The model takes into account that when the system switches to a low temperature mode, the use of plastic pipes for the renovation of the heating network is accordingly started.

3.3. Sector final consumption input data

3.3.1. Final consumption of the household sector

A significant factor affecting the total consumption of fuels is the housing stock and the heated areas of buildings. Input data on housing stock taken from the CSB database (Centrālā Statistikas pārvalde, 2020g).

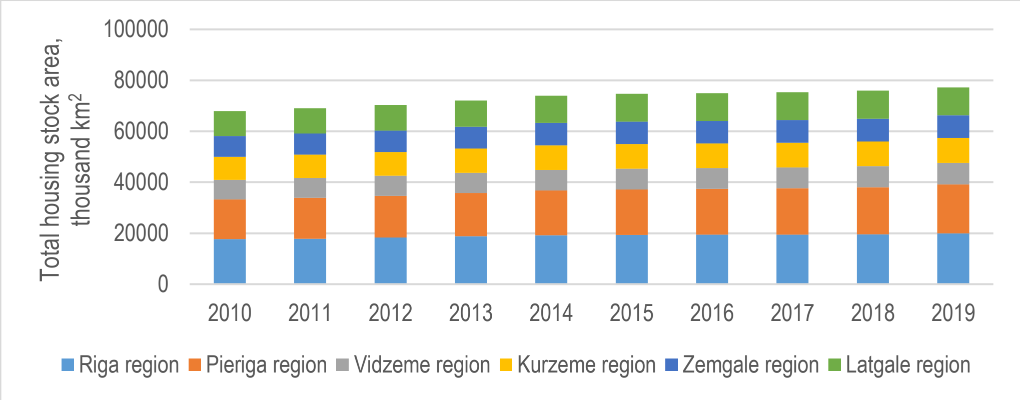


Fig. 3.3.1. Changes in the total housing stock area in the statistical regions.

The volume of new buildings for the period from 1990 to 2018 was taken from the CSB databases – BUG060 (Central Statistical Bureau, 2020b) and A_MAG030 (Central Statistical Bureau, 2020a). A division into single-apartment and multi-apartment buildings is used.

TABLE 3.3.1. NEW CONSTRUCTIONS ACCEPTED FOR OPERATION IN STATISTICAL REGIONS IN THE PERIOD FROM 1990 TO 2018 (CENTRAL STATISTICAL BUREAU, 2020A)

Region	One-apartment buildings, thsd. m^2	Multi-apartment buildings, thsd. m^2
Riga region	4583.1	4248.5
Vidzeme region	563.9	178
Kurzeme region	632.7	321.2
Zemgale region	900.6	248.2
Latgale region	529.9	340.3

The number and areas of renovated multi-apartment buildings are compiled from publicly available information from the financial support provided for the insulation of buildings in various support programmes (ALTUM, 2020).

TABLE 3.3.2. AREAS OF RENOVATED BUILDINGS (THSD M^2) IN STATISTICAL REGIONS

	2013	2014	2015	2016	2017	2018
Riga region	34.3	192.6	282.3	282.3	282.3	465.7
Vidzeme region	145.1	274.4	369.4	369.4	369.4	426.8
Kurzeme region	155.7	261.2	406.4	406.4	406.4	504.7
Latgale region	31.7	42.2	50.1	50.1	50.1	65.3
Zemgale region	55.4	113.5	168.9	168.9	168.9	211.8

Using publicly available data on the thermal energy consumption of more than 600 buildings before and after renovation, average specific thermal energy consumption indicators were determined in different regions in multi-apartment buildings.

TABLE 3.3.3. SPECIFIC INDICATORS OF THERMAL ENERGY CONSUMPTION IN MULTI-APARTMENT BUILDINGS IN PROJECTS CO-FINANCED BY ALTUM, KWH/M^2 OF HEATED AREAS PER YEAR

	Before renovation		After renovation	
	Total thermal energy consumption	Thermal energy consumption for heating	Total thermal energy consumption	Thermal energy consumption for heating
Riga region	176	142	93	57
Vidzeme region	187	150	94	61
Kurzeme region	156	118	87	50
Latgale region	175	144	86	58
Zemgale region	174	139	87	56

Figure 3.3.2 shows changes in the consumption of primary resources in households. Overall, resource consumption in households has decreased if comparing 2012 and 2018, but low resource consumption was observed in 2015.

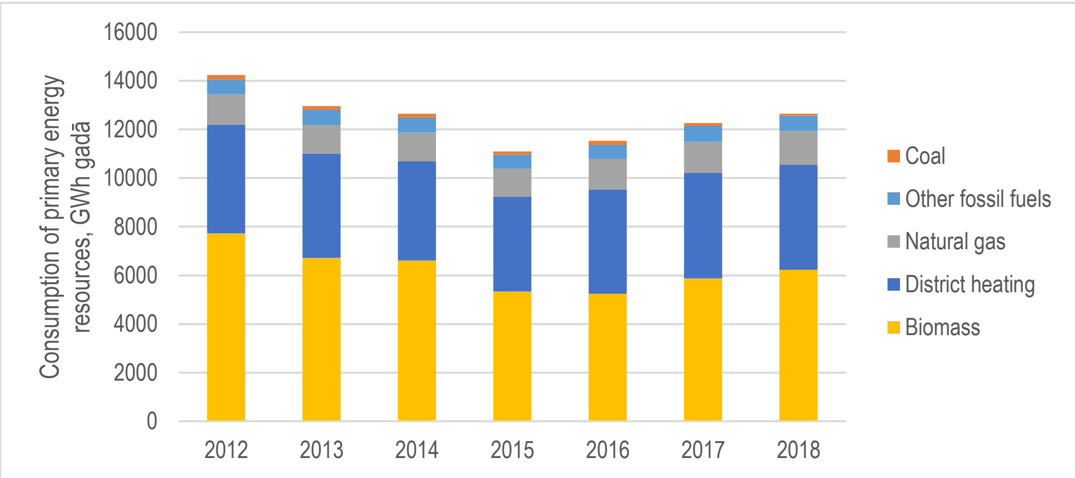


Fig. 3.3.2. Consumption of primary energy resources in household sector (Central Statistical Bureau, 2020c)

Table 3.3.4 defines the consumption of resources by region, taking into account statistical data on the consumption of centralised thermal energy in households and the total distribution of energy resources, which has been adopted proportionally in all regions. Riga region has the highest consumption of energy resources, where centralized thermal energy and biomass are the most used, but coal is used the least.

TABLE 3.3.4. BREAKDOWN OF PRIMARY ENERGY RESOURCES BY REGION

	Riga region	Vidzeme	Kurzeme	Latgale	Zemgale
Centralised thermal energy	2852	225	396	527	315
Petroleum products	390	119	49	41	44
Coal	69	21	9	7	8
Natural gas	789	240	98	82	89
Biomass	3571	1085	445	373	403

Input data on RES technologies installed in the household sector are obtained by analysing the projects implemented by the CCFI programme. Information was collected on the financing obtained in the 1st and 2nd rounds of the CCFI competition "Use of renewable energy resources in the household sector" for the installation of solar collectors (603 projects in total) and heat pump technologies (2691 projects in total) in household buildings. The findings were broken down by region, assuming that all the technologies mentioned in the project applications had been installed (KPFI.LV, 2020).

By collecting information on projects for the production of thermal energy from the installation of solar collectors, it has been obtained that the technologies were selected with an average installed capacity of 5–5.5 kW. In turn, the total installed capacity in 2012 was 3250 kW and in 2013 the total installed capacity was 1597 kW. The specific production for solar collectors is assumed to be 500 kWh/MWh.

The evaluation of projects related to the installation of heat pumps in households resulted in an average capacity of 12.5 kW per installed installation in 2012 and 11.1 kW in 2013. The heat produced is determined based on load factors and hours of operation of the particular heat pump. It is assumed that in the following years the growth of installed solar collectors and heat pumps continues by 10% and 15% respectively due to the initiative of households.

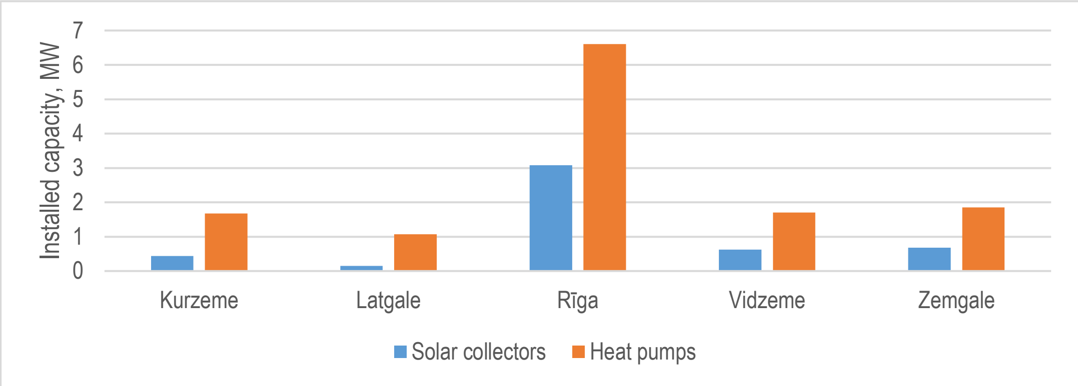


Fig. 3.3.3. Installed capacity of certain solar collectors and heat pumps in the framework of CCFI projects in households.

Household electricity consumption in densely populated areas was determined from the information available on the geospatial planning platform of administrative territorial reform (Vides aizsardzības un reģionālās attīstības ministrija, 2020a). The output data of AS "Sadales tīkls" collected in the maps, which are available in the *geojason* file with the spatial analysis tool. The available data were displayed on the map and, with the help of the layer of planning regions available in the GIS Latvia database 10.2, divide the planning region using the ArcGIS Pro Split tool. The calculated consumption is summarised in Table 3.3.5.

TABLE 3.3.5. HOUSEHOLD CONSUMPTION IN REGIONS

Planning region	GWh
Kurzeme	218,76
Latgale	181,73
Riga	1059,17
Vidzeme	140,31
Zemgale	192,78

3.3.2. The public sector

Information on the public sector is collected from several sources of information. The total area of state buildings in different regions has been determined according to the list of buildings owned, possessed and used by the available EM state institutions (Ministry of Economics, 2019), however, this list does not include municipal buildings, which are also to be defined as public buildings. The areas of educational institutions in different regions are determined in accordance with the Register of Educational Institutions (Ministry of Welfare, 2020), the legal status of which is defined as "Local Governments" or "Institution of Indirect Administration". The area of educational institutions is determined on the assumption that the average area of one Educational Institution is 1812 m^2, which is according to the information published by the Ministry of Economics (Ministry of Economics, 2017). The areas of social care buildings, which are determined using information on registered social care service providers (Ministry of Welfare, 2020), have also been determined separately. The area of social buildings owned by local governments is determined on the assumption that the average area of one building is 1500 m^2, which is according to the information published by the Ministry of Economics (Ministry of Economics, 2017) on the total number and total area of medical treatment institutions.

The obtained information on the area of the identified public buildings in different regions is summarised in Figure 3.3.4. The total area determined by public authorities is more than 2.1 million. m^2, the area of municipal schools is more than 4.1 million m^2, while the total defined area of social care centres is more than 1.1 million m^2. As can be seen in the figure below, most of them, or 44% of all these buildings, are located in the Riga planning region.

