Energy and Climate Modelling and Energy System Integration in Latvia

DLV 2: Scope, structure, and functionality of TIMES Latvia model

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Abbreviations

CCUS - carbon capture and utilisation or storage
CGE - Computable General Equilibrium
CHP – cogeneration plant
DH - district heating
ENTSO-E - European Network of Transmission System Operators
ETS – emission trading system
EU – European Union
GDP – gross domestic product
GHG- Greenhouse Gases
IESE RTU – Institute of Energy Systems and Environment, Riga Technical University
IPCC - Intergovernmental Panel on Climate Change
LASAM - Latvian Agricultural Sector Analysis Model
LPG – Liquid petroleum gas
LULUCF - Land Use, Land-Use Change and Forestry
NECP - National Energy and Climate Plan
RES – renewable energy sources
TSO - transmission system operators

1 Introduction

To achieve ambitious climate objectives, further decarbonising the energy system is critical as the production and use of energy across economic sectors accounts for more than 75% of the EU's greenhouse gas emissions. In this context, Latvia aims to develop a strategy and action plan for energy infrastructure as part of its National Energy and Climate Plan (NECP), including a longer-term view to 2050. As an input to this strategy, an analysis of possible infrastructure development pathways for energy system integration in Latvia is needed. The pathways should facilitate the integration of various energy carriers and help understand the impact of choices between the development of new infrastructure or the re-purposing of existing ones, considering existing natural gas networks, central heating installations and networks, the increased energy efficiency of buildings, as well as regional infrastructure and market development trends. There is a need to look broadly at the energy infrastructure that is in place and to evaluate possibilities for re-purposing and better linking this existing infrastructure, as well as also considering additional infrastructure needs. This complex task can only be achieved based on an in-depth and integrated analysis at its core. Therefore, energy system modelling tools can serve as a basis for a comprehensive evidence-based decision-making process.

The TIMES Latvia model has been developed with the aim to analyse future pathways of the energy sector of Latvia. The model is based on the current situation in Latvia, which has required adaptation of the starter model structure, considering examples of best modelling practices. Institute of Energy Systems and Environment located in Riga Technical University (IESE RTU) has been working with the TIMES model since 2018 and has been improving the tool continuously, for example, by introducing soft-linkages between different models in order to increase the adequacy and accuracy of the Latvian multi-modelling system.

Within the project, several further development steps have been done within the TIMES model to improve the Latvian long-term energy and climate planning, including:

- Improved data availability and data assessment through communication with stakeholders for a smoother description of the real processes and sub-processes.
- Further development of the basic TIMES structure, covering all sectors and related sub-sectors of the Latvian economy, including energy transformation processes.
- An update and clarification of assumptions (future projections, instead of forecasts) used in the TIMES model: energy demand, primary resource potential, policy settings, techno-economic parameters, and environmental parameters.
- Actualisation of driver parameters in the TIMES model through soft-linkage with the Computable General Equilibrium (CGE) model and communication with stakeholders, particularly on energy demand and/or resources for all six sectors and sub-sectors, as defined by gross domestic product (GDP) and value-added in different sectors, population, development of sectors and sub-sectors, and availability of technologies and resources.
- The new technology database was updated and expanded. New perspective technologies with relevant economic and technical parameters were introduced.

The actions taken have significantly improved the accuracy of the TIMES model and allow for more appropriate use of the policies and policy instruments included in future development scenarios.

This report describes the scope, boundaries, and TIMES modelling approach, as well as the main structure of the TIMES Latvia model. In addition to this Report, other features of the model have been described in the following deliverables of the project:

- Report "Prospective technology study for all sectors in Latvia (update)" – describes the cost assumptions and technical parameters of existing and future technologies included in the TIMES Latvia model;
- Report "Baseline scenario description" – describes the main assumptions within the Baseline scenario and soft-linkage with the CGE model;
- Data sheet "Compiled input data tables" – describes the main assumptions and input data used within the TIMES Latvia model;
- Data sheet "Results_tables_7.10_RTU_share" – presents the preliminary Baseline scenario results;
- Model files "Times_model_Baseline_version_07102022" – contains all TIMES Latvia model files suitable for the VEDA modelling software.

The model has been developed according to the requirements defined in the request for service, therefore, this Report highlights the model features and additional analyses performed.

The minimum requirements have been considered for optimal boundaries of the developed model covering the time horizon from 2007 to 2050 with a time step of one year until 2030 and 5 years until 2050. The reference energy system covers the entire energy balance as described in **Section 2.1.** Detailed sectoral GHG emission calculations are included within the model as described in **Section 2.1.3.**

The reference system for non-energy sectors has been defined and described in **Section 2.3** including the emission projections in industrial production, agriculture, waste, land use, land-use change and forestry. The links between the energy sector and non-energy sectors have been identified as biogas production and limitations for available biomass resources in the energy sector.

The report describes the potential energy savings and energy efficiency potential in different sectors (see **Section 2.1.2**). The developed TIMES Latvia model allows for setting renewable energy sources (RES) and energy efficiency targets to European Union (EU) requirements which will be further used in scenario modelling as part of DLV4 within the project. Several energy efficiency policies have been already introduced within the TIMES Latvia model as Baseline policy measures (see additional Report on Baseline scenario description).

An additional section (**Section 2.4**) has been included in the Report to reflect planned infrastructure and capacity developments in other Baltic countries, as well as market data analysis on the future impact on the national energy sector of Latvia.

The model includes new infrastructure/technology development pathways in addition to existing and traditional infrastructure/technologies which are described in detail within the **Report on Prospective Technologies.** Among these new infrastructure/technology pathways are energy storage, carbon capture and utilisation or storage (CCUS), biomass gasification, hydrogen, and power-to-heat technologies. The costs and technical performance of the future technologies are described according to available information from several sources.

The TIMES Latvia model developed can be further improved by a more detailed aggregation of energy demand, soft-linkage with additional models or additional tools that could be useful for the understanding of different aspects of the future energy system. An example of the possible future development options of the model could be improved analysis of social behaviour aspects derived from the System dynamics model as described in **Section 2.5.**

The results, relevant model files and analyses will be publicly available on the website of the RTU IESE website www.videszinatne.lv to allow for expert and peer review by using VEDA software.

1.1 Aim and scope of the model

The main aim of the TIMES Latvia model is to assist policymakers in understanding, technically and economically, how Latvia can transform the sectors of its economy, particularly the energy system and its end-use sectors, but also other sectors relevant to climate policy such as agriculture, to deliver decarbonisation and climate neutrality consistent with national development priorities.

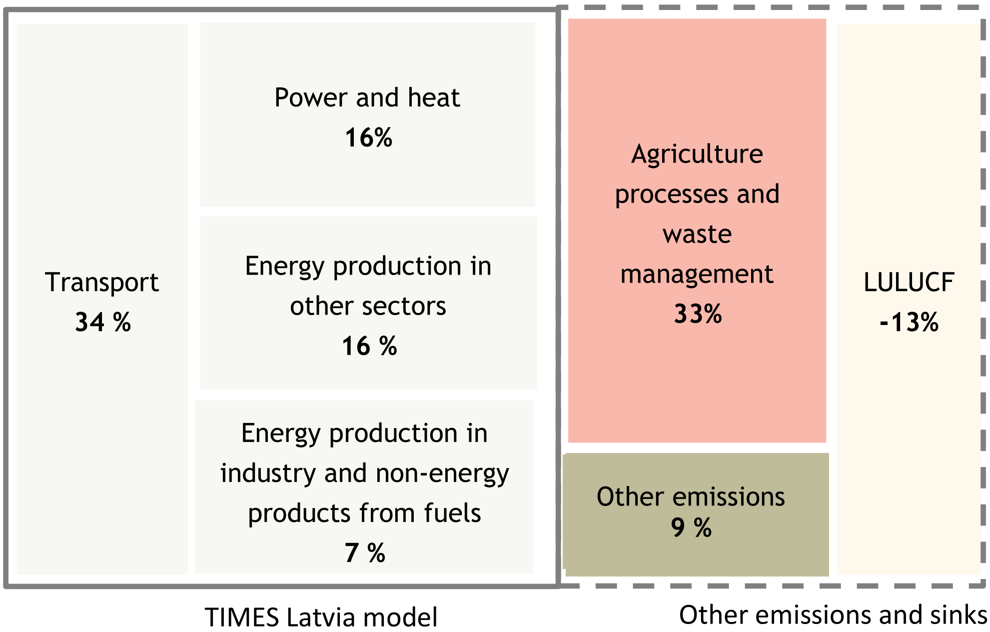
The model is used to identify the least-cost combination of technologies and fuels to meet future energy demand which is given exogenously based on a set of scenario drivers with soft linkage to the economic forecast model (CGE model). Simultaneously it fulfils other technical, environmental and policy constraints (e.g. CO_2 mitigation policy). The model outputs include technology investment and energy commodity use across all sectors, which can be aggregated to report primary energy supply and final energy consumption, seasonal/daily/hourly electricity demand and supply by technology type, carbon dioxide (CO_2) emissions, cost of energy supplies, and the marginal cost of energy and emission commodities, among others.

1.2 Model boundaries

The TIMES Latvia model based on the TIMES modelling framework has been developed and improved as closely and correctly as possible to characterise the energy sector and relevant sub-sectors. In the TIMES Latvia energy system model, the full energy system is depicted from resource supply to end-use energy service demand, such as space heating, production processes, and personal/freight transport (in vehicle- or tonne-kilometre). The model represents a broad suite of energy and emission commodities, technologies, and infrastructure. However, the model does not include detailed analyses and forecasts for non-energy sectors such as agriculture and waste management and land use and Land Use, Land-Use Change and Forestry (LULUCF) sectors. The TIMES model boundaries from the emission calculation perspective based on the national

GHG inventory in the year 2017 are shown in Figure 1-1. The more detailed forecasts from these sectors can be derived from sectoral submodels.

Figure 1-1 Boundaries of TIMES Latvia Answered according the national GHG emission inventory in 2017



The structure of the TIMES Latvia model is based on the energy balance of 2017 but has been calibrated according to the latest available energy balance data up to 2020. The modelling process analyses each end-use sector (residential, commercial, industry, agriculture, and transport) in-depth by identifying sector-specific end-use processes. This allows to improve each sector separately, bring the model closer to real-life, obtain more complete results and more accurately incorporate different policy measures, such as sector-specific funding, taxation or GHG targets.

The TIMES tool is a linear optimisation tool that is not suitable for modelling social factors, such as human behaviour. The model optimises the energy sector according to the input values, such as sector development trends, technology, resource costs, introduced policies etc. The model also does not make it possible to assess the changes in the energy system based on Latvia's economic performance indicators in general. Therefore, to compensate for these shortcomings, a soft linkage with the General Equilibrium model has been introduced. In addition, certain resource availability limitations have been derived from the forestry management model and the agriculture model LASAM, taking advantage of each model.

1.3 TIMES modelling approach and previous application

TIMES (The Integrated MARKAL EFOM System) is the successor to the MARKAL energy system framework, which includes several unique features that make it particularly suitable for Latvia. TIMES is a widely applied, dynamic, technology-rich linear programming energy systems optimisation framework. In its partial equilibrium formulation, TIMES is used with a linear optimization software to determine the energy system configuration with the lowest total discounted system costs (capital, fuel and operating costs for resource, process, infrastructure, conversion, and end-use technologies) over the entire modelling horizon.

