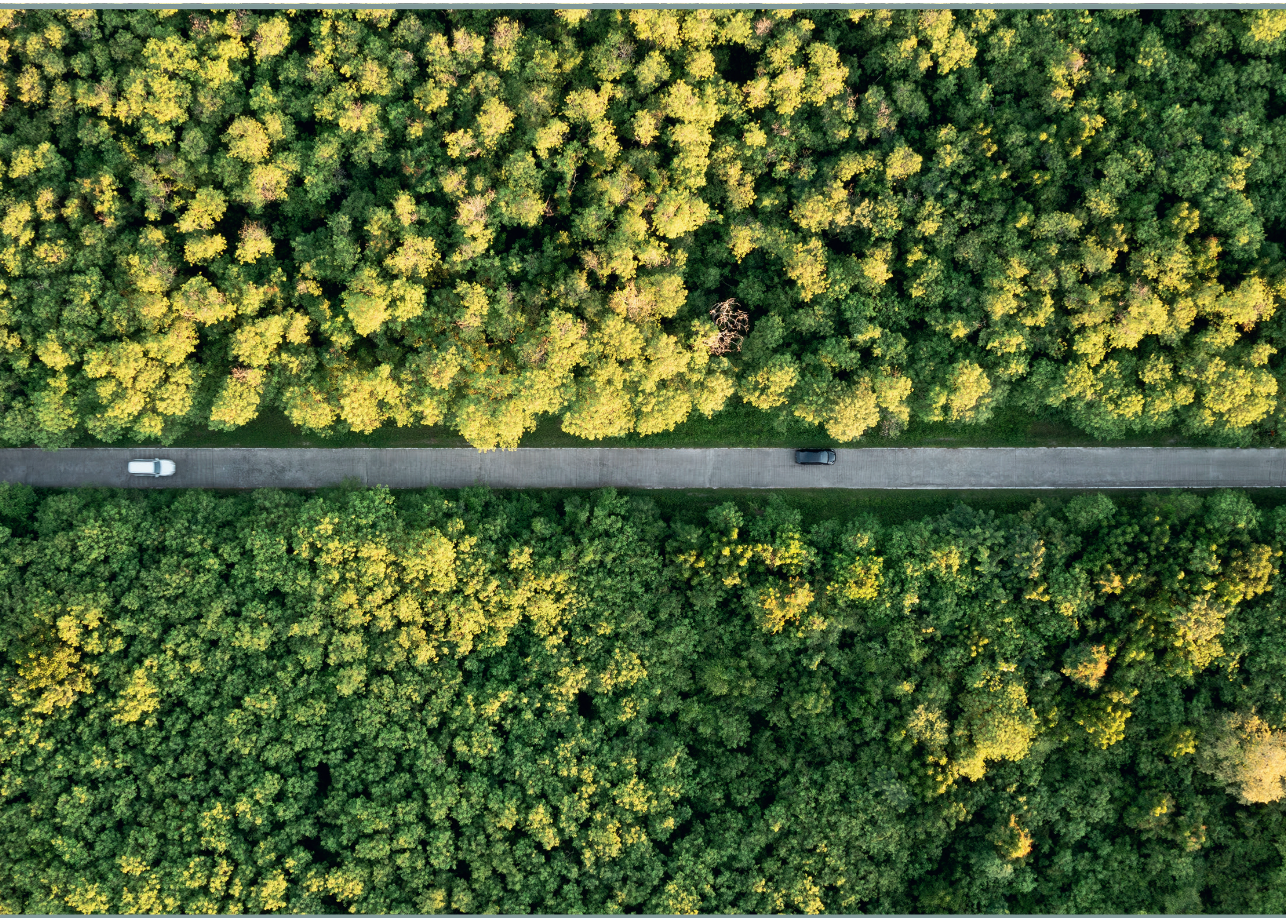
RIGA TECHNICAL UNIVERSITY

**Signe Allena-Ozoliņa**

# OPTIMAL PATHWAY TO A CLIMATE-NEUTRAL ENERGY SECTOR IN LATVIA

Summary of the Doctoral Thesis



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**RIGA TECHNICAL UNIVERSITY**
Faculty of Natural Sciences and Technology
Institute of Energy Systems and Environment

**Signe Allena-Ozoliņa**
Doctoral Student of the Study Programme "Environmental Engineering"

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Scientific Supervisors

Professor Dr. sc. ing.
GATIS BAŽBAUERS

Associate Professor Ph. D.
IEVA PAKERE

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# DOCTORAL THESIS PROPOSED TO RIGA TECHNICAL UNIVERSITY FOR PROMOTION TO THE SCIENTIFIC DEGREE OF DOCTOR OF SCIENCE

To be granted the scientific degree of Doctor of Science (Ph. D), the present Doctoral Thesis has been submitted for defence at the open meeting of RTU Promotion Council on 5 June 2025, at 14:00, at the Faculty of Natural Sciences and Technology of Riga Technical University, 12/1 Āzenes Street, Room 607.