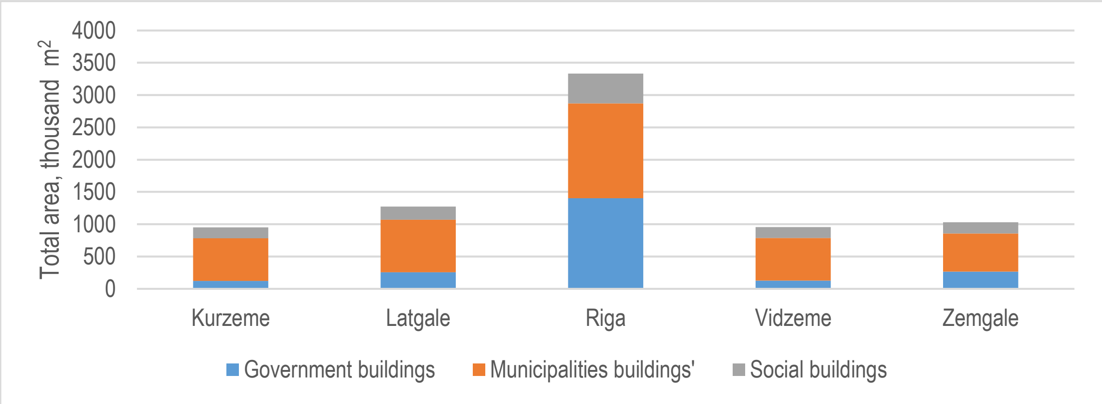


Fig. 3.3.4. Areas of public buildings in the planning regions

The average consumption of thermal energy in different types of public buildings is determined in accordance with the consumption for heating indicated in the issued energy performance certificates of buildings. Changes in thermal energy consumption in the buildings of educational institutions, medical treatment institutions and sports facilities from 2016 to 2020 can be seen in Figure 3.3.5.

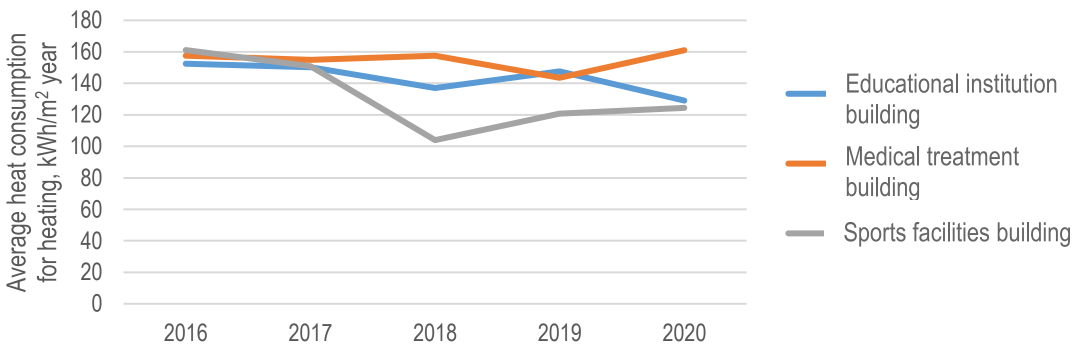


Fig. 3.3.5. Average thermal energy consumption in different types of buildings

Input data on solar collectors installed in the public sector are obtained by analysing projects implemented by the CCFI programme in the calls "Transition of technologies from fossil to renewable energy sources", "Complex solutions for reduction of greenhouse gas emissions in municipal buildings", "Low energy buildings" and "Use of renewable energy resources for reduction of greenhouse gas emissions". Information was collected on the funding obtained in the CCFI tenders for projects for solar collector (50 projects in total) and heat pump technologies (25 projects in total) for public buildings (Ministry of Environmental Protection and Regional Development, 2020b). The findings were broken down by region and call for tenders, assuming that the technology was installed in the year following the approval of the project application.

The percentage of CCFI projects for the installation of solar collectors in public buildings can be found in Figure 3.3.6. Vidzeme (43%) and Riga (37%) regions used the most of this opportunity.

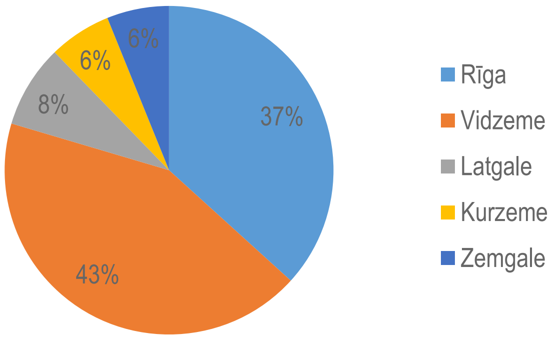


Fig. 3.3.6. Installed solar collectors by regions of Latvia from CCFI projects, 2010-2014.

The total installed solar collector capacity is 2632,16 kW and the percentage breakdown by region is shown in Figure 3.3.7. 50% of the total installed capacity is in Riga region. Although there are 6% fewer public buildings in Riga region for which solar collectors were installed, their total capacity is higher than for Vidzeme region, which had the most approved CCFI projects with this technology. Kurzeme region (2%) and Zemgale region (5%) have the lowest solar collector capacity.

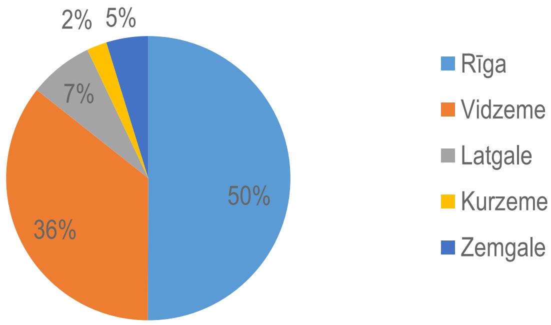


Fig. 3.3.7. Percentage capacity distribution for installed solar collectors by region

As can be seen from Figure 3.3.8, the most heat pump technologies were installed in Riga region (28%) and Latgale region (28%), but the least in Zemgale region (4%).

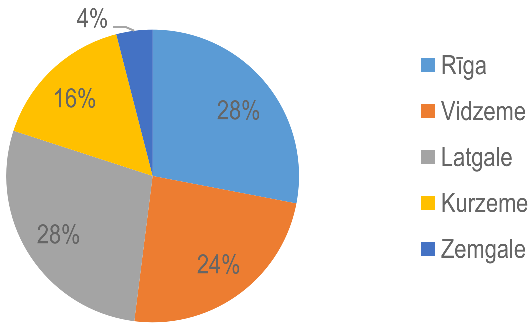


Fig. 3.3.8. Breakdown of installed heat pumps by region from CCFI projects, 2009-2014.

Of the total installed heat pump capacity of 3127.75 kW, almost half or 49% is made up of heat pumps installed in Riga region (see Figure 3.3.9). Latgale region with the same number of installed heat pumps accounts for 29% of the total heat pump capacity.

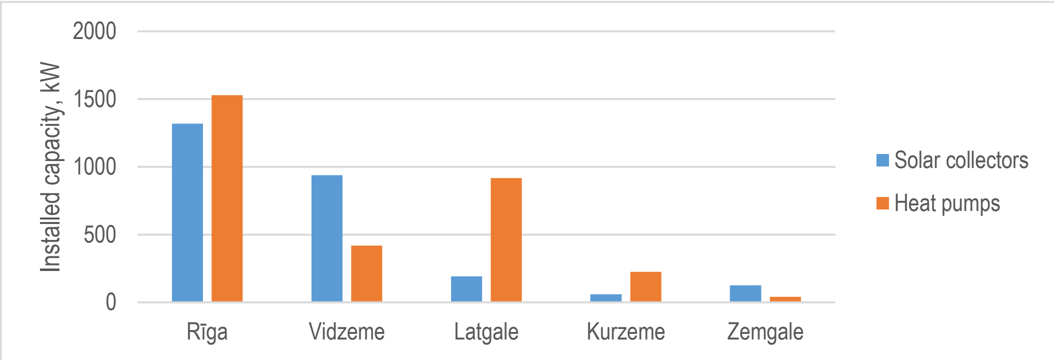


Fig. 3.3.9. Percentage capacity distribution for installed heat pumps by region.

In order to install solar collector technology on public buildings, the largest number of projects were submitted in the call of 2010 (31%) and the call of 2011 (29%). According to the graph of Figure 3.3.10, the lowest activity was in 2012 in the call (6%).

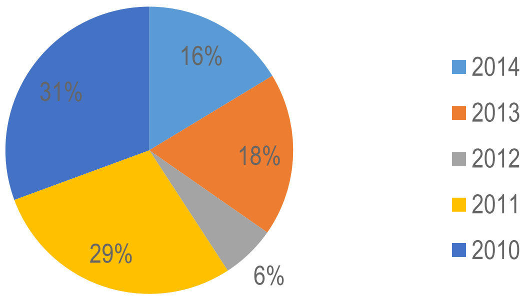


Fig. 3.3.10. CCFI projects with solar collector installation.

The largest number of projects on the installation of heat pump technology was in the call of 2013 (28%), but in 2009 4% of the total number of projects were in the call for funding for the installation of heat pump technology. As can be seen from the graphic of Figure 3.3.11, in 2014, 2011 and 2010 there were an equal number of heat pump technology project applications, which account for 20% of the total number of projects.

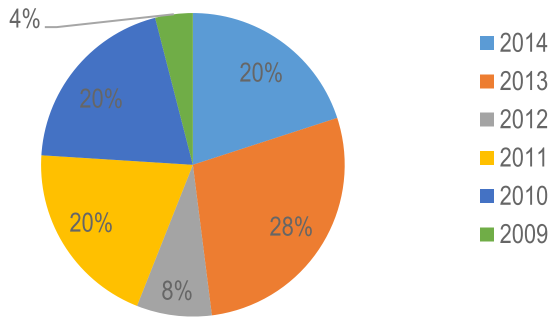


Fig. 3.3.11. CCFI projects with heat pump installation.

In all CCFI projects on solar collectors and heat pumps for public buildings, it can be observed that solar collector projects are 32% more than heat pump projects. Looking at solar collector and heat pump projects, Vidzeme region (36%) and Riga region (34%) were the most active region for the introduction of these technologies. The smallest number of projects in the call for solar collector and heat pump technologies was financed in 2009, which accounts for 1% of all projects, but most of them, 27%, they were in 2010; and in 2011 26% of projects were financed from the total number of projects in 2009-2014.

3.3.3. Industry and services sector

The input data on individual heating in the industrial and service sector are derived from environmental reports provided by enterprises and institutions. The Air-2 report form developed by the State Ltd "Latvian Environment, Geology and Meteorology Centre" (LVĢMC) is be completed by operators who have a permit for the performance of Category A or B polluting activities or a certification of a Category C polluting activity in the field of energy, as well as those complying with the polluting activity referred to in the Annex to Regulation (EC) No 166/2006 of the European Parliament and of the Council of 18 January 2006 on the introduction of a European pollutant release and transfer register and council Directives 91/689/EEC and 96/61/EC and emitting the pollutants listed in Annex II to Regulation No 166/2006. By the amount of resource consumed by these enterprises, it is possible to evaluate the general amount of resources used for thermal energy in the country in the production and services sector (LVĢMC, 2020b).

The database reports are publicly available, however, the search possibilities on the portal are limited, the fuel section offers a separate choice for the production of heat or electricity or for technological processes, choosing whether to display the data in the territorial or organizational cross-section. For the comparison of regions, the two sets of data are needed in a linked way, showing both the company and their locations. The necessary data for 2017-2019 were requested from the GMC.

In order to carry out an overview of regions, all enterprises of the database were divided into planning regions and categories according to the NACE classification available in the Lursoft database.