The modelling approach has been widely applied to simulate country-specific or multiple-country development pathways. In many countries, researchers have used the Integrated MARKAL-EFOM System (TIMES) model generator to analyse local, national, or global energy systems and the potential to reach climate targets. In most cases, the basic sectoral structure of TIMES needs to be adjusted and modified to represent a country-specific energy system. As part of this work, several TIMES models developed for different countries have been analysed, some of the key characteristics and customisations made in other countries are presented below.

One of the first TIMES energy system models have been created for Denmark (TIMES-DK). The model divides the country into two energy regions – Denmark East and Denmark West and covers five sectors – supply, power, heat, industrial, residential and transport. The year was divided into 32 time slices representing four seasons, weekly and daily variations. That increases the variability of the model regarding heating demand, availability of intermittent renewable energy sources and technologies like solar PV and wind turbines. In addition, the efficiency of large-scale heat pumps is assumed to be dependent on the outdoor temperature. Import and export prices are divided into 32-time slices as well. The model divided the residential sector according to the building type and construction period, district heating (DH) area and regions resulting in 36 building groups. The industry sector in contrast is divided into 12 sectors, covering primary, secondary and tertiary sectors. The transport sector has two large groups – passenger and freight, divided into aviation, maritime and inland waterway transport. Inland passenger transport has been divided into eight modes including cars, buses, railways, motorcycles and non-motorised modes like walking and cycling[1].

TIMES-Nordic is a multi-country model that includes Denmark, Norway and Sweden. The modelling structure of each country's energy system replicates the structure of the TIMES model, which represents the Danish energy system (TIMES-DK). The entire national energy system is divided into five sectors: supply, energy and heat, industry, households and transport. Descriptions of some sectors vary from country to country due to differences in the factors on which the national economy is based. For example, the mining, iron and steel, aluminium, pulp and paper industries are added to Norway and Sweden, complementing the original structure of TIMES-DK[2].

German researchers have developed the TIMES model to improve investment decision-making. In the adapted energy model, the country is divided into four regions, but investors are split into three groups depending on the costs of capital and budget restrictions[3].

British researchers have developed a model framework for the residential sector in UK TIMES to analyse homeowners' preferences for heating technologies. Households were divided into three

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[1] Balyk O.et al. TIMES-DK: Technology-rich multi-sectoral optimisation model of the Danish energy system. Energy Strateg. Rev. 2017: 23:13–22. doi: 10.1016/j.esr.2018.11.003.

[2] Salvucci, R. et al. 2019. The role of modal shift in decarbonising the Scandinavian transport sector: Applying substitution elasticities in TIMES-Nordic. Applied Energy 253, 113593.

[3] Tash A., Ahanchian M., Fahl U. Improved representation of investment decisions in the German energy supply sector: An optimization approach using the TIMES model. Energy Strateg. Rev. 2019: 26: 100421.

groups depending on the number of bedrooms and into four groups depending on the existing heating technologies – gas heaters, electric heaters, heat pumps and solid fuel boilers. In this model, 16-time slices have been used representing four seasons and four-day splits[4].

In France, researchers have developed the integrated MARKAL-EFOM System (TIMES) model using TIMES to evaluate the possibility to achieve negative emissions in the Power energy (power) sector by using bio plants with carbon capture and storage. Their study shows that these technologies could be important to achieving European emission targets[5].

The linear optimisation bottom-up energy system model TIMES has been previously applied to analyse the Portuguese power sector[6]. The authors have analysed different levels of decarbonisation and the impact on power cost levels as the ultimate objective of the model is the satisfaction of the energy services demand at the minimum total system costs. The Portuguese TIMES model included more than 60 end-use demands from industry, residential, services, agriculture and transport. Authors conclude that decarbonisation up to nearly 80% does not significantly impact the power sector unit costs.

Although TIMES is a powerful modelling tool, some articles discuss the need to consider not only technology development but also feedback loops, social behavioural changes and other factors[7]. Some TIMES models have been improved by adding consumer behaviour in the optimization model using social surveys. [8,9]

The linear optimisation TIMES model has been previously used to evaluate some specific modelling tasks, for example, the sensitivity of the European road transport sector considering different variations of investment cost and vehicle efficiency. Previous research has introduced the consumer behaviour aspect into the TIMES optimisation model[10]. The classic consumer choice model is incorporated into a typical long-term energy modelling framework as a case study of purchasing light-duty vehicles. Thirty-six consumer segments were created to represent different factors, such as driving distances and acceptance of new technologies into the TIMES-Nordic model. Results showed that rail and non-motorised transport modes, e.g., walking and cycling, increase passenger mobility while rail replaces trucks and ships for freight. Also, other papers represent the importance of the modal shift to reach carbon neutrality in the transport

[4] Li P. H., Keppo I., Strachan N. Incorporating homeowners' preferences of heating technologies in the UK TIMES model. Energy 2018:148: 716–727.

[5] S. Selosse and O. Ricci, "Achieving negative emissions with BECCS (bioenergy with carbon capture and storage) in the power sector: New insights from the TIAM-FR (TIMES Integrated Assessment Model France) model," Energy, vol. 76, pp. 967–975, 2014

[6] P. Fortes, S. G. Simoes, J. P. Gouveia, and J. Seixas, "Electricity, the silver bullet for the deep decarbonisation of the energy system? Cost-effectiveness analysis for Portugal," Appl. Energy, vol. 237, pp. 292–303, 2019

[7] Bolwig S. et al. Review of modelling energy transitions pathways with application to energy system flexibility. Renew. Sustain. Energy Rev. 2018: 101: 440–452, 2019.

[8] Reveiu A., Smeureanu I., Dardala M., Kanala R. Modelling domestic lighting energy consumption in Romania by integrating consumers behavior. Procedia Comput. Sci., 2015:52: 812–818.

[9] Cayla J. M., Maïzi N. Integrating household behavior and heterogeneity into the TIMES-Households model. Appl. Energy 2015: 139: 56–67.

[10] K. Ramea, D. S. Bunch, C. Yang, S. Yeh, and J. M. Ogden, "Integration of behavioural effects from vehicle choice models into long-term energy systems optimization models," Energy Econ., vol. 74, pp. 663–676, 2018

sector[11]. The modal shift within the updated TIMES model for Denmark only applies to domestic passenger services, as ships and aircraft do not compete with domestic modes of transport in national transport due to the small size of Denmark. Modes of transport consume not only fuel but also the necessary infrastructure and time to meet the demand for travel.

When developing the structure of the TIMES Latvia model, experience from previous applications in other countries have been considered. The general structure and distribution of end-use sectors and processes is similar to the models described above. For example, authors have included eight inland transport modes, including non-motorised modes such as walking and cycling, similarly to the TIMES DK model, together with travel time and various distances to model the possible modal shift in the transport sector. The previous experience is also used for the implementation of prospective technologies - for example: carbon capture and storage and hydrogen production. On the other hand, some subsectors have not been developed to the same level of detail as in some other country models due to a lack of available data (e.g. building division in the residential sector as presented in the UK TIMES model or TIMES DK model). These modelling features can be improved in future development phases.

1.4 Comparison of TIMES and MARKAL models

The previous energy and climate modelling tool MARKAL-Latvia model used for modelling targets and objectives of the NECP was based on the MARKAL (MARKet ALocation) modelling framework and has been adapted to Latvia's circumstances since 1995. However, due to increased analytical and planning requirements, Latvia has decided to change its current modelling system to a new TIMES model which was one of the main aims of this particular project. It was decided in January 2022 (shortly after the start of the Deliverable 2 work) to develop the new TIMES Latvia model without direct adaptation of the existing MARKAL–Latvia model. However, this section briefly summarises the main differences and similarities of both modelling tools based on the information provided by the program developers[12].

The TIMES and MARKAL models are technology-explicit, dynamic partial equilibrium models of energy markets and share the same basic modelling paradigm. TIMES is the successor to MARKAL and comes with new robust features and continued support.

In both cases, equilibrium is obtained by maximizing the total surplus of consumers and suppliers via Linear Programming. The two models also share a multi-regional feature, which allows the modeller to construct geographically-integrated (even global) cases. However, there are also significant differences between the two models.

First of all, MARKAL has fixed length time periods, but TIMES allows the user to define period lengths in a completely flexible way. This is a major model difference, which required a complete re-definition of the mathematics of most TIMES constraints and of the TIMES objective function. The variable period length feature is very useful in two instances: first, if the user

[11] J. Tattini, M. Gargiulo, and K. Karlsson, "Reaching carbon neutral transport sector in Denmark – Evidence from the incorporation of modal shift into the TIMES energy system modeling framework," Energy Policy, vol. 113, no. November 2017, pp. 571–583, 2018, doi: 10.1016/j.enpol.2017.11.013.

[12] Loulou R., Remne U., Kanudia A., Lehtila A., Goldstein G. Documentation for the TIMES Model. PART I. 2005. Available online: https://iea-etsap.org/docs/TIMESDoc-Intro.pdf

wishes to use a single year as the initial period (handy for calibration purposes); second, when the user contemplates long horizons, where the first few periods may be described in some detail by relatively short periods (e.g. 1 year), while the longer-term may be regrouped into a few periods with long durations (e.g. 5 or more years).

Another benefit associated with the TIMES model is the more flexible use of time slices. In MARKAL, only electricity and low-temperature heat were divided into rigidly defined time slices. In TIMES, any commodity and process may have its own, user-chosen time-slices. These flexible time-slices are separated into three groups: seasonal (or monthly), weekly (weekday vs weekend), and daily (day/night), and any time slice may be expanded.

Other differences are related to a more flexible process definition, the possibility to model the construction phase and dismantling of facilities, improved vintaging of processes, more commodity-related variables, and a more accurate and realistic depiction of investment cost payments, in the TIMES model compared to MARKAL.

2 Structure of the TIMES Latvia model

2.1 Reference energy system

The reference energy system describes the structure and energy flows of the energy system of Latvia covering primary energy resources, conversion technologies (e.g. electricity and heat production technologies) transmission and distribution infrastructure (e.g. electricity grid, heating networks or gas pipeline), end-use technologies (e.g. boilers, heat pumps, cars) and energy service demands. Figure 2-1 presents a simplified version of the reference energy system for Latvia.

The TIMES Latvia model consists of two main parts - the supply block and the demand block. The supply block consists of primary energy resources and secondary energy e.g. heat and electricity. Primary energy resources in the model comprise domestic renewables and imported fuels, which are used as inputs to conversion and process technologies. The supply block or used energy resources are influenced by various factors - prices, availability, restrictions, and policy measures. The energy from the supply block is transferred to the demand block.