OFFICIAL REVIEWERS

Associate Professor Dr. sc. ing. Vladimirs Kirsanovs
Riga Technical University

Professor Dr. sc. ing. Anna Volkova
Tallinn University of Technology, Estonia

Professor Dr. rer. oec. Wolfgang Irrek
Ruhr West University of Applied Sciences, Germany

DECLARATION OF ACADEMIC INTEGRITY

I hereby declare that the Doctoral Thesis submitted for review to Riga Technical University for promotion to the scientific degree of Doctor of Science (Ph. D.) is my own. I confirm that this Doctoral Thesis has not been submitted to any other university for promotion to a scientific degree.

Signe Allena-Ozoliņa ............................................(signature)

Date:............................

The Doctoral Thesis has been written in English. It consists of an Introduction, three chapters, Conclusions, 59 figures, and seven tables; the total number of pages is 153. The bibliography contains 129 titles.

# CONTENTS

# INTRODUCTION

The consequences of global warming have become more realistic and more prominent in all regions. Therefore, policymakers implement various laws, regulations, policy measures, and other regulatory frameworks to limit the increase of the global average temperature. Energy production is one of the main drivers of global warming, which is related to all other sectors.

## Research Topicality and Hypothesis

The hypothesis of the research is that the existing policies and measures (PaM) are insufficient to meet Latvia's 2030 climate targets. Achieving the required greenhouse gas (GHG) emission reductions for climate neutrality by 2050 will necessitate the implementation of additional, science-based PaM that are evaluated for long-term effectiveness.

Energy is the foundation of any country and economic sector. The production, export, import, use, and management of energy are among every nation's most critical strategic concerns. Equally significant are the environmental pollution caused by the energy industry and the growing importance of energy security, especially in recent years. This is particularly relevant in Europe, including Latvia.

Despite being grounded in large constructions, transport networks, and logistics, the energy sector remains fragile and sensitive to political developments and economic changes. Effective management requires precise and nuanced research. Recent decades of research in the energy field indicate the necessity of developing renewable environmental technologies, yet investments continue to be made in fossil fuel plants.

Globally, in 2019 compared to 2010, net GHG emissions have increased in all major sectors, and about 34 % of net GHG emissions came from the energy sector. Although the rate of GHG emissions growth between 2010 and 2019 was 1.3 % per year compared to 2.1 % in the previous decade, the amount of average annual GHG emissions was higher than in any previous decade (IPCC, 2023).

It is necessary to be able to make long-term decisions, which must be based on scientific research, at the level of any country, municipality, company, and even household.

Latvia is rich in green resources that must be optimally utilised through cooperation between business sectors, municipalities, ministries, and scientific institutes. Implementing technologies and solutions that are both economically viable and capable of achieving energy efficiency and environmental goals is essential. Energy demand must be met wisely to preserve and improve the surrounding environment.

While each of us is responsible for our choices, the state and municipalities must lead by example by making strategic, scientifically based decisions and supporting innovative technologies and solutions.

## Aim and Objectives

The aim of this work is to evaluate various PaM (e.g., increase in fossil fuel tax, subsidies for building insulation, and transition to electric transport) for achieving climate neutrality by modelling and analysing the national energy sector as a whole as well as individual economic sectors separately.

The main objectives for achieving the goal are:

- adapt the TIMES modelling tool to Latvia's energy sector to provide detailed results for justified decision-making at both national and company levels;
- identify and incorporate the latest technology database and other parameters into the model structure;
- analyse the impact of various policy instruments on achieving climate neutrality;
- conduct optimisation to find the most cost-effective solutions for reaching climate goals;
- determine the resource allocation of the energy sector that ensures Latvia's climate neutrality goals with the lowest possible total costs.

## Scientific Novelty

A novel TIMES modelling approach has been developed, including innovative solutions (introduction of a comfort level factor in the transport sector, demand for heated $m^2$ in the residential and commercial sectors, industrial heat recovery in the industrial sector, etc.), which provides expanded opportunities to analyse a wide range of PaM and perform optimization tasks to determine how to achieve climate goals with minimal total costs and determine the amount of investment necessary to achieve climate neutrality in 2050.

The scientific work is based on three pillars: PaM, climate neutrality, and the optimisation between them, which is carried out using the TIMES modelling tool (see Fig. 1).