- A(1-3) agriculture, including logging and fisheries and fur farms;
- B, C(5-33) industrial enterprises;
- D (35) electricity, heat, gas supply;
- E (36-39) water supply, waste management, included in the services sector;
- F (41-43) construction enterprises, which are counted as industrial sector;
- G (45-47) trade, included in services sector;
- H (49-52) transport, separated and not viewed here;
- I -N (55-82) services;

- O, P, Q (84-88) public authorities, included in the services sector but distinguished separately by sorting data to facilitate assumptions about the energy consumption of public authorities in regions in the future work with these data for the SD model. This mainly includes all educational institutions, medical institutions, state and large municipal enterprises;
- R, S (90-96) services;
- T (97) distinguished as households, not considered here.

Fuel consumption is considered in natural units of fuel, but in order for these data to be comparable, it needs to be converted into a single unit. With the help of coefficients, fuel consumption was converted into megawatt hours. Consumption of the primary resource was further divided by fuel types – natural gas, to which liquefied gas is also added; biomass (predominantly wood, this group includes pellets, firewood, wood chips and other wood, straw); waste incineration — use of tyres as fuel; coal; petroleum products (diesel, fuel oil and liquid fuels) and biogas.

The information on the number of enterprises that had submitted the environmental reports for which the average consumption is analysed, it is summarised in Table 3.3.6. Table 3.3.7 shows the total consumption of primary resources in gigawatt hours by sector and year.

TABLE 3.3.6.NUMBERS OF ENTERPRISES IN THE REGIONS

	2017		2018		2019	
	Manufacturing	**Services**	**Manufacturing**	**Services**	**Manufacturing**	**Services**
Kurzeme	220	141	207	138	229	149
Latgale	201	246	198	249	208	240
Riga	524	534	549	563	553	604
Vidzeme	233	193	233	182	236	201
Zemgale	255	220	257	210	274	221

TABLE 3.3.7.TOTAL CONSUMPTION OF PRIMARY ENERGY SOURCES IN THE REGIONS, GWH

	2017		2018		2019	
GWh	**Manufacturing**	**Services**	**Manufacturing**	**Services**	**Manufacturing**	**Services**
Kurzeme	153.57	38.85	154.46	333.64	146.46	40.63
Latgale	130.85	69.24	122.50	65.03	127.28	62.02
Riga	479.58	75.96	499.80	71.79	437.70	90.54
Vidzeme	233.56	88.10	235.75	78.23	301.96	89.31
Zemgale	216.34	39.56	618.07	35.09	518.28	35.38

Tables 3.3.8 and 3.3.9 summarise the total consumption of the primary resource in the production and services sector. The public sector is included in the services sector. The obtained data on the total consumption of natural gas and biomass in these sectors have been adjusted according to the available information in the total energy balance.

TABLE 3.3.8.TOTAL CONSUMPTION IN MANUFACTURING SECTOR BY RESOURCE, MWH

	2017	2018	2019
Kurzeme			
Natural gas	145485	193387	115987
Biomass	368531	376660	370421
Incineration of waste	53333	100278	100833
Coal	240620	334690	305271
Petroleum products	21374	23885	22499
Zemgale			
Natural gas	168845	152563	86300
Biomass	733750	860995	855073
Coal	23475	28350	26206
Petroleum products	8106	5172	6531
Riga			
Natural gas	688278	728890	540891
Biomass	1508254	1675705	1560407
Peat	3621	5167	6203
Biogas	0	22347	25748
Coal	1322	2132	633
Petroleum products	24354	24900	29953
Latgale			
Natural gas	117412	127820	78535
Biomass	445880	506209	519113
Coal	762	792	977
Petroleum products	4201	4987	4719
Vidzeme			
Natural gas	281369	273729	441342
Biomass	765251	958765	1033319
Peat	0	28	204
Coal	3543	6258	3579
Petroleum products	5310	5068	3684

Figure 3.3.12 shows the consumption of primary resources in the production sector in 2017. The largest it is in Riga (RR), where biomass is most used, but in Kurzeme (KR), compared to other regions, coal is used more.

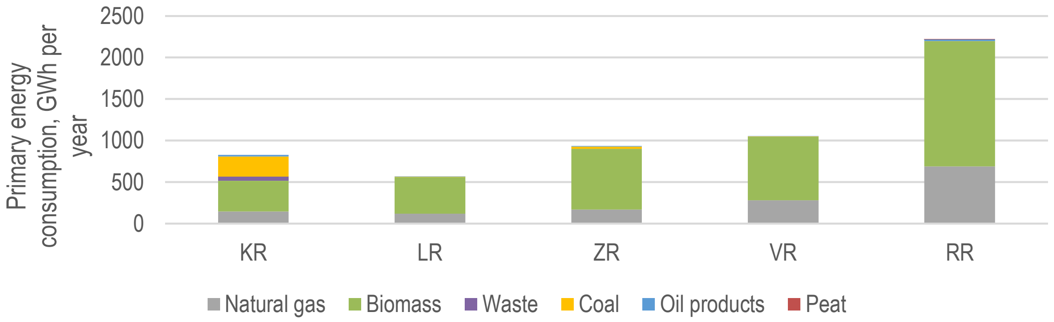


Fig. 3.3.12. Distribution of consumption of primary resources in production sector in 2017.

Consumption of energy resources in services and public sector can be seen in Table 3.3.9. Comparing data for 2017 and 2019, natural gas is used more as biomass in Kurzeme and coal is used more as a resource than it was in 2017. In Latgale, the use of biomass has decreased, but the use of natural gas and peat has increased. In Zemgale and Vidzeme, the use of natural gas is increasing, while the use of biomass in the services and public sector is increasing in Riga.

TABLE 3.3.9.TOTAL CONSUMPTION OF PRIMARY ENERGY RESOURCES BY SERVICES AND PUBLIC SECTOR BY RESOURCES, MWH

	2017	2018	2019
Kurzeme			
Natural gas	74344	92310	103193
Biomass	139407	126767	86825
Coal	83	0	614
Petroleum products	832	815	696
Latgale			
Natural gas	21715	29052	26002
Biomass	270030	206859	140939
Peat	134	818	1383
Coal	18206	14095	9321
Petroleum products	5278	5186	5051
Zemgale			
Natural gas	174039	196014	223165
Biomass	121398	91236	61910
Coal	13049	7496	6164
Petroleum products	474	357	326
Vidzeme			
Natural gas	81328	66506	84980
Biomass	333751	244559	203981
Coal	6544	5853	6193
Petroleum products	3400	4471	4736
Riga			
Natural gas	918575	916950	906826
Biomass	91525	109468	147179
Coal	3784	6722	2708
Petroleum products	12072	15169	10272

According to the data of 2017 (Figure 3.3.13), Riga region consumes 5 times more resources in the services and public sector than Kurzeme region. In Kurzeme, Latgale and Vidzeme the major resource is biomass, while in Zemgale natural gas is slightly more used. In Riga, the most used as an energy source is natural gas.

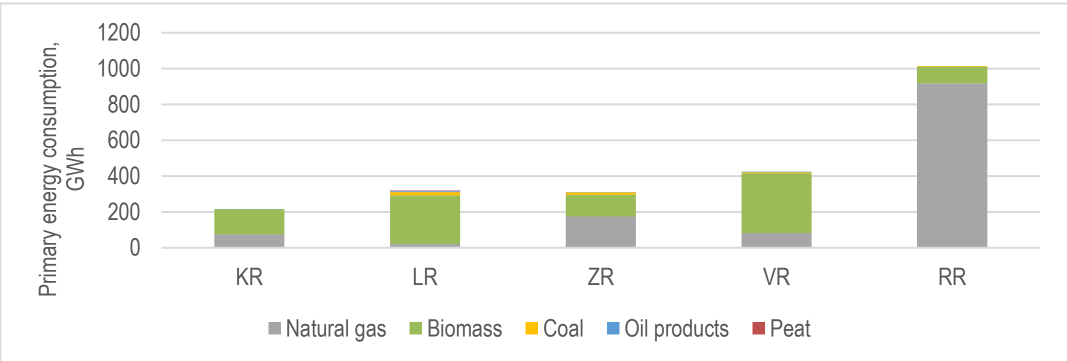


Fig. 3.3.13. Distribution of consumption of primary resources in the services and public sector in 2017.

The industrial and service sectors are distributed into large and small enterprises to model the impact of EE policies on the overall consumption. Large companies in this case include both those that classify as large enterprises by law (employ more than 249 employees, or whose turnover for the reporting year exceeds EUR 50 million and the annual balance sheet total of EUR 43 million), as well as large electricity consumers (annual electricity consumption exceeds 500 MWh). The number of large enterprises is summarised in Table 3.3.10, broken down by region and sector.

TABLE 3.3.10. NUMBERS OF LARGE ENTERPRISES IN THE REGIONS

	Manufacturing	Services	Public	Transport	Agriculture	Other
Kurzeme	60	49	6	1	5	5
Latgale	37	33	4	1	1	9
Riga	210	469	65	11	10	31
Vidzeme	56	32	6	0	2	5
Zemgale	56	43	9	1	9	2

The number of small enterprises for 2017 has been calculated by subtracting the number of large enterprises from the total, the number of enterprises in other years has been calculated in proportion to the division of the respective region for 2017. The total number of economically active enterprises is taken from the CSB database SRG010 (Central Statistical Bureau, 2020i)..

3.4. Input of the transport sector

Part of the raw data on the transport sector is obtained from the results of the project "Formulation of Sustainable and Renewable Transport Policy in Latvia (4muLATe)" Nr. VPP-EM-2018/AER-2-0003, which is summarized in the deliverable "Analysis of existing framework conditions and best practices". Vehicle statistics in planning regions were obtained from the information available to the Road Traffic Safety Directorate (CSDD, 2020) on the distribution of vehicles belonging to natural persons by cities and municipalities. Data were compiled for the period 2015-2019.

The largest number of cars from 2015-2019 is in Riga region, which accounts for almost half of the total number of cars each year (see Figure 3.4.1). The fewest natural persons of cars are in Vidzeme, but Zemgale, Kurzeme and Latgale have very similar indicators. Overall, the number of light vehicles is increasing and has increased by 6.5% since 2015.

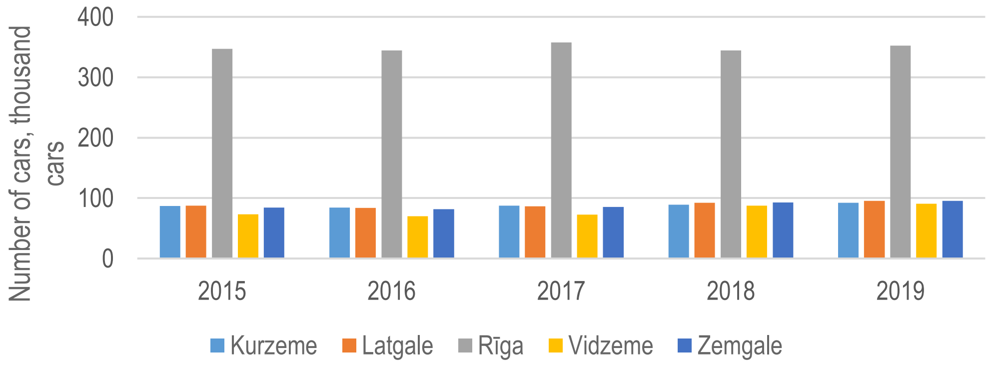


Fig. 3.4.1. Numbers of cars, 2015-1019 (CSDD, 2020)

The largest number of cargo vehicles is in Riga region, but the smallest in Vidzeme region (see Figure 3.4.2). Comparing data of Kurzeme, Zemgale and Latgale regions, the largest number of cargo vehicles of these three regions is in Kurzeme. In all regions there is a tendency that the number of goods vehicles increases and has increased by 5.8% since 2015.