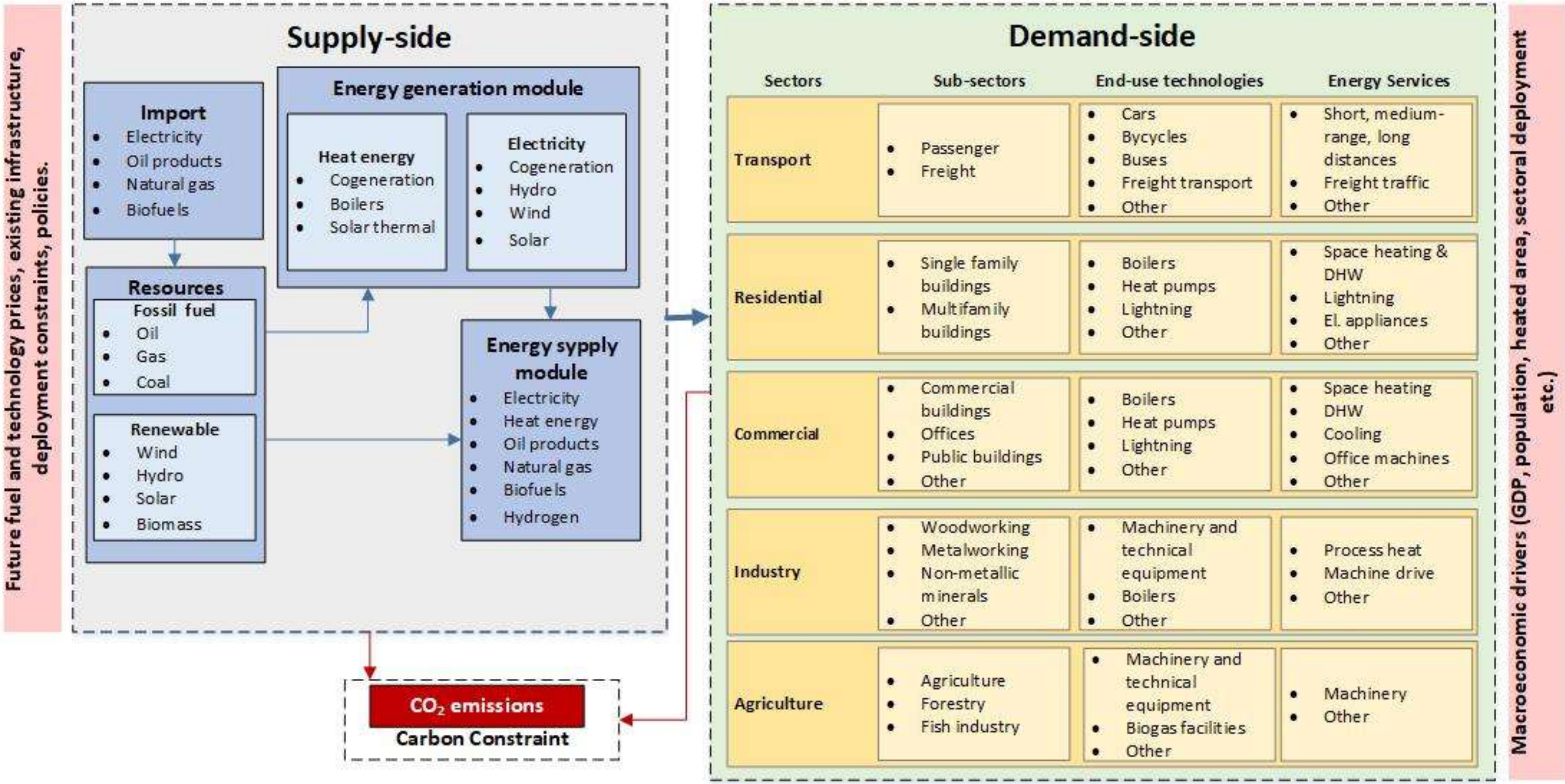
The demand block consists of the final consumption sectors. Energy commodity outputs from the conversion and process technologies are distributed to five end-use sectors and subsectors (residential, commercial, industry, transport and agriculture). Each of the final consumption sectors consists of sub-sectors, which are described in more detail over the next sections.

In the end-use sectors, energy commodities are converted to energy services by end-use technologies. Carbon dioxide (CO_2) emissions from fossil fuels are tracked at the resource-supply and sectoral consumption levels. Primary energy resources are consumed directly in the consumption sectors or in the energy sector, producing secondary energy - heat and electricity. Demand in the consumption sectors is influenced by various factors, such as population, GDP, heating area.

The task of the model is to provide energy services for certain types of energy demand. In the transport sector, these are freight transport and the demand to travel different distances; in households, these are e.g. heating and hot water. All energy services are provided by different technologies with different technical and economic parameters and also depend on the sector. In the transport sector, they will be represented by different types of cars, buses, and trucks, but in the household sector, they will be represented by different types of boilers, or by heat pumps. Key forecasts and assumptions in the TIMES model are presented in the compiled input data file and report “Prospective technology study for all sectors in Latvia”.

The model seeks to optimize an energy system that provides energy services at the lowest possible total cost. The optimization tool considers all eligible costs - investment, fuel costs, operating costs, and taxes. One of the most important input parameters is technical parameters and the associated costs which were provided in the previous deliverable of the project “Prospective technology study for all sectors in Latvia”.

Figure 2-1 Reference energy system in the TIMES Latvia model



2.1.1 *Time Slice structure*

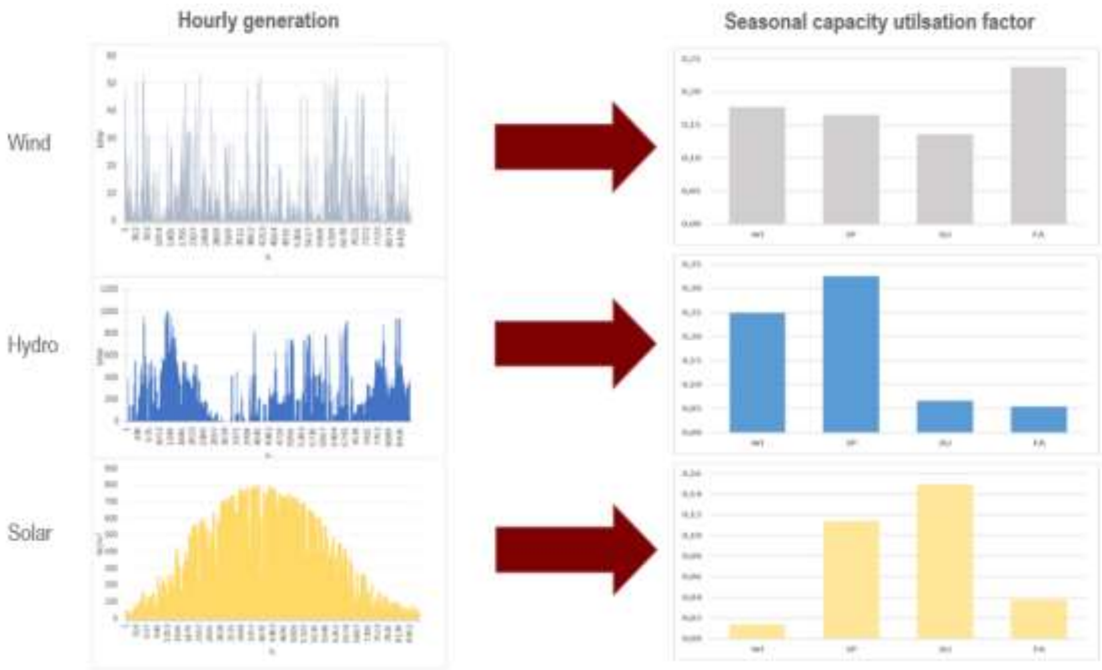
The TIMES model aims to ensure that all the lowest-cost energy demand in the economy is met, given that both energy generation and energy demand change over time. It is therefore essential to note that the availability of energy resources and the cost of energy generation are variable over the year. The demand of the economy for energy resources and energy (e.g., electricity, district heating, natural gas) also changes during the year and during the day.

For the model to balance energy generation and energy demand, optimisation of the energy supply system takes place by splitting the modelling into 12 time slices (4 seasons x 3 hours) divided in:

- **Seasons:** winter, spring, summer, autumn;
- **Hour:** day, night, peak hours

Energy demand is divided into seasons and hours of the day. On the other hand, energy generation must be constant and intermittent to ensure this fluctuating demand. Power and heat generation is divided into the 12 time slices described above. In the case of non-renewable energy sources (e.g. wind, sun, and hydropower), it is not always possible to use all or most of the installed capacity. As can be seen in Figure 2-2, hourly energy generation for intermittent RES is highly variable, therefore, a seasonal capacity utilisation factor has been introduced.

Figure 2-2 Example of the seasonal capacity factor for intermittent RES



To overcome fluctuating demand for energy and amount of electricity produced from RES (e.g. from solar and wind), the model considers electricity storage technologies, based on data provided by the Danish Energy Agency[13]:

- Lithium-ion NMC battery (Utility-scale, Samsung SDI E3-R135);
- Vanadium Redox Battery;
- NaS battery;

[13] Datasheet for energy storage - version – October 2018 – Updated January 2020 https://ens.dk/en/our-services/projections-and-models/technology-data/technology-data-energy-storage

- $Na\text{-}NiCl_2$ battery.

2.1.2 *Energy savings and energy efficiency in the model*

Final energy demand reduction in the TIMES Latvia model is achieved through a wide range of actions. The efficiency first principle is key to minimise the challenges of decarbonising the energy supply and several energy efficiency measures are included as possible choices within the TIMES model.

Conversion from less efficient to more efficient heating options is integrated through a technology -ich database implemented in the TIMES Latvia model. For example, more advanced biomass combustion technologies with integrated flue gas condensers allows higher efficiency for heat production. Similarly, energy efficiency improvements through district heating network renovation is allowed within the model to reduce heat losses.

A significant role in future energy sector development is associated with the deep renovation of the building stock in Latvia. One possible energy-efficiency measure is increased thermal insulation of buildings which reduces demand for heat and can be applied to the residential, commercial, and public sectors.

Energy efficiency product standards (e.g. Ecodesign, Energy Labelling) that deliver energy efficiency gains for end-user appliances are also included in the TIMES Latvia model through improved technologies in the residential, commercial, and industrial sectors.

Within the transport sector, the TIMES Latvia model allows a switch from low-efficiency transport options to more efficient modes of transport. In addition, behavioural changes where consumers actively reduce demand by utilizing more public transport are included.

2.1.3 *GHG emission calculations*

The GHG emissions within the TIMES Latvia model have been calculated according to the Intergovernmental Panel on Climate Change (IPCC) guidelines for the energy sector[14]. The TIMES Latvia model includes all GHG emissions arising from stationary and mobile combustion.

Emissions from the non-energy uses of fuels are generally not included in the model. In general, emissions of each greenhouse gas from stationary sources are calculated by multiplying fuel consumption by the corresponding emission factor. Emissions depend also on factors such as combustion technology, operating conditions, control technology, quality of maintenance, age of the equipment used to burn the fuel. Within the IPCC guidelines, this is taken into account by splitting the fuel combustion statistics over the different possibilities, each with a specific emission factor. Therefore, GHG emission factors applied are different in each sector in the TIMES Latvia model. This is summarized in Appendix 1. Three types of GHG emissions from mobile and stationary combustion sources have been included within the model: CO_2, CH_4 and N_2O with various global warming potentials.