The TIMES modelling tool allows, on one hand, the evaluation of the ability of pre-developed PaM to achieve climate neutrality. On the other hand, modelling the attainment of climate neutrality helps identify areas where PaM with lower total costs can be developed.

The optimisation includes an analysis of each economic sector – energy transformation, residential, commercial, transport, agricultural and industrial, which are presented in scientific articles listed in Table 1.

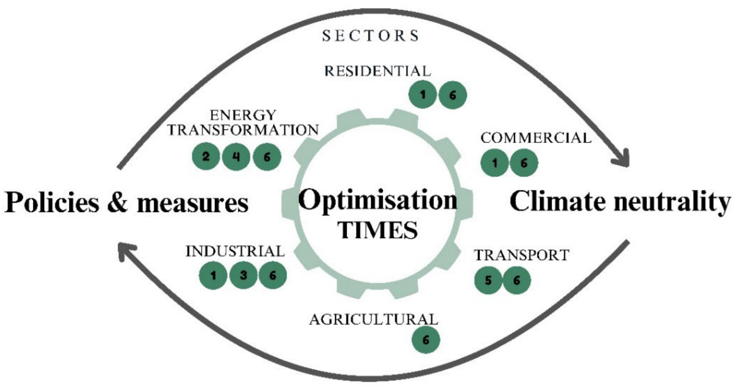



Fig. 1. Three pillars of the research algorithm.
Numbers represent scientific articles of the analysed sectors.

Table 1

Scientific Articles Used in the Doctoral Thesis

| No | Publication title | Analysed sectors |
|---|---|---|
| **1.** | Adaptation of TIMES model structure to industrial, commercial and residential sectors | Industrial<br>Commercial<br>Residential |
| **2.** | Integrated MARKAL-EFOM System (TIMES) Model for Energy Sector Modelling | Energy transformation |
| **3.** | Decarbonisation Pathways of Industry in TIMES Model | Industrial |
| **4.** | Can energy sector reach carbon neutrality with biomass limitations? | Energy transformation |
| **5.** | Passenger transport shift to green mobility – assessment using TIMES model | Transport |
| **6.** | Cost-Optimal Policy Strategies for Reaching Energy Efficiency Targets and Carbon Neutrality | All |

To identify cost-effective PaM for achieving climate neutrality, leading to specific energy efficiency and climate goals, novel modifications to the model have been made, including:

- sector linkages for energy system optimisation have been established;
- a detailed, sector-specific technology database has been included;
- heat recovery from industrial equipment has been incorporated;
- the modal shift of transport modes for different distances has been established, including the social factor;
- the demand for heated and cooled $m^2$ in the residential and commercial sectors has been incorporated to include energy efficiency measures.

## Practical Significance

Enables the adoption and development of science-based, well-reasoned decisions and PaM to achieve climate neutrality goals for:

- ministries (economy, environment) – provides a foundation for national decision-making and the development of PaM;
- municipalities – serves as a basis for making local policy decisions, particularly in the development of heat supply systems;
- representatives of various sectors – aids in investment evaluation.

## Approbation of the Research Results

1. Dzintars Jaunzems, Ieva Pakere, Signe Allena-Ozolina, Ritvars Freimanis, Andra Blumberga, Gatis Bazbauers, **Adaptation of TIMES model structure to industrial, commercial and residential sectors,** Environmental and Climate Technologies, 2020, Vol. 24, No. 1, 392–405. ISSN 1691-5208. e-ISSN 2255-8837. doi:10.2478/rtuect-2020-0023
2. Signe Allena-Ozolina, Ieva Pakere, Dzintars Jaunzems, Andra Blumberga, Gatis Bazbauers, **Integrated MARKAL-EFOM System (TIMES) Model for Energy Sector Modelling,** 2020, IEEE 61st International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON 2020): Conference Proceedings, Latvia, Riga, 5–7 November

2020. Piscataway: Institute of Electrical and Electronics Engineers Inc., 2020, 456–462. ISBN 978-1-7281-9511-7. e-ISBN 978-1-7281-9510-0. doi:10.1109/RTUCON51174.2020.9316623