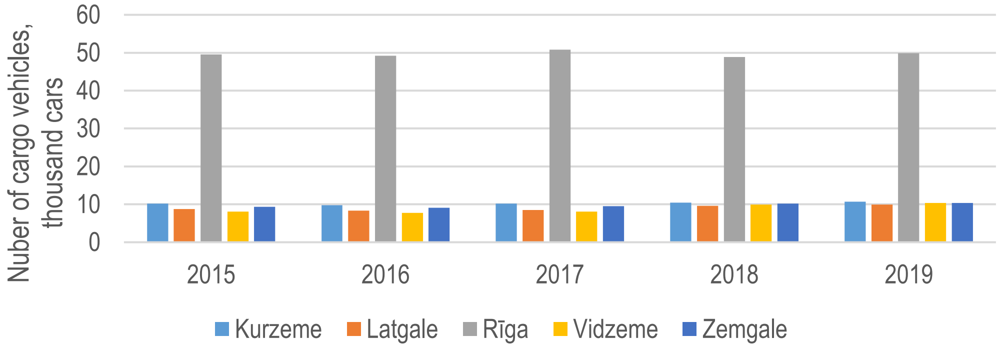


Fig. 3.4.2. Numbers of cargo vehicles, 2015-2019 (CSDD, 2020)

Looking at the number of buses in Figure 3.4.3, it can be seen that the number of buses tends to decrease. Comparing 2015 and 2019, the number of buses has decreased by 5.6%. The largest number of buses is in Riga, which accounts for almost half of the total number of buses. In Zemgale the number of buses has decreased the most (by 21%), but Latgale is the only region where the number of buses has increased, by 12%.

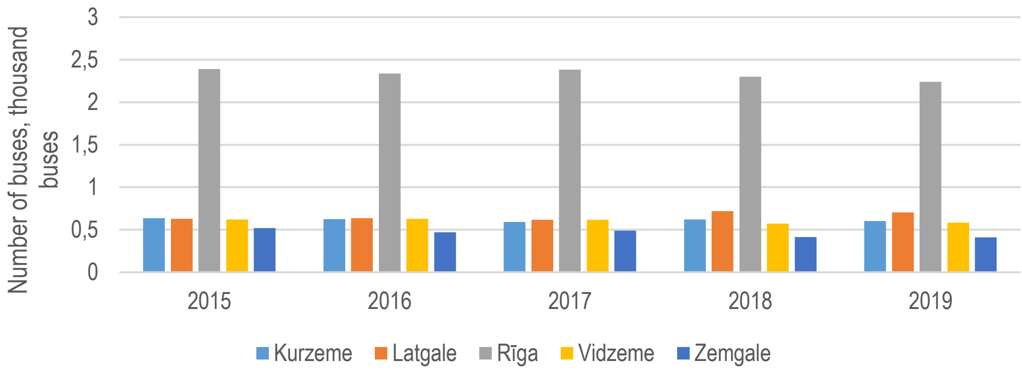


Fig. 3.4.3. Numbers of buses 2015-2019 (CSDD, 2020).

The total number of vehicles has increased by 7.4% between 2015 and 2019. The total number of vehicles is shown in Figure 3.4.4, which includes cars and cargo vehicles, buses, motorcycles, tricycles, trailers, semi-trailers, quadricycles and mopeds. Overall, the largest number of vehicles is in Riga, but in Kurzeme, Latgale, Vidzeme and Zemgale the number of vehicles is relatively similar. The largest increase in the number of vehicles was observed in Vidzeme and it was by 26% and in Zemgale by 15%, but the smallest increase in the number of vehicles is in Riga, by only 2%.

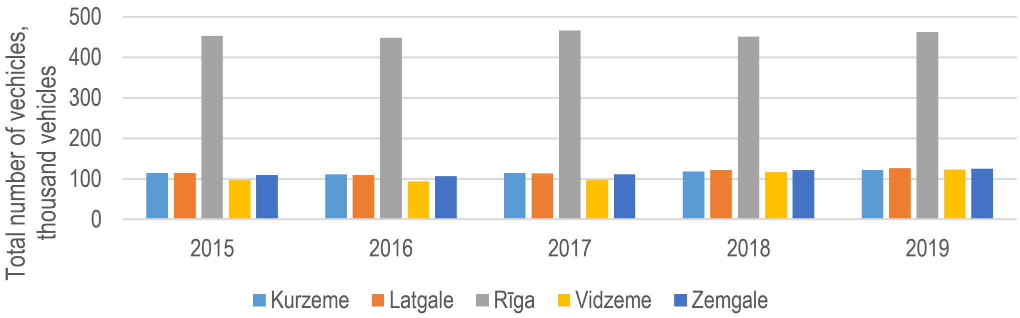


Fig. 3.4.4. Total number of vehicles, 2015-2019 (CSDD, 2020)

Of the number of average vehicles data for 2015-2019, the majority or 76% consists of cars, 10% consists of freight vehicles and buses make up only 1%, while other vehicles (motorcycles, tricycles, trailers, semi-trailers, quadricycles and mopeds) account for 14% of total vehicles.

Modelling the development of the transport sector information is included on the age structure of different vehicles, adopted in the same way in all planning regions. When studying the Latvian fleet, you can see that it is quite outdated. In the category of light road transport, the number of vehicles over 11 years of age continues to grow, but as of 2014 the share of passenger cars aged up to 5 years is starting to increase. In 2017, the share of this group constituted 10.0 % (Centrālā Statistikas pārvalde, 2020h).

TABLE 3.4.1. NUMBER OF DIFFERENT CARS BY AGE IN 2017 (CENTRĀLĀ STATISTIKAS PĀRVALDE, 2020H).

	Trucks	**Buses**	**Passenger cars**
Up to 5 years	18401	1062	64909
from 6 to 10 years	16429	838	92024
11 years and more	52313	2801	532603
Total	87143	4701	689536

In the percentage breakdown (see Figure 3.4.5), passenger cars, lorries and buses are more than half of the vehicles over the age of 11. Passenger cars (77%) are the most numerous such vehicles, while buses (23%) are the most recent vehicles under 5 years of age.

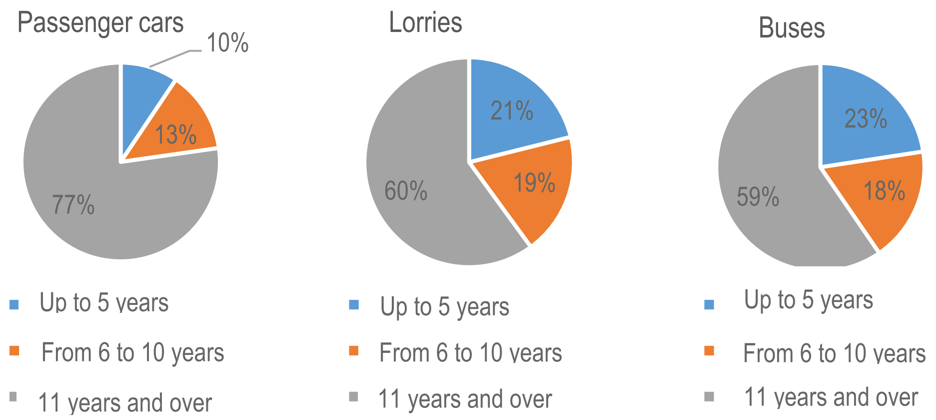


Fig. 3.4.5. Breakdown of different vehicles by age in 2017 (Centrālā Statistikas pārvalde, 2020h).

An analysis of trucks by age shows that the proportion of vehicles over the age of 11 is lower and accounts for 60% in 2017. In turn, the share of trucks under 5 years of age increased from 15.7 % to 21.2 % between 2013 and 2018. The number of buses aged over 11 fell from

64.7% to 60.8% between 2010 and 2018. The share of buses under the age of 5 has increased – from 15.1% in 2010 to 22.6% in 2017.

When comparing vehicles by type of fuel, diesel fuel is the most popular among passenger cars, trucks and buses. Until 2014, petrol was the most popular fuel for light road transport (see Figure 3.4.6). In 2018, the share of diesel-powered cars comprised 56.3 %. Between 2009 and 2018, the share of petrol and gas-powered passenger cars increased significantly from 3.1% to 5.6%. In recent years, the number of cars operating on other types of fuel is also beginning to increase. The number of electric vehicles is also increasing, but their share remains minimal.

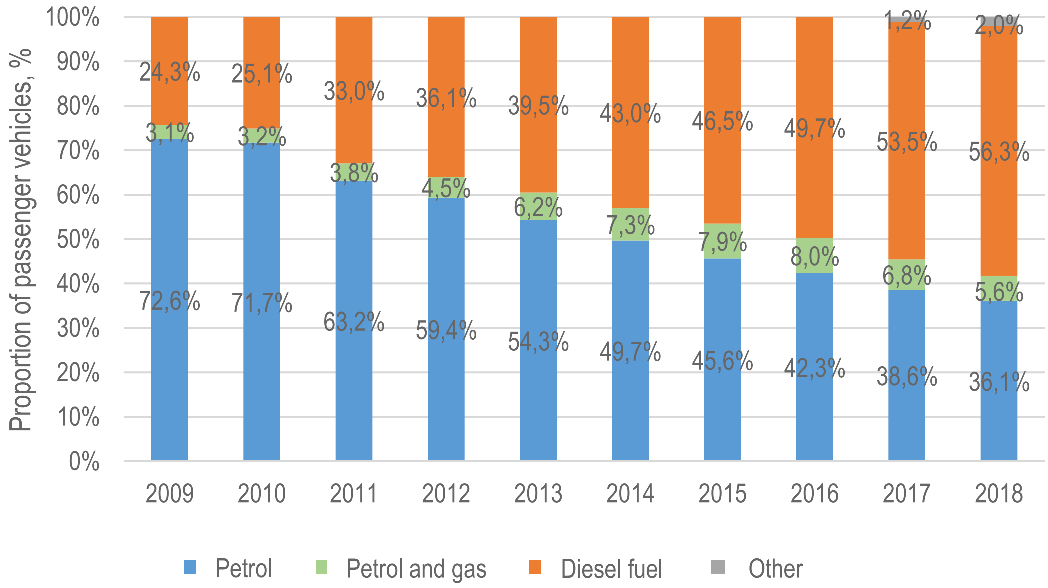


Fig. 3.4.6. Breakdown of passenger cars by type of fuel (Centrālā Statistikas pārvalde, 2020h).

Diesel vehicles also dominate between trucks. In 2018, the share of diesel trucks constituted 94.2 %, while the share of trucks with petrol comprised 3.8 % (see Figure 3.4.7).