To properly identify the effects of climate policies, production plants and power generation installations are differentiated into those that are subject to the Emission Trading System (ETS) and those that are not. This allows to distinguish production and electricity generation processes included in the ETS scheme

[14] I2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Available online: https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/2_Volume2/19R_V2_2_Ch02_Stationary_Combustion.pdf

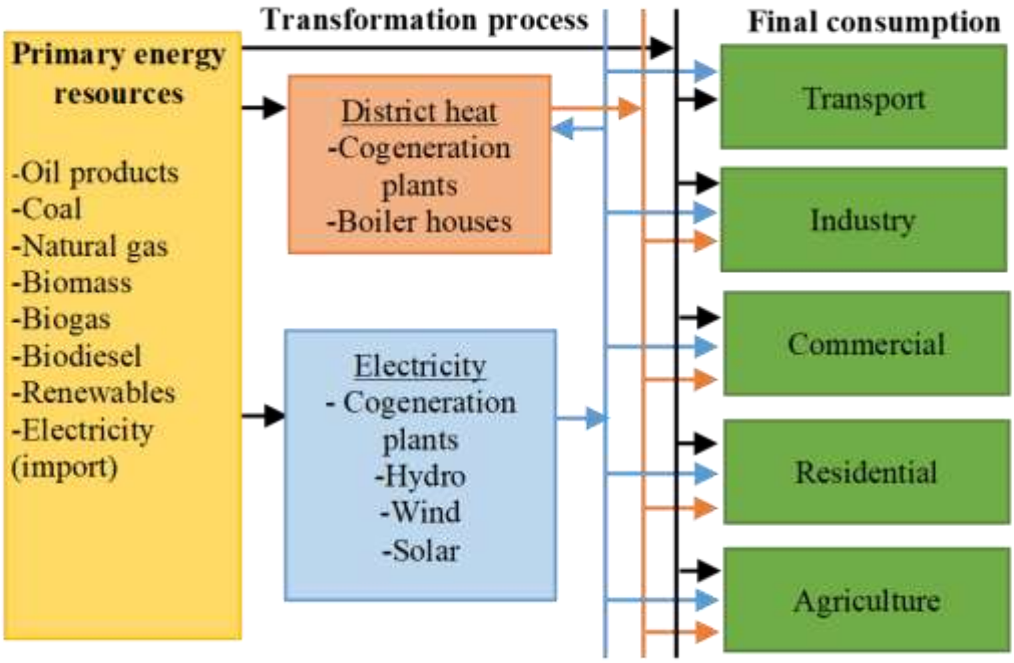
from the ones not included. This way, EU climate policy translated into ETS CO_2 prices can be incorporated into the model and the CO_2 emissions resulting from this can be properly accounted for and reported.

2.2 Sectoral structure of the model

2.2.1 *Energy transformation sector*

The energy transformation sector (or power sector) includes centralised electricity and heat production and its distribution through the related infrastructure (power grid and heating networks) (see Fig.2-3). To better model trends in the DH sector, it is divided into two sub-sectors – Riga and the rest of Latvia. An additional breakdown relates to the participation (or non-participation) of energy producers in the ETS, as this implies different CO_2 costs and taxation. Therefore, "ETS" and "non-ETS" sub-sectors are introduced.

Figure 2-3 Structure of the energy transformation sector in the TIMES Latvia model



For the distribution of the consumption of primary energy resources and the amount of heat produced, the available reports on fuel consumption[15] and the publicly available annual reports of the largest energy producers [16,17] have been used. Data on the installed capacity of boiler houses, hydroelectric plants, wind plants and cogeneration plants are taken from the Central Statistical Bureau of Latvia and from issued GHG permits[18]. The distribution of the installed capacities for heat and power production is shown in Table 2-1.

[15] "Valsts statistisko pārskatu 2-Gaiss datu bāze." https://www.meteo.lv/lapas/vide/parskatu-ievadisana/parskatu-ievadisana?id=1039&nid=376

[16] AS Rīgas Siltums, "Gada pārskats 2017," 2017

[17] AS Latvenergo, "Latvenergo koncerna konsolidētais un AS Latvenergo 2017. gada pārskats."

[18] Valsts vides dienests, "SEG atļaujas." http://www.vvd.gov.lv/izsniegtas-atlaujas-un-licences/seg-atlaujas/?company_name=Olaines&org_id=&perm_date_from=&perm_date_to=&s=1

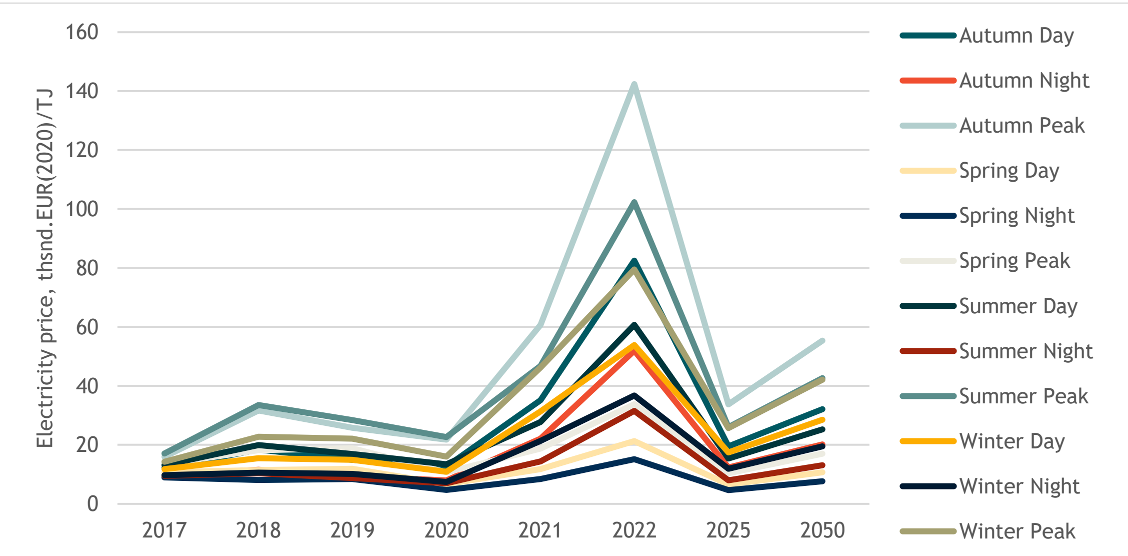
Table 2-1 Existing heat and power capacities by energy source and location in power sector modelling

Plant type	Fuel type	Location	Installed power capacity, MW	Installed heat capacity, MW
Hydro power plant	RES	Not divided	1564	n/a
Onshore wind power plants	RES	Not divided	77	n/a
Solar PV plants (small scale)	RES	Not divided	2	n/a
CHP plants	Biomass	Riga	8	160
		Latvia	82	501
	Natural gas	Riga	1050	2243
		Latvia	93	449
	Biogas	Riga	1	2
		Latvia	59	64
Heat only boilers	Biomass	Riga	n/a	41
		Latvia	n/a	1254
	Natural gas	Riga	n/a	291
		Latvia	n/a	638

Although the amount of electricity produced by solar energy is not reported in the energy balance of Latvia in 2017, solar power plants are used by both the residential and commercial sectors, and exist in the industrial sector mainly for self-consumption. Consequently, in the TIMES model, the authors included a certain proportion of electricity produced by solar panels in the power sector. The total amount of solar electricity produced in different sectors was estimated to be around 5.65 TJ in 2017.

In addition, limits on annual quantities of imported and exported electricity are also taken into consideration, reflecting the available installed capacities for international power trading. The maximum possible value of electricity imports and exports is 20 TJ which is input to the model as upper constraints to the electricity flow. In addition, the electricity price is divided among the time slices (see Fig.2.4) described in Section 2.1.1.

Figure 2-4 Electricity import price distribution among time slices based on historical trends



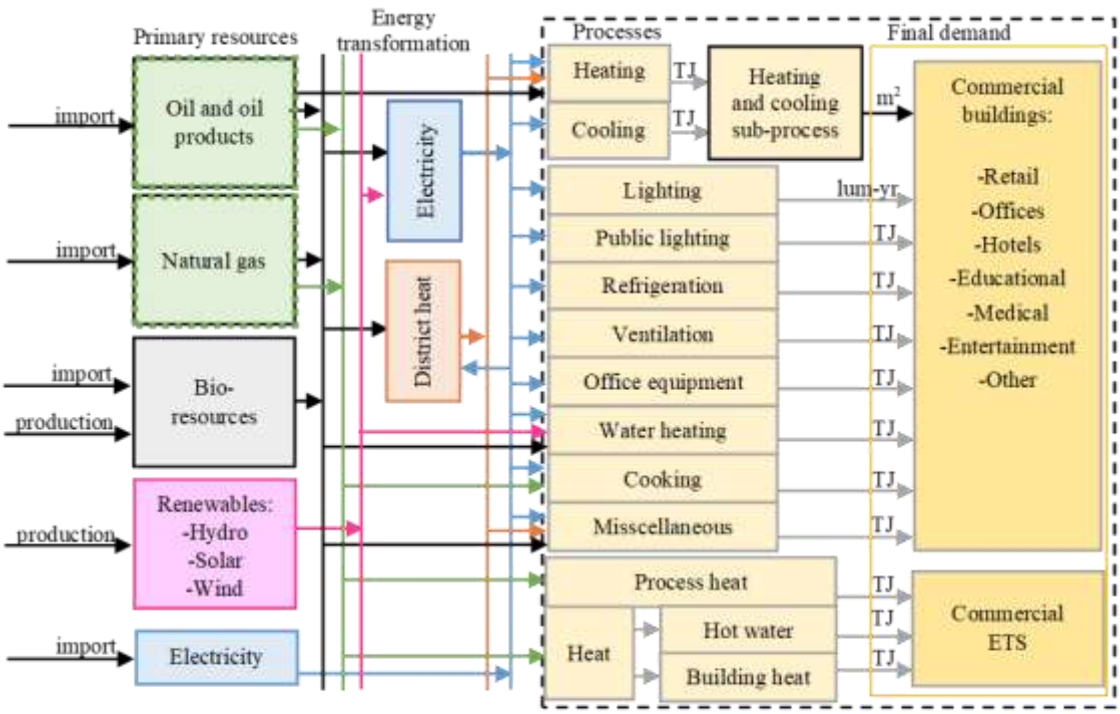
2.2.2 Commercial sector

The commercial and public sector in the TIMES Latvia model includes the private and public service sectors. There are different buildings and different levels of energy consumption in the commercial sector. Therefore, it has been divided into seven sub-sectors based on the building classification and floor areas.

Resource consumption for almost all commercial sub-sectors has been divided into ten processes – heating, cooling, cooking, lighting, public lighting, refrigeration, ventilation, water heating, office equipment and others.

A new process of heating and cooling demand was created – heating and cooling area (m^2) - to allow the addition of more precise policy measures directly to the energy efficiency of specific buildings (see Fig.2-5). Like other demand processes, demand for heating and cooling area (m^2) is affected by demand drivers like GDP growth and elasticity derived from the CGE model.

Figure 2-5 Structure of the commercial sector in the TIMES Latvia model



Specific plants appear in the commercial sector as ETS participants. Those mostly cover different manufacturing processes. In the TIMES model, they have been divided into processes similar to the industrial sector: process heat, building heat and hot water.

The available statistical data only presents the total consumption of primary energy sources, heat and overall power consumption in the commercial sector. Therefore, the specific consumption for different end use purposes (Table 2-2) has been determined through these assumptions by knowing the area of each type of building.