3. Signe Allena-Ozolina, Dzintars Jaunzems, Ieva Pakere, Andra Blumberga, Gatis Bazbauers, **Decarbonisation Pathways of Industry in TIMES Model,** Environmental and Climate Technologies, 2021, Vol. 25, No. 1, 318–330. ISSN 1691-5208. e-ISSN 2255-8837. Available from: doi:10.2478/rtuect-2021-0023
4. Signe Allena-Ozolina, Ieva Pakere, Dzintars Jaunzems, Andra Blumberga, Armands Gravelsins, Dagnis Dubrovskis, Salvis Dagis, **Can energy sector reach carbon neutrality with biomass limitations?** Energy, 2022, Vol. 249, Article number 123797. ISSN 0360-5442. Available from: doi:10.1016/j.energy.2022.123797
5. Signe Allena-Ozolina, Ieva Pakere, Dzintars Jaunzems, Ritvars Freimanis, Andra Blumberga, Gatis Bazbauers, **Passenger transport shift to green mobility – assessment using TIMES model** Environmental and Climate Technologies, 2022, Vol. 26, No. 1, 341–356. ISSN 1691-5208. e-ISSN 2255-8837. Available from: doi:10.2478/rtuect-2022-0026
6. Ieva Pakere, Ritvars Freimanis, Signe Allena-Ozolina, Pauls Asaris, Andrea Demurtas, Marine Gorner, Jessica Yearwood, **Cost-Optimal Policy Strategies for Reaching Energy Efficiency Targets and Carbon Neutrality,** Environmental and Climate Technologies, 2023, Vol. 27, No. 1, 999–1014. ISSN 1691-5208. e-ISSN 2255-8837. Available from: doi:10.2478/rtuect-2023-0073

## Thesis Structure

The Doctoral Thesis is based on six thematically related scientific articles that have been presented and applauded in various scientific conferences. All articles are accessible in international citation databases. Scientific articles describe the modelling approach to the identification and evaluation of PaM for achieving climate neutrality in the energy sector.

The Thesis consists of an introduction and four chapters:

- Literature review;
- Research methodology;
- Results;
- Conclusions.

The introduction presents the aim of the Doctoral Thesis, the scientific and practical importance of the work, and a brief outline of the approbation of published research results at various scientific conferences.

Chapter 1 of the Thesis includes a literature review on the topicality of energy system transformation towards climate neutrality. Chapter 2 describes the research methodology for implementing and evaluating PaM for different sectors. Chapter 3 presents the energy resource transition at different levels – technological, process, sub-sector, sector, and finally, overall energy sector. In the last chapter, the main conclusions are drawn.

# 1. LITERATURE REVIEW

The main goals of the European Union (EU) Green Deal are to reduce greenhouse gas (GHG) emissions by 55 % by 2030, compared to 1990, and to reach climate neutrality by 2050 (EC, 2019). Previous Research on EU Green Deal targets spans various aspects, including the efficiency of effort-sharing regulation and overall binding policy (Veum & Bauknecht, 2019), fairness and ambition levels (Hof et al., 2016), and how these targets mark a shift towards a more technology-neutral EU climate policy (Fitch-Roy et al., 2019). Research shows a need for a governance framework to ensure that Member States contribute to the EU-level target (Resch et al., 2019). Implementation of climate actions and reaching the set EU targets have important impacts on the overall energy system operation (Rafiee et al., 2021; Simoes et al., 2017), environment (Meessen, 2020), and economics (Temursho et al., 2020) as well as on the specific subsectors (Li et al., 2020; Runge-Metzger & Wehrheim, 2019; Siddi, 2021) which need to be considered.

To comply with EU climate ambitions, researchers have been testing different policies and scenarios to develop guidelines for policymakers and search for cost-effective renewable energy solutions (Papadogeorgos et al., 2017). The OECD report (OECD, 2019) reports that even though Latvia has achieved a high renewable energy share, a long way towards more sustainable use of available resources is ahead. Also, other research (Dolge & Blumberga, 2021) confirmed that the existing climate policies are not enough to reach the Green Deal targets in Latvia.

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 (Bolwig et al., 2018). Some TIMES models have been improved by adding consumer behaviour in the optimisation model using social surveys (Li et al., 2018; Reveiu et al., 2015; Cayla & Maïzi, 2014).

## 1.1. Multi-sectoral energy systems analysis

In France, researchers have developed the integrated MARKAL-EFOM System (TIMES) model to evaluate the possibility of achieving negative emissions in the energy sector by using bio-plants with carbon capture and storage. The study shows that these technologies will be important in achieving European emission targets (Selosse & Ricci, 2014). Soft linking between two models, Dispa-SET and JRC-EU-TIMES, has been done to analyse the potential of sector coupling in Europe (Pavičević et al., 2020).

Researchers from China have created a multi-sectoral energy model merging electricity, transportation, heat, and industrial sectors to model the decarbonisation of an energy system (Burandt et al., 2019). Often, researchers combine different types of models, for example, technically detailed bottom-up and top-down models that simulate demand and prices on energy (Andersen et al., 2019; Wu et al., 2018). The system dynamics approach has been used to model the transition from fossil fuels to renewable energy resources by taking into account different techno-economic parameters, political and social aspects, as well as human behaviour (Gravelsins et al., 2018).