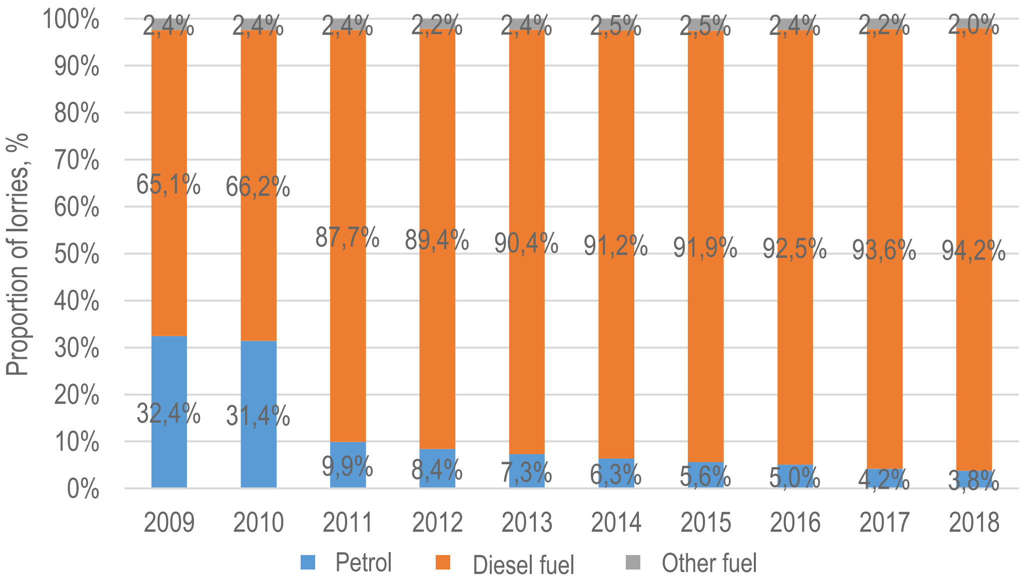


Fig. 3.4.7. Breakdown of cargo vehicles by fuel type.

Statistics show diesel dominance in the bus fleet. 99.2 % of all buses in the country are diesel fuelled, 0.6 % are on petrol and 0.2 % on other fuels (see Figure 3.4.8).

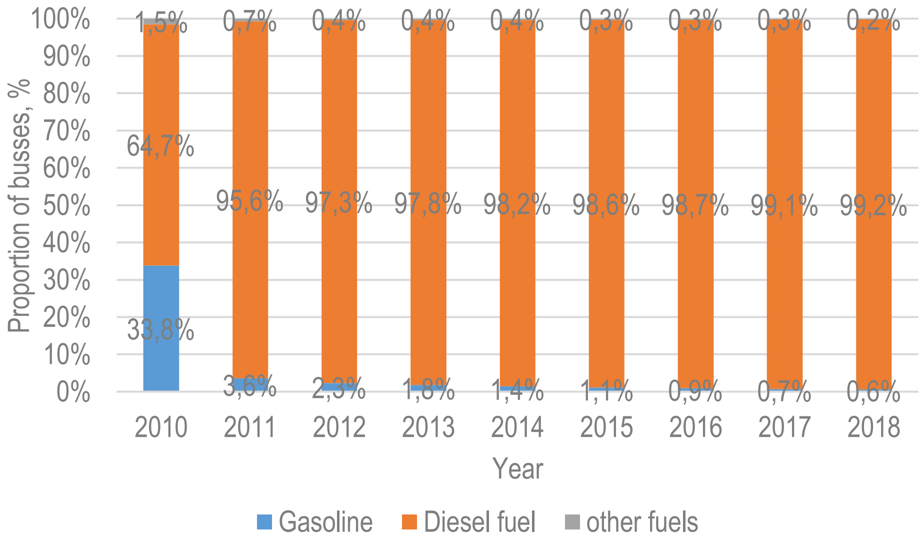


Fig. 3.4.8. Breakdown of buses by type of fuel (Centrālā Statistikas pārvalde, 2020h).

Historical data available in the CSB database are used to determine the average fuel consumption (see Figure 3.4.9). It can be seen that vehicles with a higher engine capacity have a higher fuel consumption. The average fuel consumption decreases between 1996 and 2015 from 9.1 l/100 km to 7.7 l/100 km. One of the factors that contributed to this is the development and deployment of more efficient technologies (Centrālā Statistikas pārvalde, 2020f).

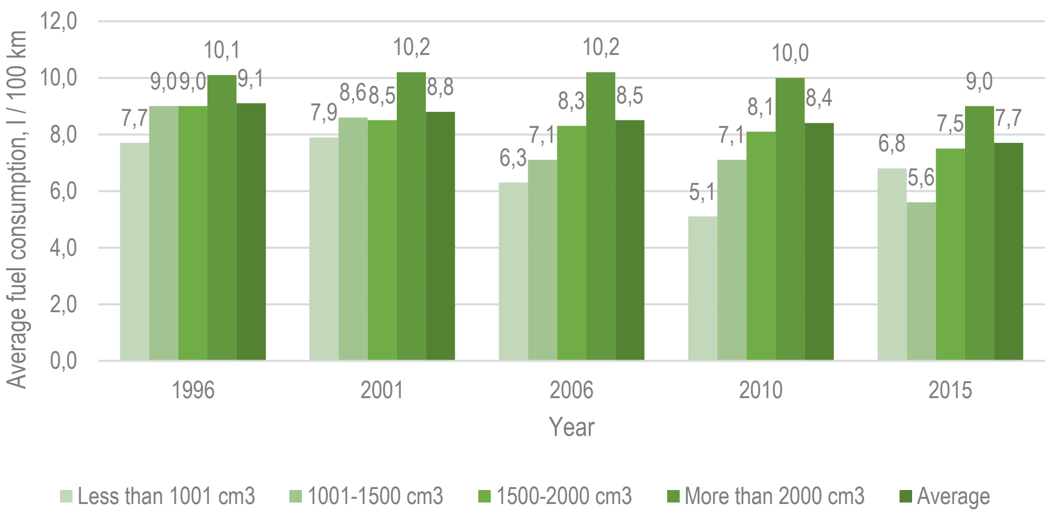


Fig. 3.4.9. Average fuel consumption depending on the engine capacity of the vehicle, litres per 100 km (Centrālā Statistikas pārvalde, 2020f).

On average, the kilometres travelled per car per year, depending on the engine capacity of the car, can be seen in Figure 3.4.10. It can be observed that cars with a larger engine capacity travel on average more kilometres per year than those with a smaller engine capacity. Between 1996 and 2015, the average annual mileage of all cars increased from 12219 km to 13210 km (Centrālā Statistikas pārvalde, 2020e).

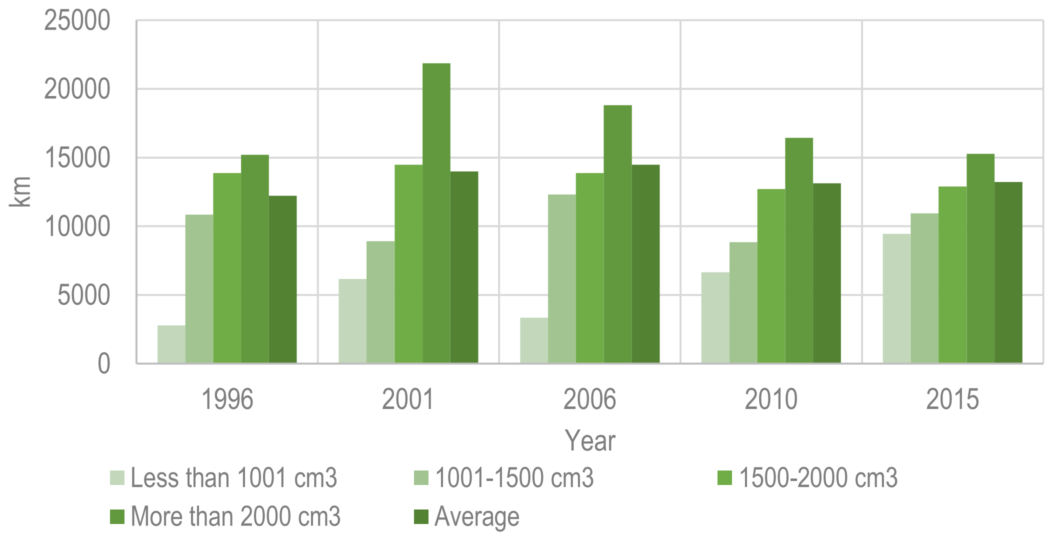


Fig. 3.4.10. Average kilometres travelled per car per year (Centrālā Statistikas pārvalde, 2020e).

3.4.1. Costs of vehicles and fuel

Vehicle prices vary considerably depending on many factors, including the age, assembly, technical condition of the vehicle, etc.. The prices of passenger cars, lorries and buses are shown in Table 3.4.2, depending on the type of fuel for new and used cars. Prices are based on one of Europe's largest car advertising portals *Mobile.de* offers. For light road transport fuelled with natural gas and biofuels, the price is calculated as the weighted average price of traditional technologies (diesel, petrol), plus EUR 1000 in the case of the installation of the gas appliance in the case of LPG and the cost of adapting the vehicle in the case of biofuels. In turn, for trucks and buses fuelled with natural gas and biofuels, the price is calculated as the weighted average price from traditional technologies (diesel), adding EUR 5000 in the case of installation of the gas appliance in the case of LPG and the cost of adapting the vehicle in the case of biofuels (Deutschlands größter Fahrzeugmarkt, 2020).

TABLE 3.4.2. VEHICLE PRICES, THSD EUR (CAR ADVERTISEMENT PORTAL MOBILE.DE).

	Passenger vehicles		Trucks and buses	
	New, thsd. EUR	Used, thsd. EUR	New, thsd. EUR	Used, thsd. EUR
Diesel fuel	24	3,1	90	20
Petrol	23	2,6	70	15
Petroleum gas	24,5	3,85	85	22,5
Hybrids	35	17,5	375	185
Electricity	40	20	175	120
Natural gas	24	19	95	32,5
Hydrogen	70	25	1100	550
Biofuels	24,5	3,85	85	22,5

The price of fuel is an important aspect that affects transportation costs. Average energy prices (excluding VAT) for final consumers over the period 2006-2018 are shown in Figure 3.4.11. During this period, fuel prices both increased and decreased several times. Over 12 years, petrol price increased by 53.5 %, but prices of diesel by 36.3 % (Centrālā statistikas pārvalde, 2020b).

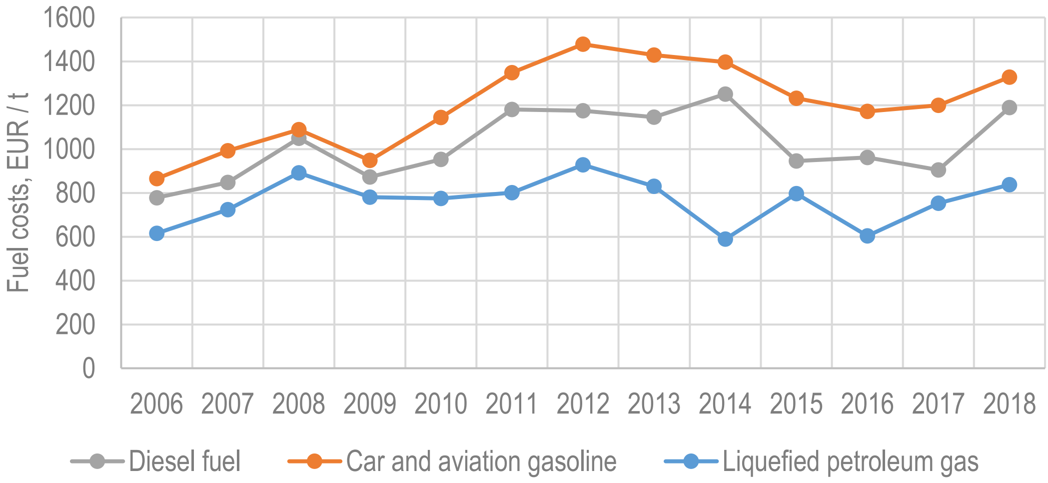


Fig. 3.4.11. Average prices of energy resources for final consumers (excluding VAT) (Centrālā statistikas pārvalde, 2020b)

3.4.2. Freight and passenger transport

Data on freight transport were compiled on the basis of the CSB data "Cargo turnover in road transport", The total volume of freight transport is increasing due to the increase in tonne-kilometres, which is a unit of measure of transport to characterize the transportation of one tonne of goods within one kilometre. In 2017, domestic transport accounted for 21.6 % of total domestic transport (see Figure 3.4.12). The growth rate of domestic transport is below the total. Between 2009 and 2017, domestic cargo turnover grew by 33.7 %, while total turnover increased by 45.8 % (Centrālā statistikas pārvalde, n.d.).