Table 2-2 Assumptions for energy distribution in the commercial sector

Parameter	Retail	Offices	Hotels	Education	Medical	Entertainment	Other
Share of heated area	85%	80%	75%	80%	80%	70%	30%
Specific heat consumption for space heating, kWh/m^2							
existing buildings	130	140	135	160	160	150	120
renovated buildings	110						
newly built buildings	100						
Specific heat consumption for hot water heating, kWh/m^2	10	10	35	21	24	10	5
Share of mechanically ventilated area							
existing buildings	60%	50%	50%	30%	50%	30%	30%
renovated buildings	70%	70%	70%	50%	70%	60%	40%
newly built buildings	80%	80%	80%	60%	80%	70%	50%
Power consumption for ventilation, kWh/m^2	20	20	20	20	30	30	20
Share of building area with space cooling							
existing buildings	40%	50%	60%	40%	40%	20%	5%
renovated buildings	60%	70%	70%	50%	70%	60%	5%
newly built buildings	80%	80%	80%	60%	80%	70%	20%
Specific cooling consumption, kWh/m^2	53	53	40	40	53	40	20
Average minimum level of illumination, lux	369	383	314	352	457	325	291
Specific power consumption for lighting, kWh/m^2	29	14	12	10	34	13	20

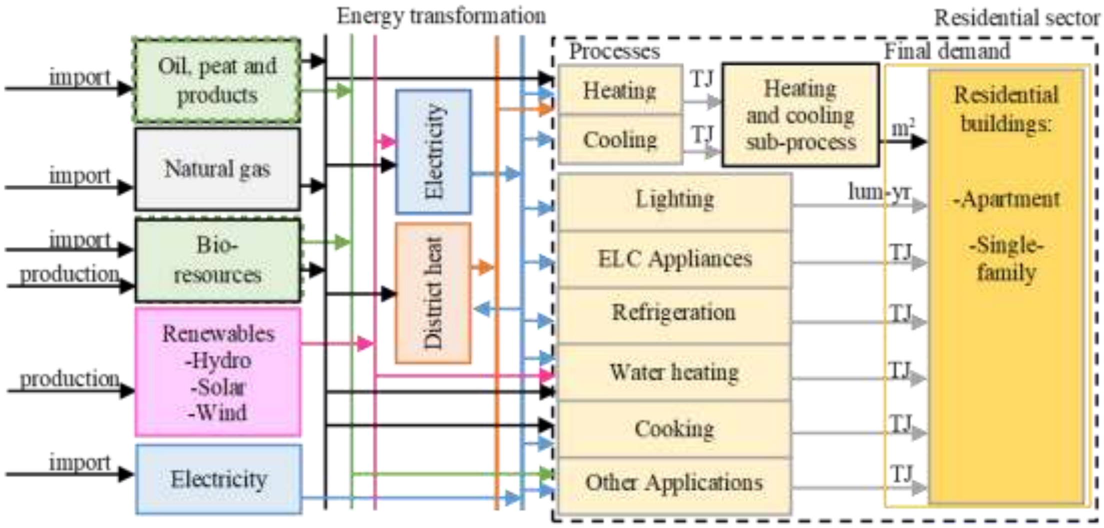
The structure of electricity consumption differs between the various sub-sectors of the commercial sector. In retail buildings, as well as in buildings for medical facilities and entertainment, most of the electricity is spent on lighting. In office buildings, office equipment consumes the most power but, in hotels and educational buildings, most of the energy is used for water heating. DH and primary energy sources are for three processes: water heating, space heating and other processes like cooking.

2.2.3 *Residential sector*

The second-largest part of final energy consumption (29% of the total) is dedicated to the residential sector. The residential sector was divided into two sub-sectors – single-family houses and apartment buildings, because both use different energy sources and differ in their consumption. It is assumed that the single-family houses are not connected to the district heat (DH) network, but part of the apartment buildings are connected to a centralised heat supply.

Processes analysed in the TIMES model for the residential sector are heating, cooling, water heating, refrigeration, lighting, cooking, electrical appliances, and other applications (Fig. 2-6). New heating and cooling sub-processes have been introduced, similarly to the commercial sector. This allows for the addition of policy measures related to the energy efficiency of buildings more precisely.

Figure 2-6 Structure of the residential sector in the TIMES Latvia model



In addition, heating and cooling processes have been defined as pre-processes whereas the rest of the processes like cooking, lighting and others are considered as the final demand.

The distribution of energy consumption is determined using available information on floorspace of single-family houses and buildings, as well as the total area of buildings connected to DH. The thermal energy consumption for buildings heating was calculated by adopting different levels of building efficiency in new, renovated, and existing buildings.

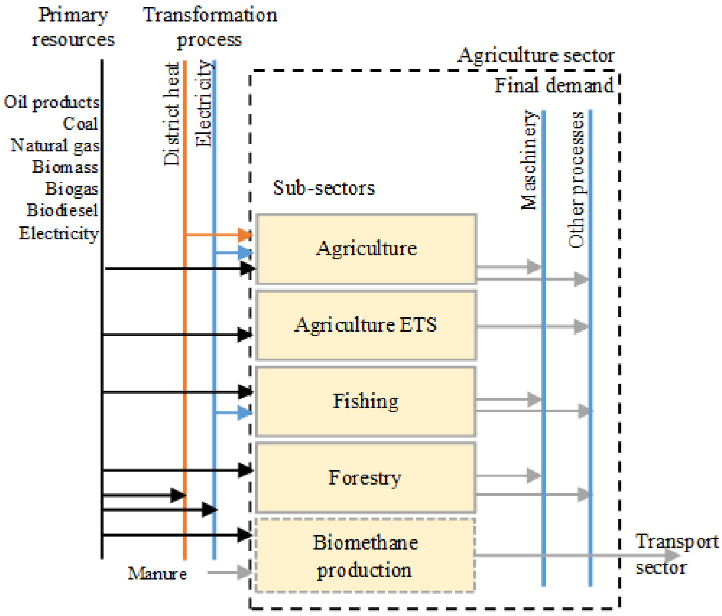
The distribution of electricity consumption is similar in single-family houses and apartment buildings, since the behaviour of the consumer is similar in both types of building. Most of the power (30%) is consumed by different electrical appliances (e.g. TV, radio, mobile charging), complemented by 20% for heating water, 18% for cooking, 15% for lighting and 13% for space heating. The percentage distribution of energy resources and electricity usage is derived from the Odyssee and Eurostat database.

Demand for energy services in the residential sector is influenced by GDP and population projections. In Latvia, GDP is projected to increase while the population shrinks. Based on the historical trends of power consumption in the residential sector, it has been assumed that the main driver of household energy demand is population (over economic growth). This leads to a slow decrease in demand for energy services in the household sector.

2.2.4 *Agriculture sector*

The agricultural sector within the TIMES Latvia model is divided into three sub-sectors: agriculture, forestry and fishing (Fig. 2-7). The main final demand technologies in the agricultural sector are various types of tractors (machinery) and other devices (various electrical appliances, heating, hot water preparation, etc.). The fuel consumed in the fishing sub-sector is determined according to the available data from the Central Statistical Bureau of Latvia. In the forestry sub-sector, it is assumed that only diesel fuel for wood harvesting and processing is consumed.

Figure 2-7 Structure of the agricultural sector in the TIMES Latvia model



Additionally to the three above-mentioned sub-sectors, the production of biomethane from biogas is dealt with separately, and future potential volume for biogas production from manure is obtained from the agriculture sectoral model LASAM (see Section 2.3).

For the use of biogas in the transport sector, it is necessary to purify it through the biomethanation process. The cost of obtaining biomethane was taken from the BIOSURF study "Technical-economic analysis for determining the feasibility threshold for tradable biomethane certificates"[19]. Two technologies were considered for the transport of biomethane, (1) connecting to the gas pipeline; and, (2) transporting it in a compressed gas tank. The costs of connecting to the gas pipeline are in line with tariffs determined by JSC "GASO"[20], while the costs of transporting a compressed gas tank were taken from scientific literature[21].

2.2.5 *Transport sector*

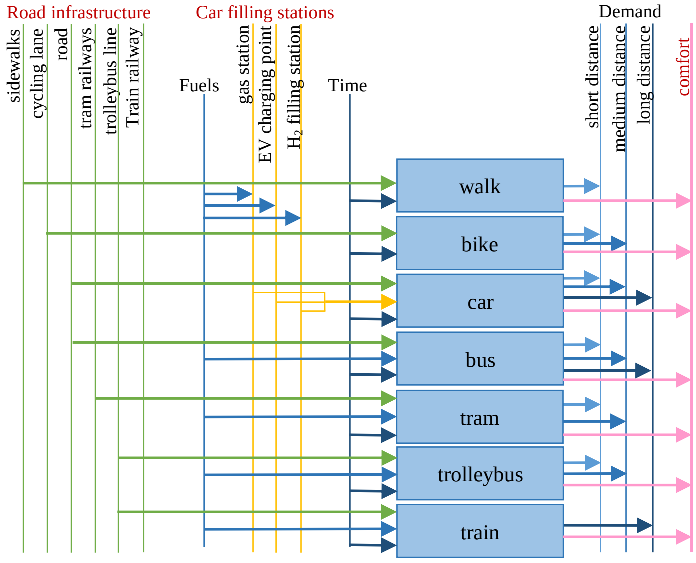
The transport sector in the TIMES model consists of two blocks - passenger transport and freight transport. Freight transport consists of rail transport, road transport and pipeline infrastructure. Road transport is divided into light freight transport and heavy freight transport. Passenger transport includes both air transport (domestic and international flights), water transport (domestic shipping) and land transport (Figure 2-8). Land transport, which accounts for the largest share of energy consumption, includes road transport, rail transport and individual modes of transport. Road transport consists of cars, buses (both urban and interurban), as well as trams and trolleybuses, while individual modes of transport include walking and cycling.

In the standard approach in TIMES models, demand for transport is often driven by the demand for different modes of transport, by optimizing demand separately for cars and for buses. In this case,

[19] B. S. Akb et al., "Determining the Feasibility Threshold for Tradable Biomethane Certificates," no. 2016, pp. 1–24, 2020.
[20] AS „Gaso", "Dabasgāzes pieslēguma izmaksas." https://www.gaso.lv/izmaksas
[21] M. Åhman, "Biomethane in the transport sector-An appraisal of the forgotten option," Energy Policy, vol. 38, no. 1, pp. 208–217, 2010

optimization can take place by technology choices within similar vehicle classes, such as the transition from a diesel-powered, internal combustion engine car to an electric car.

Figure 2-8 Passenger transport structure and flows



To improve modelling accuracy, demand for three different distances has been included in the model: short distances (up to 5 km), average distances (5-25 km) and long distances (over 25 km). This modelling approach ensures that different transportation modes, which cover a certain distance, can compete with one another, e.g. walking, cycling, car, bus, tram and trolleybus may substitute for each other within short distances if the travel destination matches. In contrast, only cars, intercity buses and trains can be used for long distances.

The distances in the TIMES model take into account existing mobility patterns in the base year. The limit values for the distances were set to include non-motorized modes of transport - cycling and walking. Short distances of up to 5 km can be covered by all vehicles, except trains. Average distances from 5 to 25 km are provided by bicycle, tram, trolleybus, city bus and car, while long distances above 25 km are offered by car, intercity bus, and train. Considering that on average 47 km is travelled by train in the base year, and to simplify the model calculations, it is assumed that the train is used only for distances longer than 25 km, which includes the most popular routes in Latvia. The assumptions regarding the distribution of travelled distances are of high uncertainty due to the lack of precise data and can be adjusted in future studies if more detailed national surveys on the travelling habits of the Latvian population will be conducted.

The model also includes road infrastructure and car filling stations that require the necessary infrastructure to increase specific types of transport, e.g. electric vehicles.

Another very important element introduced for the transport sector is the level of comfort. It allows better inclusion of people's behaviour habits. As TIMES is an optimization tool that looks for the most cost-effective system structure, the level of comfort is important as it ensures that not all traffic flows will switch to the cheapest possible option, making model results more realistic (e.g. to reflect the tendency to continue using private cars, regardless of costs). This “comfort” parameter is an important and necessary limiting factor for the model.