German researchers have developed the TIMES model to improve decision-making related to investments (Tash et al., 2019). The energy system model has also been created for Denmark (Balyk et al., 2017).

In a study carried out in 2016 a scenario achieving 100 % renewable energy share in the EU by 2050 was introduced (Connolly et al., 2016) by showing that use of biomass for energy production is not a key pillar of renewable transition by the EU as shown in previous research (JRC, 2015). Also, for Latvia, decarbonisation is possible with limited use of biomass (Allena-Ozolina et al., 2022). Previous studies concluded that in Latvia, there is a high potential for RES integration and that targeted policies can reduce $CO_2$ emissions by 70 % in 2050 (Blumberga et al., 2016). Moreover, implementing effective policies toward bio-economy makes it possible to utilise locally available low-quality bioresources for the production of higher-added value products (Allena-Ozolina et al., 2017).

The Integrated MARKAL-EFOM System (TIMES) linear optimisation tool has been widely used to simulate the long-term effects of future transformation pathways of energy systems (Zhu & Ming, 2022; Allena-Ozolina et al., 2022; Salvucci et al., 2018).

When using modelling tools, such as TIMES, user input data, such as prices and technical potential for renewable energies, has a major impact on the modelling results; therefore, it is crucial to make modelling tools transparent and make all the input data available to the public, as most of the input data is an assumption and should be further improved by scientific debate (Connolly et al., 2016; Lima, 2019).

## 1.2. Energy system development in specific sectors and sub-sectors

### Residential sector

In many countries, sector-specific energy models have been developed, for example, the household sector model, which analyses and evaluates the implementation of renewable energy systems for regional demand (Han & Kim, 2017). Many simulations are performed to identify heat demand and to simulate future demand by clustering the residential sector in the UK (McCallum et al., 2019). Also in Quebec (Canada), the electricity supply of households, which are already low-carbon, has been modelled by combined building model simulations to investigate mitigation opportunities of greenhouse gases (GHG) (Astudillo et al., 2017).

British researchers have developed a model framework in the UK for the residential sector in TIMES to analyse homeowner preferences for heating technologies (Li et al., 2018).

### Energy transformation sector

There are many studies that analyse different parts of the energy sector, e.g., the power sector. Several European countries have set the target to reach carbon neutrality by 2050. One of the first conceptual studies analysing the 100 % renewable energy system was presented for Denmark by Lund et al. in 2010 (Lund et al., 2009).

Other Nordic countries have developed a plan to achieve carbon neutrality by speeding up the decarbonisation process in energy-intensive sectors, industrial-scale technologies, incentives for alternative technologies, and increased emission reduction requirements (CE, 2020). In addition, the Finnish government has set a very ambitious target to move toward carbon neutrality by 2035 (Khosravi et al., 2020).

The role of power storage in covering a higher share of renewable energy in Europe has been analysed by F. Cebulla et al. (2017). Another study has been done on the required backup energy in case of 100 % renewable energy usage in Europe, considering different grid connection and storage possibilities (Steinke et al., 2013). Research of 100 % renewable power system in Europe with a focus on the Netherlands (Zappa et al., 2019) shows that to meet this target, there is a need to increase the renewable energy resource (RES) and cross-border transmission capacities, as well as to use technologies with higher efficiency.

The German energy transition targets (Energiewende) a competitive low-carbon economy until 2050 by excluding nuclear power from the energy balance by 2022 (Schmid et al., 2016). Wiese et al. (2022) have compared the results from previous research on decarbonisation strategies for Germany.

The research results for the United Kingdom's heat supply decarbonisation show that it requires that heat-related emissions of $CO_2$ from buildings reach a near-zero level by 2050, and there should be a 70 % reduction in emissions from industry (Chaudry et al., 2015).

The model of deep decarbonisation for Italy shows that emissions can be cut by 79–97 % compared to 1990 levels due to increased share of RES, radical electrification of the energy and increased production energy of technologies (Borasio & Moret, 2022).

## Industrial sector

Bottom-up simulation model FORECAST model was created in order to analyse several scenarios of industry sector decarbonisation (Fleiter et al., 2018). Another model was used for the investigation of the energy efficiency performance of 18 main industrial sub-sectors of Latvia, where composite index methodology was used to develop an energy efficiency index (Dolge et al., 2020). A nonlinear autoregressive distributed lag model was used to investigate the relationship between energy efficiency and economic growth of 11 European Union countries (Marques et al., 2019).

Comparison of possible transition of industry sector performance under 2-degree target between China, India and Western Europe was done using Global TIMES model (Wang & Chen, 2019).