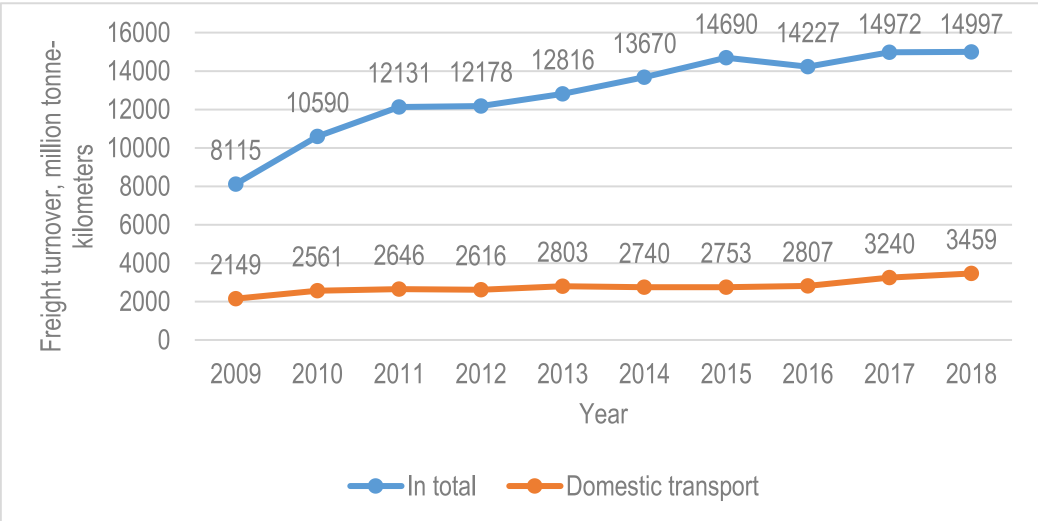


Fig. 3.4.12. Road freight turnover (Centrālā statistikas pārvalde, n.d.).

Historical data show that the majority of passenger transport is made up of regular bus transport (see Figure 3.4.13). In 2018, the share of these vehicles in passenger transport comprised 62.7 %. Then there are trams (18.9 %), trolleybuses (18.5 %) and other transport, including rail transport and aircraft (10.1 %). The total amount of passenger traffic in the period 2010-2018 remained practically unchanged and in 2018 was 224 million people (Centrālā Statistikas pārvalde, n.d.-c).

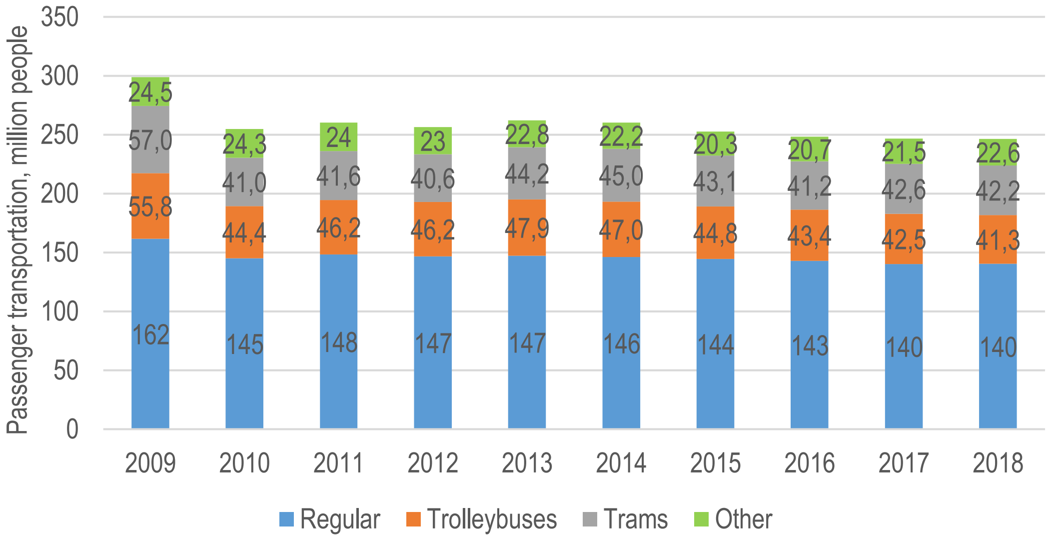


Fig. 3.4.13. Passenger transport by different means of transport (Centrālā Statistikas pārvalde, n.d.-c).

Historical data show that after 2014 passenger turnover on scheduled buses fell sharply from 2,345 million pkm to 2152 million pkm in 2018 (see Figure 3.4.14). The decrease between 2011 and 2018 amounted to 10.8 % (Centrālā Statistikas pārvalde, n.d.-d).

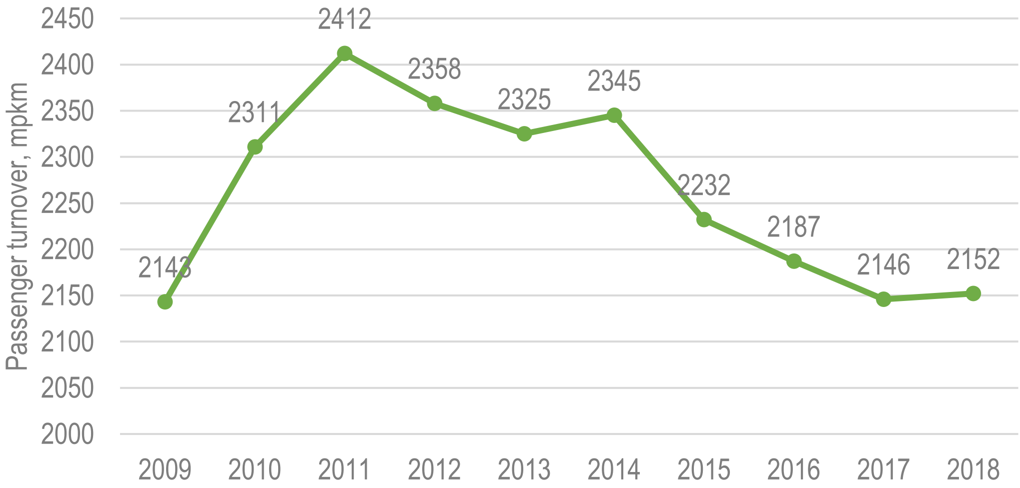


Fig. 3.4.14. Passenger turnover in scheduled buses (Centrālā Statistikas pārvalde, n.d.-d).

In Latvia, railways play an important role in the economy, freight and passenger transport (Electrification of the Latvian Railway Network</i>, n.d.). For example, rail accounts for between 50 % and 70% of total freight circulation over the last 10 years (see Chart 3.4.15). The rest of cargo turnover is related to water, land and air transport (Centrālā Statistikas pārvalde, n.d.-b).

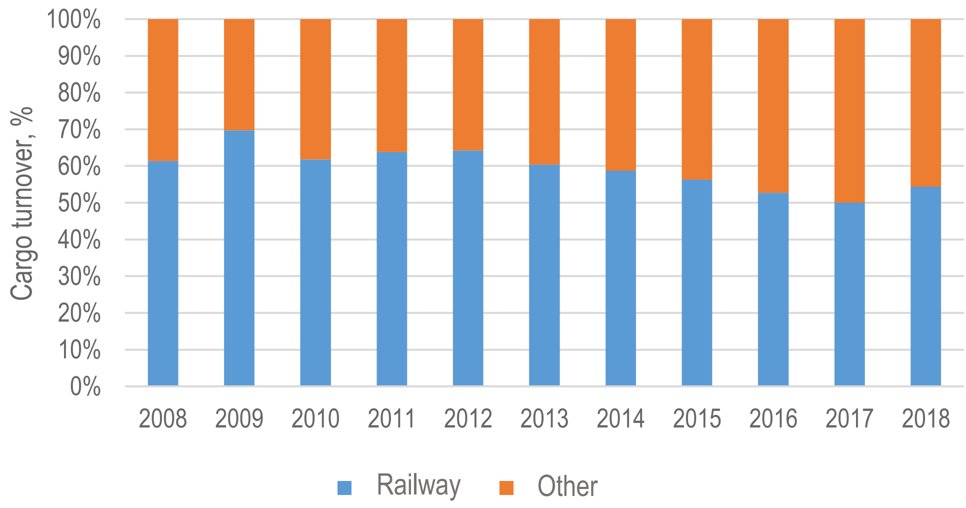


Fig. 3.4.15. Cargo turnover in the main modes of transport.

Historical data on Latvian transport-kilometre rate for freight vehicles can be seen in Figure 3.4.16. Compared to 2009, the transport-kilometre indicator in 2018 almost doubled from 685 million transport kilometres to 1 238 million transport-kilometers (Eurostat, n.d.).

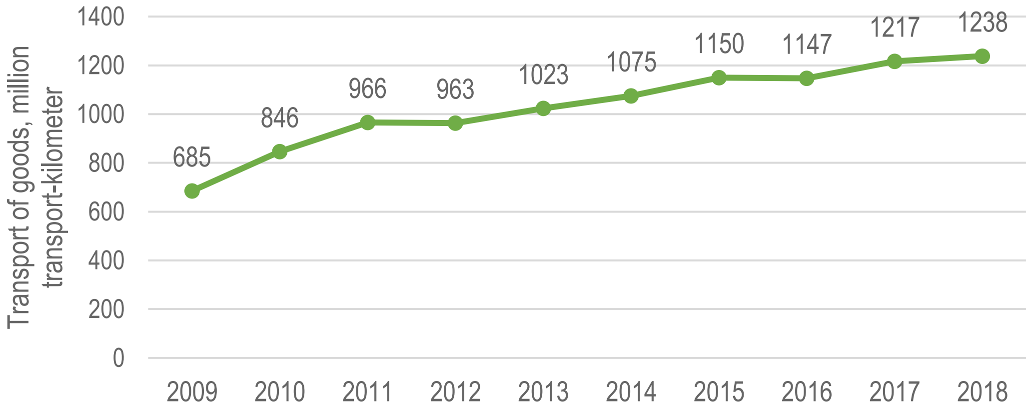


Fig. 3.4.16. Annual transport of goods by road vehicles in Latvia (Eurostat, n.d.).

In order to determine the degree of regular bus filling, passenger turnover (million pkm) was divided by passenger transport (million people). The data obtained are shown in Figure 3.4.17. Pictured is that the degree of transport filling is declining from 2011 to 2016, but has been stabilising in recent years (Centrālā Statistikas pārvalde, n.d.-c, n.d.-d).

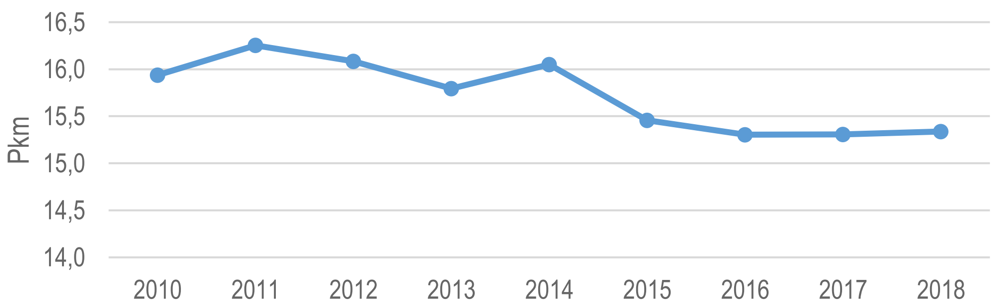


Fig. 3.4.17. Degree of regular bus filling (Centrālā Statistikas pārvalde, n.d.-c, n.d.-d).