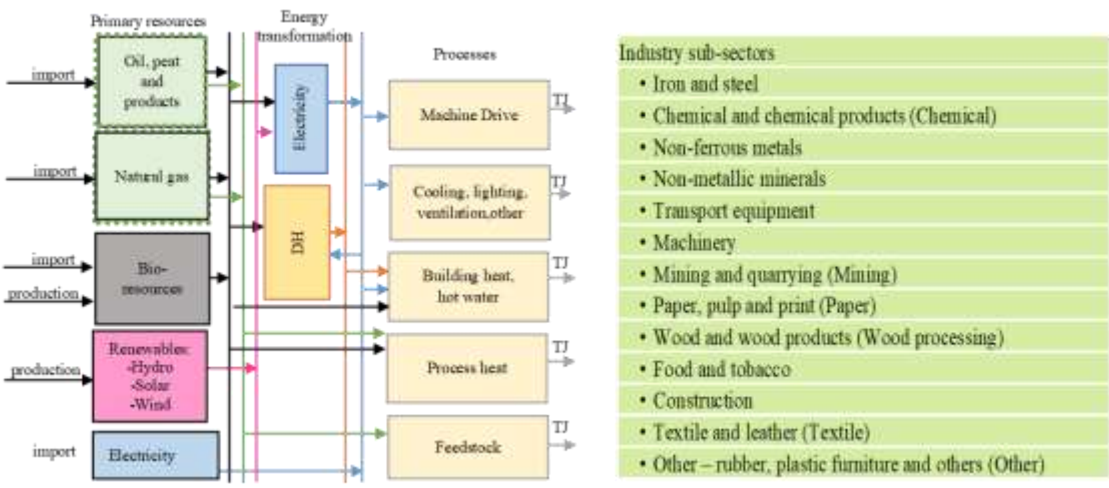
In summary, the inputs for processes in the transport sector (particularly passenger transport), are not only different fuels (diesel, gasoline or biodiesel) but also time parameters, road infrastructure, and availability of infrastructure. Output elements are distance (short, medium or long), comfort level and GHG emissions (CO_2, N_2O and CH_4).

Static comfort levels are included in the baseline scenario for both existing and new vehicles. In future scenarios, their comfort levels are however increased. The demand for travel is derived from the forecasts in the CGE model. In the TIMES model, freight transport is provided by road transport, which is divided into light and heavy road transport and rail freight transport.

2.2.6 *Industry sector*

The industry sector in Latvia consists of 13 sub-sectors (Figure 2-9). To analyse the development of the industrial sector, the model structure has been prepared in accordance with the industrial sub-sectors given in the national energy balance. The processes in different industrial subsectors are very specific when compared, for example, to subsectors in other sectors (e.g. residential). Consequently, the structure of the industrial sector model cannot be simplified. In addition, the industries included in the ETS are divided separately (e.g. metals, chemicals, etc.).

Figure 2-9 Structure of the industry sector in the TIMES Latvia model



Five different end-use processes have been analysed in the industry sector – feedstock, machine drive, process heat, building heat and hot water, and other processes including cooling, lighting, and ventilation. To determine the proportion of energy sources used for each process, the authors used data from an industrial energy audit carried out between 2016 and 2018[22]. The energy balance of 122 different companies was analysed to determine the distribution of different energy sources.

Heat consumption in the TIMES model has been divided into thermal energy used for space heating and hot water, and process heat that is used for manufacturing processes. In some sub-sectors, less than half of the heat is used for process heat (transport equipment production). Nevertheless, there are sub-sectors where even more than 90% of heat has been used for production processes – non-metallic minerals production and mining.

[22] Anna Kubule, Kristaps Ločmelis, Dagnija Blumberga, Analysis of the results of national energy audit program in Latvia, Energy, 202, 2020, 117679

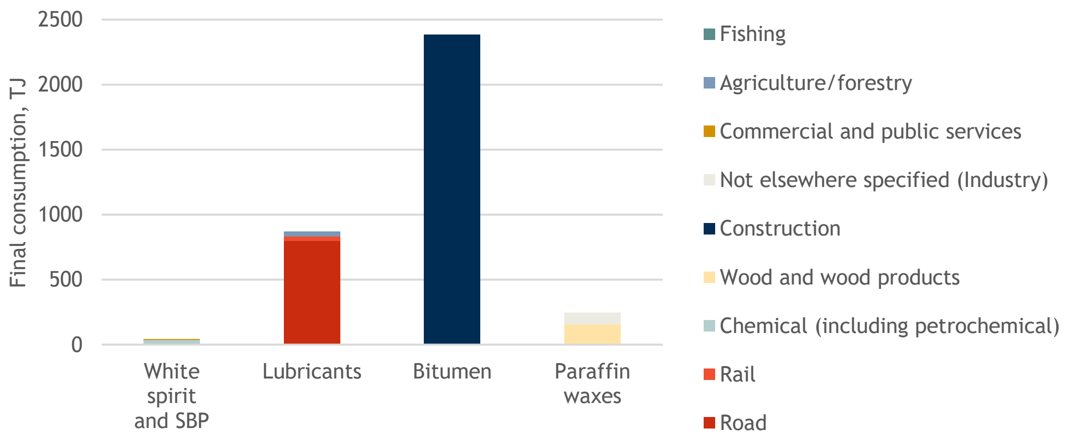
Within the TIMES model, it has been assumed that energy efficiency can be improved through the recovery of process heat. The recovered heat from the processes or equipment is transferred to the DH networks, assuming a different high-temperature recovered heat potential in each subsector. For each subsector, the two following types of processes are embedded in the model: standard production processes without heat recovery equipment and advanced processes with production heat recovery.

The results obtained by the model depend on the future demand for these energy services, which, as mentioned above, may depend on population, GDP and other factors. Demand from industry sub-sectors is also based on production values from the CGE model.

2.3 Reference energy system for non-energy sectors

All energy resources that are counted in the Energy Balance and are used for combustion are reflected in the TIMES Latvia model structure. However, there are also fuels that are used as feedstock (non-energy use of fuels) in the Energy Balance: white spirit, paraffin wax, lubricants, and bitumen. According to national statistics, fuel consumption for non-energy use was 3 543 TJ in 2017, accounting for around 2% of total final consumption in Latvia. Figure 2-10 shows the distribution of fuels for non-energy consumption according to national statistics in 2017. The highest share (67% of total non-energy use consumption) is related to bitumen used as a feedstock in the construction sub-sector, second, being the consumption of lubricants in the road transport sector (22% of total non-energy use).

Figure 2-10 Distribution of fuels for non-energy consumption in 2017 according to national statistics



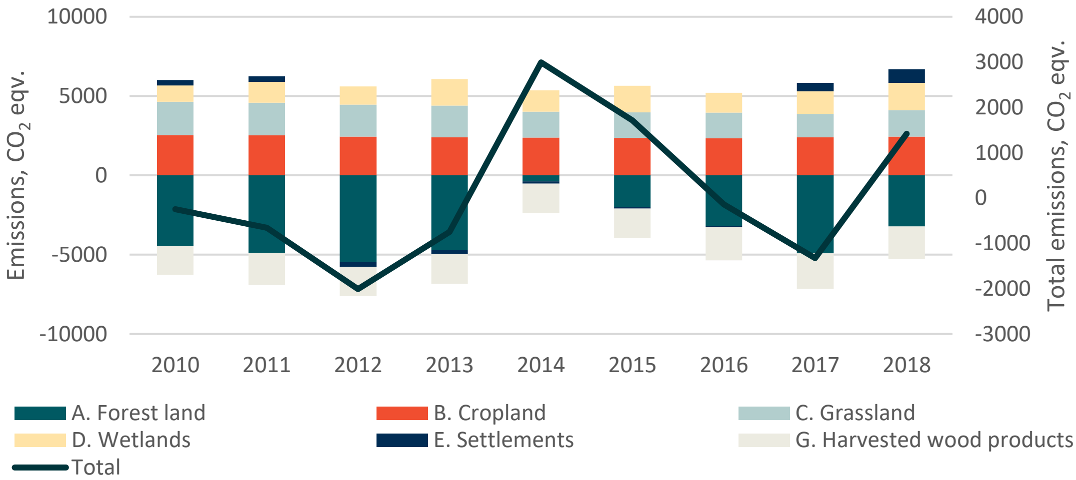
To accurately describe the non-energy use of lubricants, bitumen, paraffin waxes and white spirits, a separate feedstock commodity was created to cover non-energy resources and use, including the following sub-sectors:

1) Non-energy use for industry/transformation/energy;
2) Non-energy use in transport;
3) Non-energy use in other.

The demand for these feedstocks is allocated as a share from total demand in each subsector according to base year statistics.

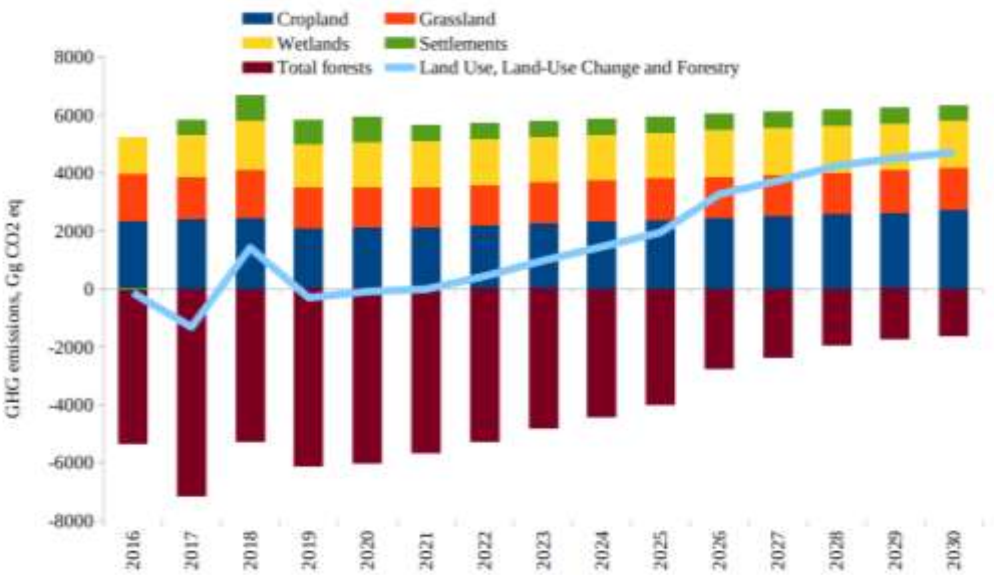
The historical trends in Land-Use, Land-Use change, and forestry (LULUCF) sector emissions can be seen in Figure 2-11 which shows a high variation of total emissions from 2010 to 2018.

Figure 2-11 Historical trends of emissions in LULUCF from GHG emissions inventories



Since TIMES Latvia is an energy system model, the emissions from LULUCF for different types of land use in Latvia have not been included in the model structure, but those emissions are included exogenously in the model in an aggregated way from other national models. As for now, the forecast from Latvia University of Life Science and Technologies showed in Figure 2-12 is reflected in the model Baseline scenario and via limitations to full climate neutrality in future development scenarios.