A techno-economic model based on TIMES has been built for the cement sector in Switzerland (Obrist et al., 2020). In another study, a detailed and rich technological database was created for the five most energy-intensive industrial subsectors – iron and steel, non-ferrous metals, non-metallic minerals, chemicals, and pulp and paper (Lerede et al., 2021).

The effect of the European Industrial Emissions Directive on the air emission values was evaluated in Spain (Calvo et al., 2021). Another study on the cement industry was made in France, where an energy model was built to assess future power generation in the cement industry on an international and regional scale (Hache et al., 2020). Energy system models and a material flow model were made to assess the impact on the cement industry performance in limiting global warming (Dhar et al., 2020). Energy conservation and $CO_2$ abatement potential were analysed in the cement industry of Germany (Brunke & Blesl, 2014), and specific characteristics of the cement industry were added to the globally integrated assessment model to analyse energy consumption and GHG emissions (Kermeli et al., 2019).

Fewer studies focus on non-energy-intensive industries like the food industry. A system dynamics model was made for assessing energy savings in the United States food industry (Xu & Szmerekovsky, 2017), while a detailed, bottom-up energy model was built for the French food and beverage industry to analyse energy efficiency and amount of $CO_2$ emissions (Seck et al., 2013). Resource efficiency is assessed in the food industry by using an optimisation model in another study (Jonkma et al., 2020).

## Transport sector

A system dynamics modelling approach is widely used for transport sector modelling. For the case of Latvia, system dynamics models are developed to analyse $CO_2$ emission reduction potential in road transport (Barisa & Rosa, 2018; Barisa & Rosa, 2018) and to explore a possible promotion of biomethane (Barisa et al., 2020). The system dynamics model is built to support policymakers in testing different policy scenarios to improve road safety in the USA (Alirezaei et al., 2017). The transition towards alternative fuels (Shafiei et al., 2015) and the potential of biofuels (Shafiei et al., 2015) were modelled in an integrated system dynamics model for Iceland.

The linear optimisation TIMES model has been previously used to evaluate the sensitivity of the European road transport sector, considering different variations of investment cost and vehicle efficiency (Lerede et al., 2021). Additionally, stochastic multicriteria acceptability analysis is used to evaluate modelling results under an economic and environmental criterion, complementing the cost minimisation approach. Electric vehicles are seen as most favourable in all three dimensions in the study. Another study presents an introduction of the consumer behaviour aspect into the TIMES optimisation model (Ramea et al., 2018).

Modal shift is assessed for Scandinavia's transport sector using the TIMES model (Salvucci et al., 2019). Also, other papers represent the importance of the modal shift to reach carbon neutrality in the transport sector (Tattin et al., 2018; Salvucci et al., 2018).

When it comes to the transport sector, changes in technology and fuel switching are not enough to mitigate climate change; policies must focus on behavioural change in the use of transportation (Green et al., 2012). Typically, the TIMES model as an optimisation tool does not include competition between different travel modes, but with the introduction of elements such as travel time budget, travel speed, comfort, etc., it can be applied for broader policy modelling (Brown et al., 2018; Ollier et al., 2022; Dalla Longa et al., 2018).

Previous studies show that issues related to the development of the energy sector are important in terms of individual countries, regions, and sectors. Similarly, developing powerful modelling tools is important for various levels of analysis and decision-making. In Latvia, too, it is necessary to develop a methodology that would be able to find the direction of development of the energy sector to ensure the fulfilment of the obligations set by the Paris Agreement and the European Climate Law – to achieve climate neutrality by 2050. For a small economy like Latvia, it is especially important to find solutions to achieve this goal with the lowest possible total costs, which this Doctoral Thesis offers.

# 2. METHODOLOGY

## 2.1. TIMES – optimisation tool for energy systems modelling

The vertically integrated model generator TIMES is used worldwide to model different local, national, or global energy systems. It aims to find the minimum global costs for energy services by considering different input data: energy service demands, estimates of the existing energy stocks, properties of the existing equipment, and future technologies. Furthermore, TIMES allows the analysis of different energy and environmental scenarios and policy measures (Loulou et al., 2016).

TIMES is also known as a bottom-up, linear programming tool applied for long-term energy systems planning to allow for the analysis of the effect of different scenarios. It optimises the whole energy system, including supply and demand services, by minimizing the total cost in the considered modelling period (Loulou et al., 2016). To achieve the goal of the Thesis, TIMES has been selected as the modelling tool due to its powerful technical and economic capabilities, which allow it to analyse the whole energy system and find the most economical allocation of technologies and resources, allowing to assess the impact of planned PaM.