In order to determine the degree of filling of freight transport, cargo transportation was divided by traffic flow (tonne-kilometres divided by transport kilometres). The data obtained are included in Figure 3.4.18. It shows that the rate had increased between 2010 and 2015, but there was a decrease in 2016 and 2017 (Centrālā statistikas pārvalde, n.d.; Eurostat, n.d.).

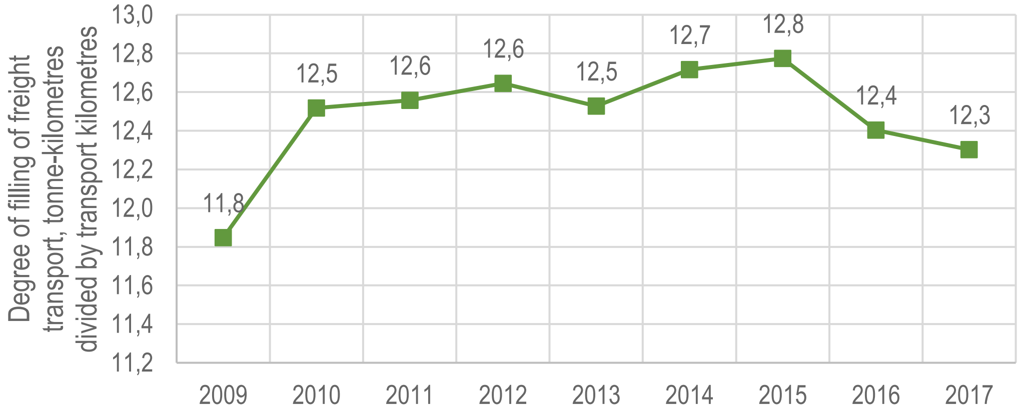


Fig. 3.4.18. Degree of freight transport filling (Centrālā statistikas pārvalde, n.d.; Eurostat, n.d.).

The average occupancy of passenger cars in 2017 is shown in Figure 3.4.19. It can be judged that the load per 1 vehicle in Latvia on average amounts to 1.9 people per vehicle in short journeys (<300 km) and 1.6 persons per vehicle during short trips in cities and oscillating-migration zones (<100 km). It should also be noted that occupancy on holidays and public holidays is higher than on weekdays (Centrālā Statistikas pārvalde, n.d.-a).

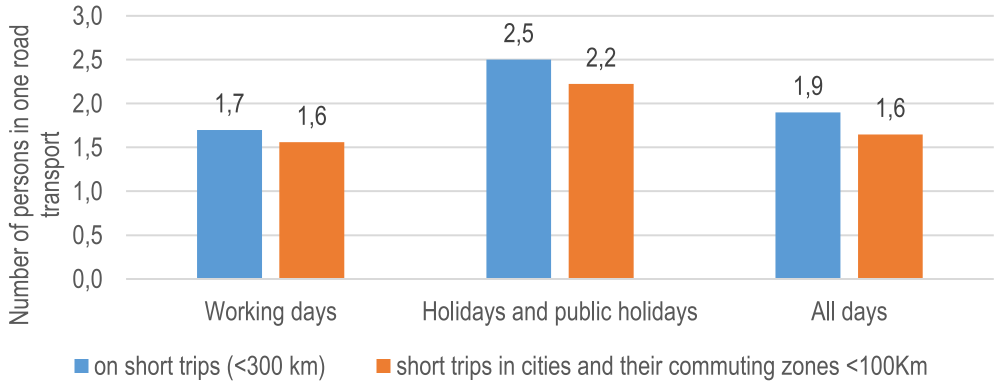


Fig. 3.4.19. Average passenger car occupancy (Centrālā Statistikas pārvalde, n.d.-a).

3.4.3. Assessment of the transport infrastructure

Currently, more than 680 petrol stations (gas stations) operate in Latvia (Degvielas Uzpildes Stacijas, Visā Latvijā</i>, n.d.). **Petrol and diesel** fuel filling stations are freely available throughout the territory of Latvia. They are located in all major cities of Latvia, but the highest density of gas stations is around Riga district, which is related to the large number of fuel consumers. The largest fuel retail company in Latvia with more than 80 petrol stations is "Circle K" (Circle K, n.d.). Other large fuel retail companies are "Viada" with 75 filling stations, "Neste" with 74 filling stations, "Virši" with 58 filling stations and "Latvijas nafta" with more than 40 filling stations(Latvijas Nafta, n.d.; Neste, n.d.-a; Viada, n.d.; Virši, n.d.). To create and develop a new fuelling network in Latvia in cooperation with private investors and the alternative investment fund «ZGI-3», in October 2016 «KOOL Latvija» was founded, the first filling station of which was opened in September 2017. Currently, the company already includes 10 gas stations (KOOL Latvija, n.d.).

In order to fulfil the binding obligations adopted within the framework of EU legislation, Latvia has committed to ensure that the share of energy produced from RES in transport in 2020 is at least 10% of the final energy consumption in the transport sector (Council of Europe, 2014). To achieve these targets, Latvia has introduced a requirement to ensure mandatory 5% biofuel blend for fossil fuels (Par Konceptuālo Ziņojumu "Par Atjaunojamo Energoresursu Izmantošanu Transporta Sektorā". Ministru Kabineta Rīkojums Nr. 379, 2017).

In Latvia it is also possible to purchase diesel fuel, which is produced from 100% renewable resources. For example, *Neste MY renewable diesel*™ characteristics are equivalent to fossil diesel. *Neste MY* is suitable for all diesel engines without their adaptation. *Neste MY* is available at Neste gas station in Riga, Ulmana g. 84, and its price is higher than for fossil diesel – 1.89 EUR/l (Neste, n.d.-b).

In 248 Latvian filling stations it is possible to fill the vehicle with liquefied propane gas (LPG). (List of LPG stations in Latvia [Tiešsaistē]. Pieejams: https://www.mylpg.eu/stations/latvia/list/ Skatīts: [13.11.2019]) The largest fuel retail companies in Latvia offering LPG as fuel are "Viada" with 64 filling stations, "Latvijas propāna gāze" with 45 filling stations, "Circle K" with 43 filling stations and "Virši" with 28 filling stations (myLPG, n.d.-a). The location of LPG gas stations in Latvia can be seen in Figure 3.4.20 (myLPG, n.d.-b).

Fig. 3.4.20. Location of liquefied propane gas retail trade enterprises in Latvia (myLPG, n.d.-b).

The national network of **electric vehicle charging stations** "E-mobi" has been established in Latvia, which is maintained by the Road Traffic Safety Directorate (CSDD). Currently, there are 72 stations operating on the E-mobi network, which ensures free movement of electric cars throughout the territory of Latvia (see Figure 3.4.21) (CSDD, n.d.-a). The network of charging stations for Latvian electric cars is also complemented by charging points installed by some companies, institutions and organisations (DELFI, n.d.; LSM, n.d.). There are 123 charging stations in Latvia, of which 112 are fast charging stations (Uzlādēts, n.d.).

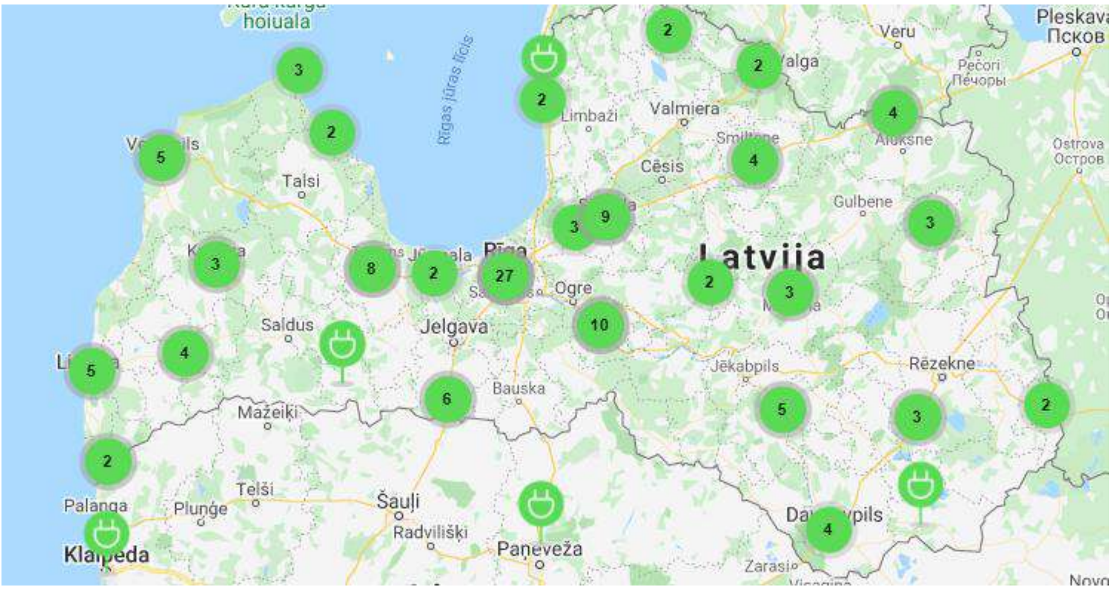


Fig. 3.4.21. *"E-mobi"* charging network station map (CSDD, n.d.-a).

According to statistics, between July 2018 and September 2019, the average monthly number of charges was 1965, while the average electricity spent on all charges was 26.6 MWh per month. On average, 13.5 kWh per charge was used to charge one electric car (CSDD, n.d.-b).

The largest state public-use railway infrastructure in Latvia has been established in accordance with the 1520 mm track standard, the total service life of which is 1827 kilometres. As of October 2019, 257 km of tracks were electrified in the territory of Latvia, which accounts for 14 % of the total national railway network and is significantly below the EU average (60 %) (VAS "Latvijas dzelzceļš," n.d.).

3.5. Technical and economic parameters of RES and fossil technologies

The technology-specific parameters relating to investment costs, fixed and variable operating and maintenance costs, as well as service life and equipment efficiency are taken from Danish technology catalogues (Table 3.5.1 and Table 3.5.2). Not only current values have been taken from the catalogues, but also forecasts for 2030.

TABLE 3.5.1. MAIN PARAMETERS OF PRODUCTION TECHNOLOGIES (1) (DANISH ENERGY AGENCY, N.D.).