Figure 2-12 Future forecasts of emissions in LULUCF[23]



Processes in the agriculture sector that are not related to energy use (enteric fermentation of domestic livestock, manure management, agriculture soils, liming, urea applications) are not included in the proposed TIMES Latvia energy system model structure. The agriculture sector (including 3 subsectors - agriculture, forestry and fishing) is represented only with energy and fuel conversion technologies, commodities (natural gas, wood waste, electricity, diesel etc.) and processes (machinery (e.g. tractors)

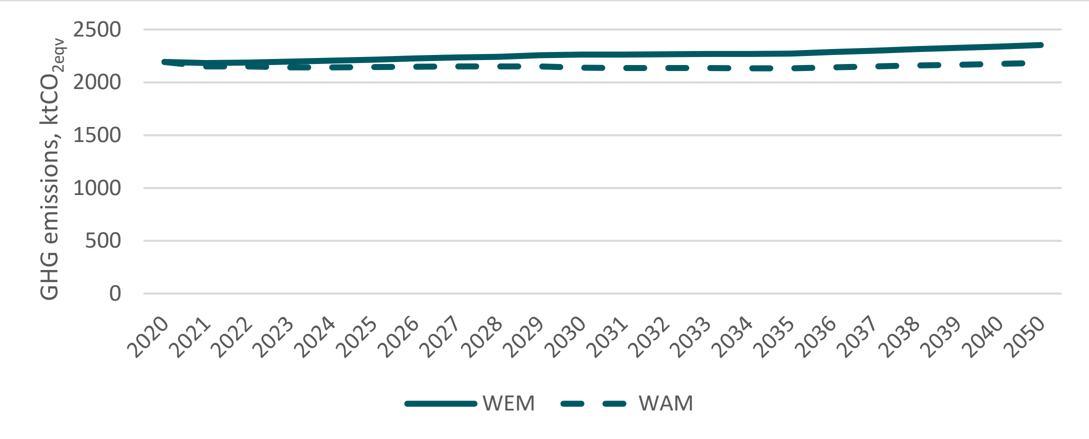
[23] Lagzdins A. SEG emisiju saistību prognoze ZIZIMM sektorā, 2021. Available online: https://www.zemeunvalsts.lv/documents/view/a5e0ff62be0b08456fc7f1e88812af3d/Prezent%C4%81cija%20Latvijas%20klimata%20saistibu%20izpilde%20ZIZIMM%20sektor%C4%81.%20A.Lazdi%C5%86%C5%A1%20zuv.b.pdf

and other processes). Additionally, there is one specific process proposed in the agriculture sector, where manure is used for biomethane production, that is used in the transport sector.

For more accurate GHG emission projections, soft linkage with other models that are dedicated to non-energy sectors and their outputs could be used as inputs for the TIMES model. One such model is LASAM (Latvian Agricultural Sector Analysis Model) developed by Latvia University of Life Science and Technologies which is developed as an econometric, recursive, dynamic model and can be used to forecast the development of multiple indicators used in the agricultural sector. The model includes projections for dairy farming, beef production, sheep and goat farming, pig farming, poultry farming, horse breeding and crop production[24]. The main outputs also include projections of emissions, value-added and employment.

Figure 2-13 shows the emission forecasts derived from the LASAM model which includes the GHG emissions from livestock (CH_4 emissions from enteric fermentation and manure management, direct and indirect N_2O emissions from manure management) and GHG emissions from soil (direct N_2O emissions from mineral fertilizers, manure applications, grazing, plant residuals, organic soils, soil management, as well as CO_2 emissions from liming and urea application). The WAM scenario includes additional measures such as the promotion of organic dairy farming, support for fertilization planning, promotion and support for the direct application of organic fertilizers to the soil, improvement of feed quality and others.

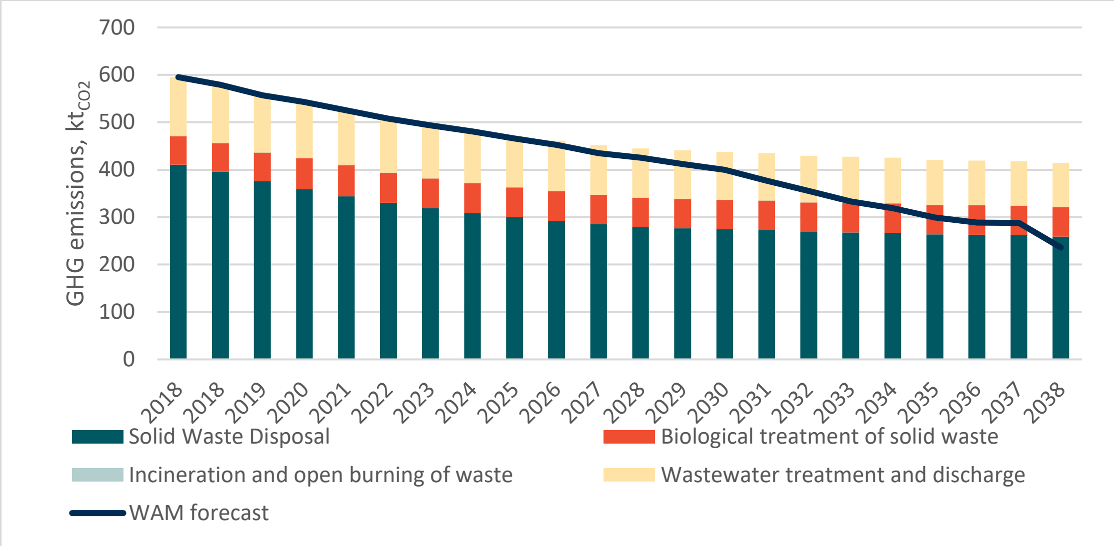
Figure 2-13 Future forecasts of emissions in the agriculture sector[25]



The Waste sector accounted for 4.7% of total Latvia's GHG emissions in 2018. According to projections compiled by the Ministry of Environment and Regional development under the current legislative framework, the recycled share of waste will continue to increase and population emissions from waste will decrease. The projections according to Reporting on Policies and Measures under Article 18 of Regulation (EU) No. 2018/1999 of the European Parliament and of the Council for the waste sector can be seen in Figure 2-14. The forecast with additional measures which includes increased processing of biological waste and increased production of waste-derived fuel shows an emissions decrease of 43% by 2050.

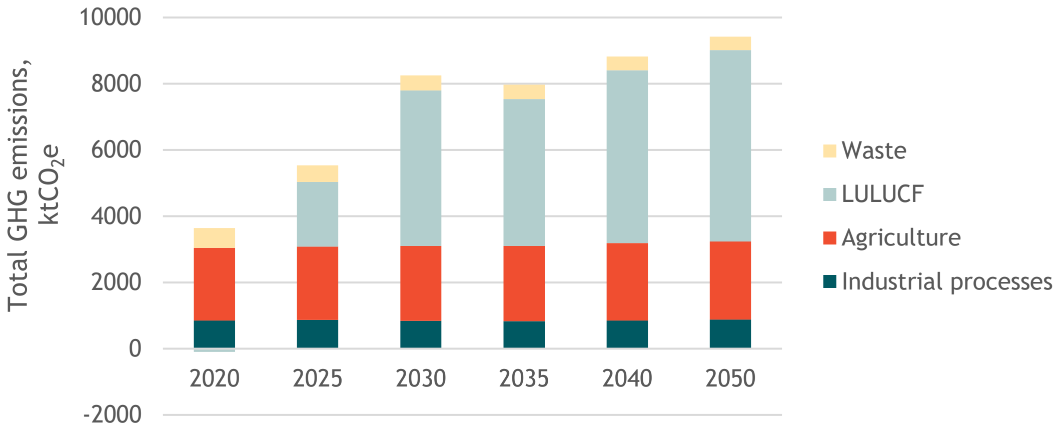
[24] Pilvere, I.; Nipers, A.; Krievina, A.; Upite, I.; Kotovs, D. LASAM Model: An Important Tool in the Decision Support System for Policymakers and Farmers. Agriculture 2022, 12, 705.
[25] LASAM (Latvian Agricultural Sector Analysis Model) interface. Available online: https://lasam.llu.lv/#

Figure 2-14 Waste sector emission forecast[26]



The compiled total GHG emissions for the reference non-energy system in the Baseline scenario are shown in Figure 2-15. Total GHG emissions of the non-energy sector are projected to increase mainly due to significant increase of LULUCF sector emissions.

Figure 2-15 Total GHG Emission forecasts for non-energy sectors in the Baseline scenario[27]



When modelling the future development scenarios for reaching low emission levels, these forecasted non-energy sector emissions are used as reference levels within the TIMES model. When modelling potential pathways for reaching carbon neutrality, is has been assumed that these non-energy sectors will also reach net-zero emission levels.

[26] Reporting on Policies and Measures under Article 18 of Regulation (EU) No. 2018/1999 of the European Parlament and of the Council, Latvia, 2021. Available online: https://videscentrs.lvgmc.lv/files/Klimats/SEG_emisiju_un_ETS_monitorings/Zinojums_par_klimatu/SEG_prognozu_pilnie_zinojumi/2021/LV_Report%20_Projections%20and%20PAMs_2021_Final.pdf

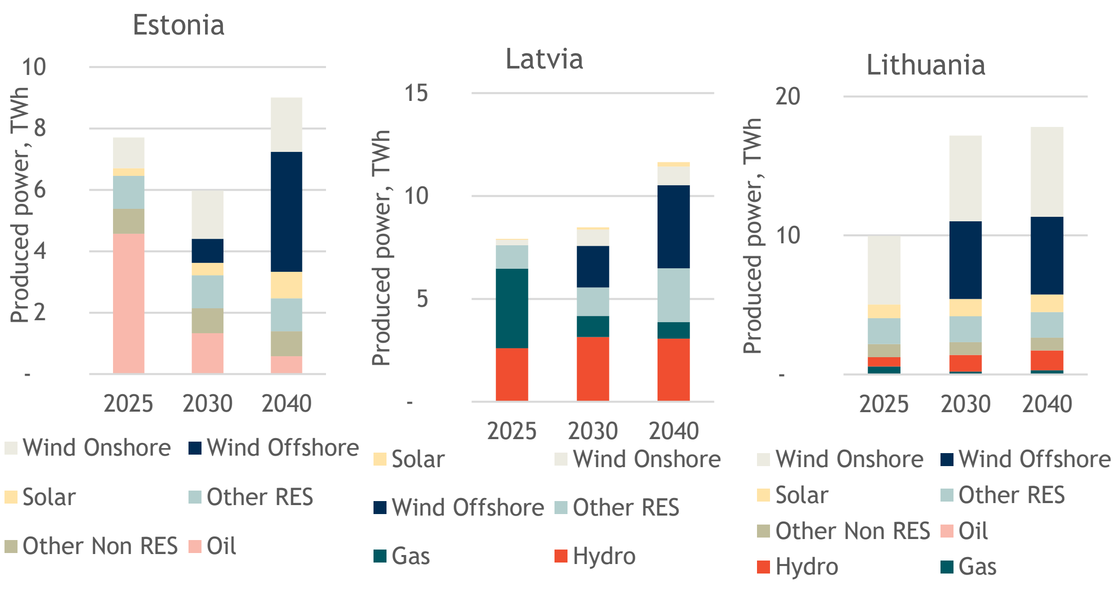
[27] Article 38 Reporting on national projections. VARAM, 2021

2.4 Planned infrastructure and capacity developments in other countries of the region

The future development of the energy supply system is highly dependent on the planned infrastructure development in other countries of the region, particularly the other countries participating with Latvia in the Nordpool power trading system (particularly focusing on Estonia and Lithuania). Therefore, the development plans of the European Network of Transmission System Operators (ENTSO-E) have been analysed and included into the TIMES Latvia model. Comprehensive supply and demand data from both gas and electricity transmission system operators (TSO) as well as from official EU and Member State data sources and key industry projections have been collected to build robust bottom-up scenarios. Within this report, the National Trends Scenario (which represents a central policy scenario) has been analysed in more detail, recognising national and EU climate targets as reflected in the latest Member States' National Energy and Climate Plans (NECPs). The electricity and gas datasets for this scenario are based on figures collected from the TSOs translating the latest policy- and market-driven developments discussed at the national level. The quantification of National Trends focuses on electricity and gas up to 2040.