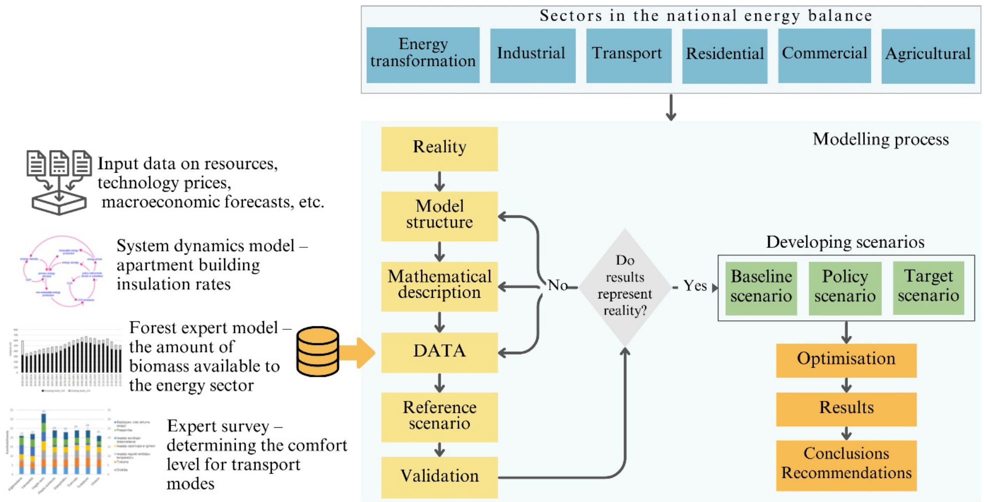



Fig. 2.1. Research algorithm and modelling steps.

The methodology applied in the Doctoral study consists of several steps (see Fig. 2.1). Description of reality, development of model structure, mathematical description of conditions, and collection of model input data are the first steps. In the next step, the reference scenario is being processed and validated. If the validation results do not describe reality sufficiently well, then the model structure, mathematical description, and data are reviewed and improved. When the validation results match the real situation sufficiently well, optimisation of the scenarios can be done. In the final phase, the results are compiled, and conclusions are put forward.

## 2.2. Development of the TIMES model for the national level energy system

The built TIMES Latvia model is a linear optimisation tool developed and improved to characterise the energy sector and relevant sub-sectors (Zhu & Ming, 2022; Allena-Ozolina et al., 2022). In the TIMES Latvia energy system model, the full energy system is represented from resource supply to end-use energy services demands, such as space heating, production processes, and personal/freight transport (in passenger or tonne-kilometre). The model represents a broad suite of energy and emission commodities, technologies, and infrastructure (Jaunzems et al., 2020). However, the model does not include detailed analyses and forecasts for non-energy sectors, e.g., agriculture and waste management.

The modelling process analyses each sector separately, making improvements in each of them, bringing the model closer to the real-life situation to obtain more complete results and incorporate different PaM, such as sector-specific funding, taxation, GHG target, etc. 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. Certain limitations on available energy sources have been derived as input parameters from the forestry management model and the agriculture model used in previous studies (Allena-Ozolina et al., 2022).

The TIMES Latvia model was developed gradually by analysing each sector, incorporating the latest available technology and other parameter databases, and creating sector-specific improvements. This approach ensures the ability to analyse the impact of various PaM. Scientific articles were written sequentially by sector, as shown in Fig. 2.2.

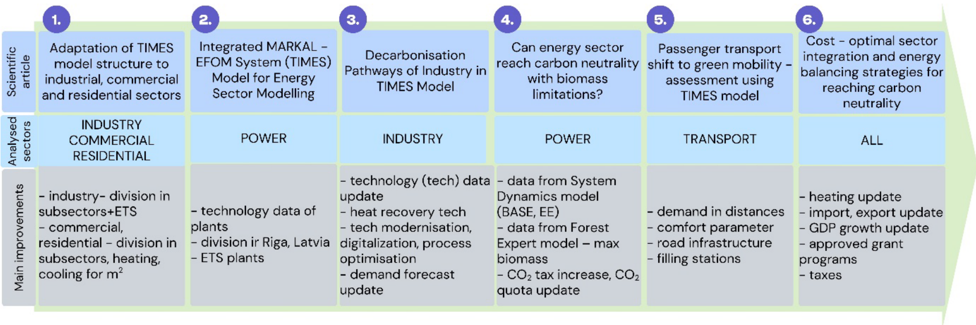



Fig. 2.2. Model development in scientific articles.