	Investment costs, EUR/MW$_e$		**Fixed O&M, EUR/MW$_e$/year**	
	2017	**2030**	**2017**	**2030**
Electricity production				
Large natural gas CHP	1300000	1200000	30000	27800
Small natural gas CHP	1300000	1200000	20000	18600
Large biomass CHP	3700000	3500000	158400	144000
Small biomass CHP	6700000	6200000	292700	280500
Biogas CHP	6700000	6000000	96500	87400
On-shore wind	1070000	910000	25600	22300
Off-shore wind	2460000	1640000	57300	37800
Large PV stations	1460000	690000	12800	8800
Medium-sized PV stations	1340000	630000	13420	9240
Household PV	1580000	870000	15750	10815
Thermal energy production				
Large-scale natural gas boilers	60000	50000	2000	1900
Large biomass boilers	700000	650000	32800	31200
Large-scale natural gas boilers	112500	104375	2800	2650
Medium biomass boilers	337500	312500	7220	6980
Household natural gas boilers	320000	300000	20900	19900
Household biomass stoves	584000	541700	43000	40500
Medium-sized oil boilers	175000	162500	3520	3225
Household oil boilers	400000	373000	16000	15700
Large-scale heat pumps	700000	590000	2000	2000
Medium heat pumps	662500	560000	2500	2115
Household heat pumps	1600000	1400000	29100	25500
Large-scale solar collector stations	615000	530000	2780	3130
Medium-sized solar collector stations	580000	478570	2780	3130
Household solar collector stations	643000	500000	16430	16430

TABLE 3.5.2.MAIN PARAMETERS OF PRODUCTION TECHNOLOGIES (2) (DANISH ENERGY AGENCY, N.D.).

	Variable O&M, EUR/MWhe		Service life, years	Efficiency, %	
	2017	2030		Electric	Heat
Electricity production					
Large natural gas CHP	4.5	4.2	25	48	
Small natural gas CHP	5.5	5.1	25	35	
Large biomass CHP	3.8	3.8	25	28	
Small biomass CHP	7.8	7.7	25	14	
Biogas CHP	5.8	5.8	25	22	
Onshore wind	2.8	2.3	25	37	
Offshore wind	4.3	2.7	25	50	
Large-scale PV stations	0.0	0.0	30	17	
Medium-sized PV stations	0.0	0.0	30	17	
Household PV	0.0	0.0	30	17	
Thermal energy production					
Large-scale natural gas boilers	1.1	1.0	25		103
Large biomass boilers	1.0	1.0	25		115
Large-scale natural gas boilers	0.0	0.0	25		101
Medium biomass boilers	0.0	0.0	20		80
Household natural gas boilers	0.0	0.0	20		97
Household biomass stoves	0.0	0.0	20		80
Medium-sized oil boilers	25.0	21.0	20		88
Household oil boilers	0.0	0.0	20		92
Large-scale heat pumps	3.3	3.7	25		350
Medium heat pumps	0.5	0.4	20		400
Household heat pumps	0.0	0.0	20		360
Large-scale solar collector stations	5.0	0.0	25		43
Medium-sized solar collector stations	0.0	0.0	25		43
Household solar collector stations	0.0	0.0	25		43

3.6. Spatial input data of the RES potential

In order to characterize the spatial potential of wind energy in Latvia, data on average wind speed in statistical regions and municipalities have been compiled. The data comes from the Global Wind Atlas tool developed by the Technical University of Denmark and the World Bank Group (Technical University of Denmark, n.d.), using wind climate data for the period 2008-2017. Taking into account the current heights of wind turbines, this study uses data on wind speeds at an altitude of 100 m.

In Figure 3.6.1 it can be observed that the highest average wind speed is characteristic in Kurzeme region (7.2 m/s), slightly lower speed is characteristic in Zemgale and Latgale regions (7.1 m/s), while the lowest average wind speed is characteristic in Vidzeme region and Riga (6.9 m/s). In Vidzeme region the highest wind speed is in Rauna municipality (7.8 m/s).

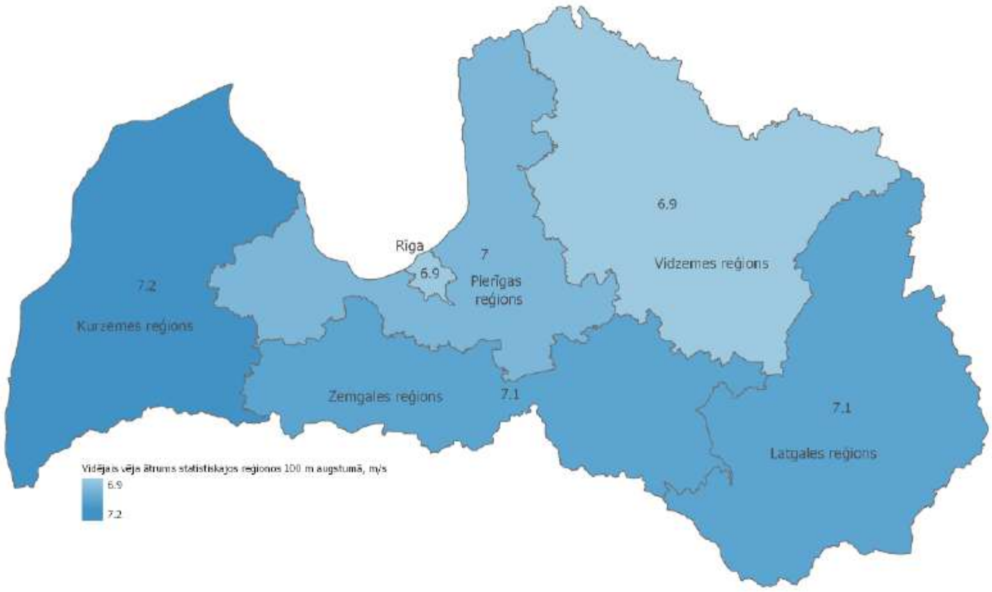


Fig. 3.6.1. Wind speed map for planning regions.

Data of the European Commission (2019) were used to discuss differences in solar irradiation in statistical regions and municipalities of Latvia. Annual data on irradiation in the plane at the angle of 35° drop have been used to express solar energy resources. Figure 3.6.2 shows that the highest intensity of solar irradiation is in Kurzeme region (1180 kWh/m^2/year), while the smallest - in Vidzeme region (1121 kWh/m^2/year).

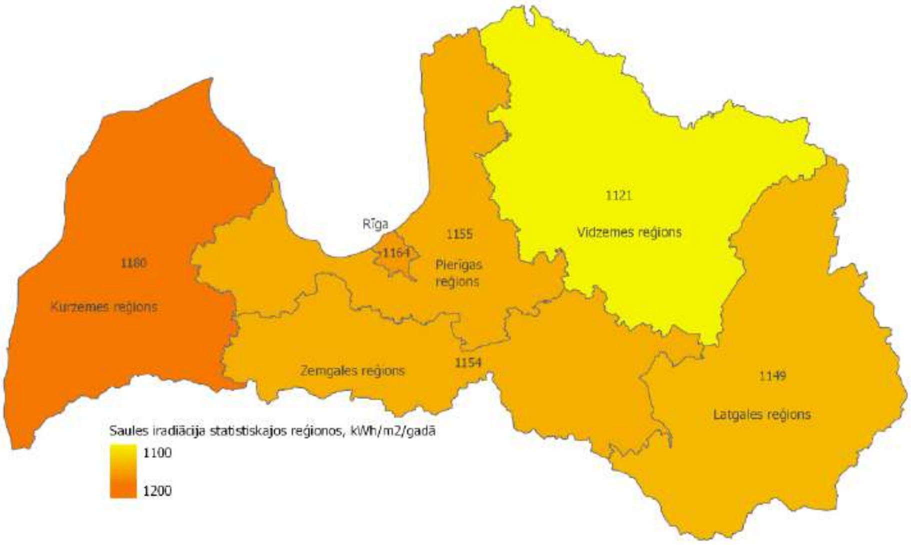


Fig. 3.6.2. Solar radiation map for planning regions.

In view of the growing demand for wood resources, as well as the principles of bioeconomy, according to which quality wood should primarily be used for the production of products with high added value, poor quality wood is considered to be a resource to be used for energy purposes in this study. The study assumes that new wood technologies, which will be installed in the event of economic benefit, will use only poor quality wood.

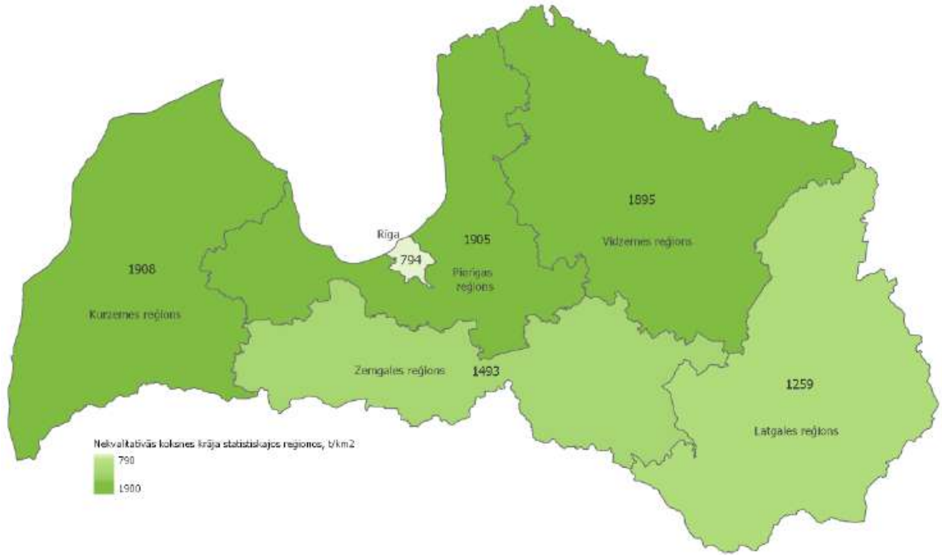


Fig. 3.6.3. Availability of poor quality wood for planning regions

Data on the amount of stock in municipalities are obtained from forest statistics of the State Forest Service for the period from 2014 to 2019 (State Forest Service, 2019). According to the literature, it is assumed that poor quality wood (branches, bark and foliage) accounts for approximately 40 % of the total stock (Townsend, 2008).

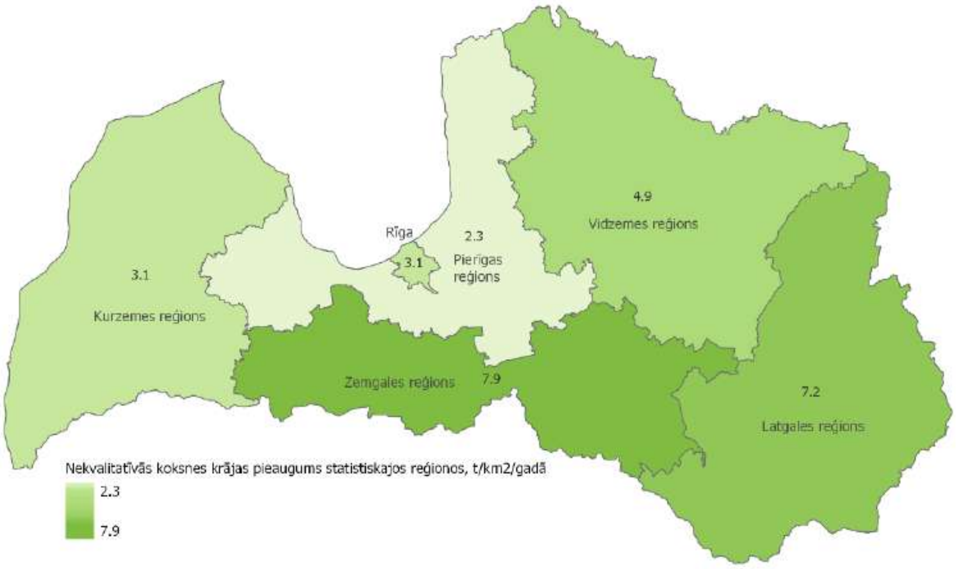


Fig. 3.6.4. The rate of growth of poor quality wood for planning regions.

Figure 3.6.3 shows the total stock of poor quality wood, while Figure 3.6.4 shows the annual increase in the low-quality wood stock.

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