Figure 2-16 shows the forecasted power production comparison among the Baltic countries in the modelled National Trends Scenario. These show that in all three Baltic countries, development of offshore wind parks will bring the highest increase in RES shares. In Lithuania, onshore wind parks will also maintain their significant role in overall power production.

Figure 2-16 Electricity production forecasts in Baltic countries according to the Ten-Year Network Development Plan[28]



Within the modelled National Trends scenario, current national policies do not consider a shift of the gas demand from methane towards hydrogen, nor do they consider significant carbon capture and storage capacities. In addition to the National Trends Scenario, there are also further development scenarios to quantify compliance with EU policies and climate ambitions reaching the 1.5 °C target of the Paris

[28] ENTSO-E//ENTSOG TYNDP 2022 Scenario Report-Version. April 2022. Available online: https://2022.entsos-tyndp-scenarios.eu/wp-content/uploads/2022/04/TYNDP2022_Joint_Scenario_Full-Report-April-2022.pdf

Agreement following the carbon budget approach. The main directions of future development scenarios in the Ten-Year Network Development Plan of ENTSO are: the significant decrease of overall energy demand with the combination of energy efficiency measures (renovation of buildings and switch to new or more efficient technologies) and the effect of further system integration. Broader electrification and system integration can make renewable electricity production more efficient. Production of renewable hydrogen is the solution whenever the electricity demand is lower than the available renewable capacity. Reports insist that the gas systems can provide significant storage capacities and flexibility to the electricity system when the electricity demand is higher than the production. The main driver of electricity demand growth is the transport sector. The overall trends show that National policies rely more on methane production until 2040, whilst the role of hydrogen increases after 2030.

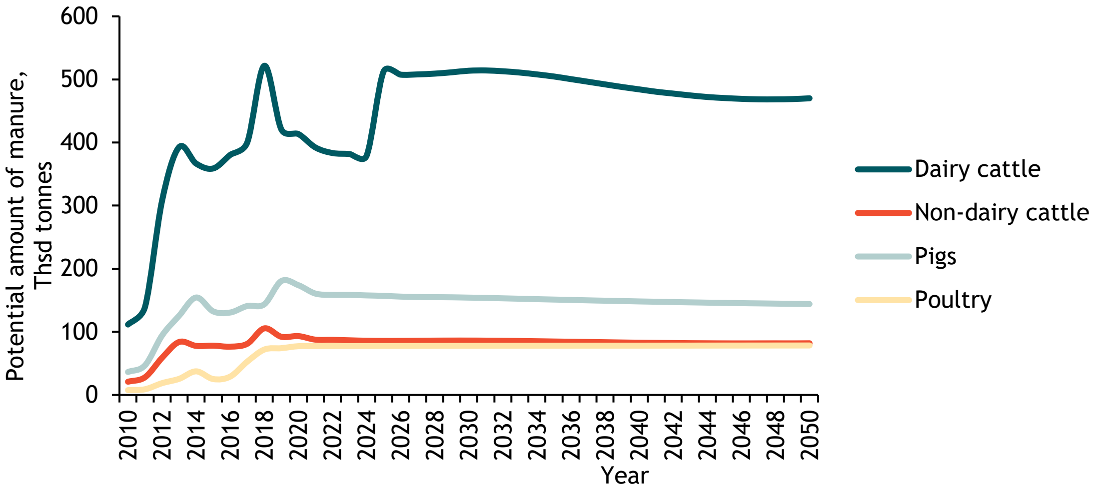
Considering ENTSO-E future development patterns, a regional dimension could be introduced in the TIMES Latvia model. In the existing model version, import and export flows were generalized to simplify the operation of the model. In the future, new regions may be introduced to represent Lithuania and Estonia, with which significant energy trade is planned. This addition would allow to forecast the energy production mix in neighbouring countries and to forecast future import and export prices as well as potential trading limitations more precisely.

2.5 Further development of TIMES Latvia model with additional tools

The use of the TIMES model is unsuitable for several important socio-technological aspects, especially behaviour and human factors. Therefore, other specific models, such as the System Dynamics model previously developed for Latvian energy sector analysis can be used to supplement the TIMES model to obtain more accurate results and compensate any shortcomings.

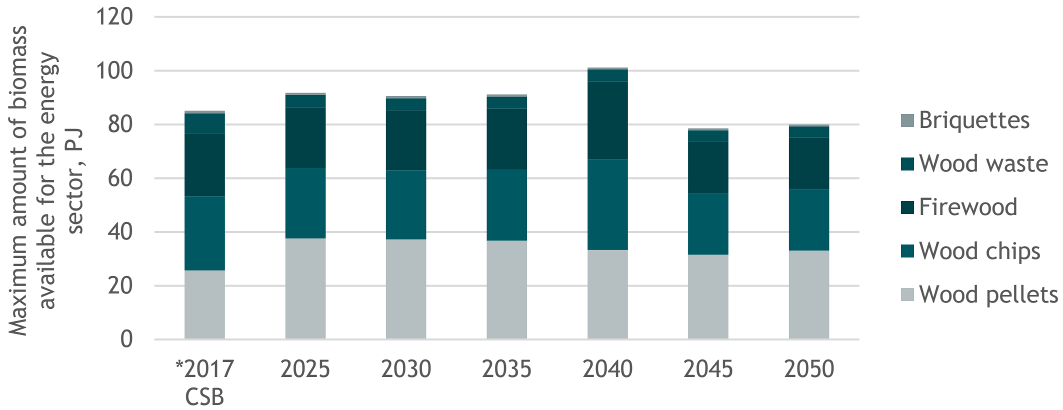
The limitations on available manure for the potential production of biogas have been derived from the LASAM model (Fig.2-17). Manure mass used for anaerobic digestion is estimated based on the number of farm animals, produced manure and proportion of manure used as feedstock. The statistical results indicate that there is an increasing trend in the number of poultry in recent years. The calculation results regarding quantities of manure used for anaerobic digestion show that dairy cattle is the main group of livestock providing manure as a resource for biogas production. Non-dairy cattle (pigs and poultry), as individual groups of livestock, contribute to manure production to a lesser extent. However, taken together, these three groups have the potential to produce between 36% and 46% of the total amount of manure used for anaerobic digestion during the period 2010-2030.

Figure 2-17 Limitations of available manure for biogas production[29]



Another soft linked model which outputs are used in the TIMES Latvia model is the forest management model “Forest expert” developed by Latvia University of Life Sciences and Technologies. The maximum amount of biomass available for the energy sector is obtained from the "Forest Expert" linear optimisation model, which provides a higher quality of data on the development of forest resources. The model includes tree growth rate models, compliance with binding regulatory enactments and standards for predicting timber outcomes, algorithms of tree trunks, and assortment forecasting. The results of the "Forest Expert" model show that the available amount of wood pellets for the energy sector will increase, but the availability of other wood biomass will decrease by around 30% in 2050 compared to 2017.

Figure 2-18 Maximum amount of biomass available for the energy sector from the “Forest expert” model[30]



Maximum biomass availability is projected in 2040 (Figure 2-18), which is influenced mainly by the availability of white alder, the volume of felling of which is significantly higher (short circulation time ~ 31 years). There are no restrictions to even out felling volumes in the long run. The biomass limitation derived from the "Forest Expert" model is used in all TIMES scenarios.

[29] Lagzdins A. The present and future availability of livestock manure for biogas production in Latvia, 2022, Rural Sustainability research

[30] Dubrovskis D., Daģis S. “Meža eksperts” modeļa uzturēšana un parametru aktualizēšana, 2021. Available online: https://videszinatne.rtu.lv/wp-content/uploads/2021/02/3_LLU-Meza-eksperts.pdf

In addition, the previously built system dynamics model which covers energy production and consumption to describe the entire energy supply system could be used to model the energy efficiency potential more accurately[31]. The developed structure of the Supply-Demand model for the energy sector in Latvia searches for the balance between energy supply and the demand by ensuring the lowest possible energy costs considering the resource costs, necessary investments, maintenance costs and taxes. In addition, social behaviour factors are considered within the model, such as the decision-making process, inconvenience costs of different technologies and the feedback loops associated with the increased energy efficiency of consumers. Those can be further integrated within TIMES Latvia to model the actual building renovation rates by considering the complex nature of insulation projects.

[31] Blumberga, A.; Bazbauers, G.; Vancane, S.; Ijabs, I.; Nikisins, J.; Blumberga, D. Unintended Effects of Energy Efficiency Policy: Lessons Learned in the Residential Sector. Energies 2021, 14, 7792. https://doi.org/10.3390/en14227792

Appendix 1 GHG emission factors applied in the TIMES Latvia model for the main fuels

CO_2 emission factor, tCO_2/TJ		
Fuel type	Energy Production, Residential, Commercial, Industry sectors	Transport sector
LPG	63.1	62.75
Gasoline	69.3	71.18
Aviation Gasoline	NO	70
Kerosene type jet fuel	NO	72.10
Diesel oil	74.1	74.75
Coal	94.60	NO
Peat and peat briquettes	101.39	NO
Natural Gas	55.12	57.76

	CH4 emission factor, tCO2/TJ				
Fuel type	Power	Residential	Agriculture	Industry	Transport
LPG	0.001	0.005	0.005	0.003	0.029
Gasoline	0.003	0.01	0.01	0.003	0.033[32]
Diesel oil	0.003	0.01	0.01	0.003	0.00566[33]
Other oil products	0.003	0.01	0.01	0.01	0.0039
Coal	0.001	0.3	0.3	0.002	N/a
Peat and peat briquettes	0.001	0.3	0.3	0.001	N/a
Natural Gas	0.001	0.005	0.005	0.2	0.092
Biomass	0.03	0.193	0.3	0.003	N/a

	N_2O emission factors, t CO_2/TJ	
Fuel type	Other sectors	Transport
LPG	0.0001	0.00374
Gasoline	0.0006	0.0019[34]
Diesel oil	0.0006	0.001[35]
Other Oil Products (excluding non-energy uses)	0.0006	0.0039
Coal	0.0015	N/a
Peat and peat briquettes	0.0014	N/a
Natural Gas	0.0001	0.003
Biomass	0.004	N/a

[32] For Gasoline in Aviation - 0.0005 t_{CO2}/TJ; For gasoline in light duty trucks - 0.028 t_{CO2}/TJ; For heavy-duty trucks and buses - 0.017 t_{CO2}/TJ; For Gasoline in Domestic navigation - 0.047 t_{CO2}/TJ;
[33] For Light duty tracks - 0.004 t_{CO2}/TJ; For heavy-duty tracks and buses -0.00835 t_{CO2}/TJ; For railway -0.00415 t_{CO2}/TJ; For Domestic aviation-0.005 t_{CO2}/TJ
[34] For Light duty tracks - 0.018 t_{CO2}/TJ; For heavy-duty tracks and buses -0.0009 t_{CO2}/TJ; For Domestic aviation-0.0003 t_{CO2}/TJ
[35] For Light duty tracks - 0.0007 t_{CO2}/TJ; For heavy-duty tracks and buses -0.003 t_{CO2}/TJ; For Domestic aviation-0.03 t_{CO2}/TJ

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