The industrial, commercial, and residential sectors are described in the first article, which analyses and outlines the main model improvements, such as industry division into sub-sectors and separating of the European Union emission trading system (ETS) part of industry, as well as the commercial and residential sectors adding cooling and heating parameter depending on square meters. The second article examines the energy transformation sector, detailing key technological data and dividing ETS and non-ETS stations, as well as differentiating between Riga and the rest of Latvia. The third article focuses on the industrial sector, highlighting the most significant improvements in technological data updates. The fourth article also addresses the energy transformation sector, but it includes integration with other modelling tools and incorporates $CO_2$ tax and quota increases. Structural changes in the transport sector are described in the fifth article, while the sixth article covers all sectors. The modelling approach for each sector is detailed in the following subsections.

### 2.2.1. Modelling of specific sectors and sub-sectors

The following subsections describe the modelling approach and structural improvements for the industrial, commercial, residential, energy transformation, and transportation sectors, specifically passenger transport on land.

**Industrial sector modelling**

Latvia is a part of the ETS. Therefore, the energy demand of almost every industrial (IND) sector in Latvia has been divided into ETS sector and non-ETS sector consumption. The ETS system of Latvia mostly covers power plants and other incineration plants with a nominal thermal input of more than 20 MW. Also, specific equipment, like coke ovens, iron and steel, cement clinker and other technologies, are included in the ETS system (EP, 2015). In 2017, the ETS sector covered around 15.5 % of the total resource demand in Latvia, equal to 5,561 TJ. Non-ETS covered the rest of the demand, i.e., 84.5 % or 30,335 TJ (CSBL, 2017).

Data from the IND energy audits carried out from 2016 to 2018 were used to determine the share of the total energy sources used for each process. The energy balances from 122 different enterprises were analysed to identify the distribution of various energy sources.

The IND sector is Latvia's third-largest energy consumer, accounting for 21 % of the total final energy used in 2017, of which 38 % was wood biomass, 18 % electricity, 14 % oil products, and 13 % natural gas. The IND sector in Latvia consists of 13 subsectors, of which the majority of energy is used in the manufacturing of wood and wood products.

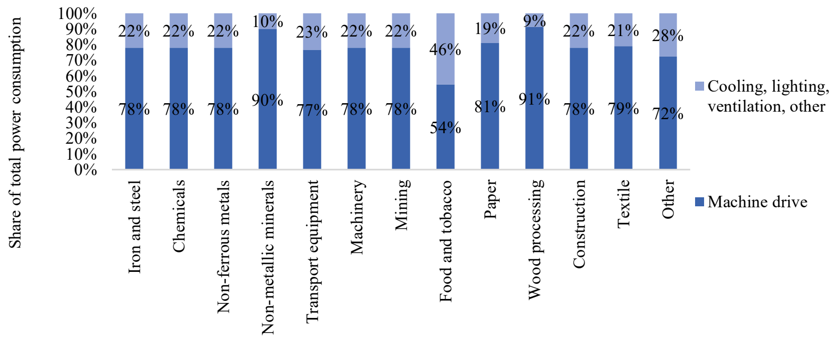



Fig. 2.3. Power consumption structure in IND sub-sectors.

In the TIMES model, power consumption in the IND sector has been divided into two large parts – electricity used for machine drive to ensure manufacturing processes, and auxiliary processes – cooling, lighting, ventilation, and other power-consuming processes. In most IND sub-sectors, around 77 % to 81 % of power is used for machine drive (see Fig. 2.3). A higher share of electricity consumption for machine drive is in the sub-sectors of non-metallic minerals and wood processing industries. In contrast, the lower share of electricity for machine drive is in food and tobacco production, only 54 %.

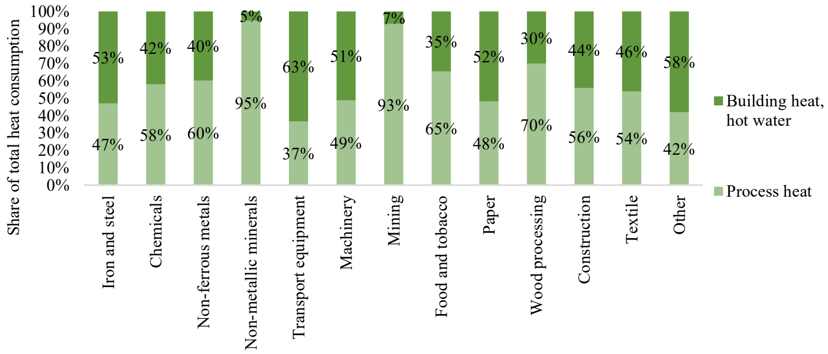



Fig. 2.4. Heat consumption structure in IND sub-sectors.

Heat consumption in the TIMES model has been divided into thermal energy used for space heating and hot water preparation, and process heat used for manufacturing processes. Differences in heat consumption division in subsectors are more significant compared to power consumption (see Fig. 2.4). In some subsectors, less than half of the heat is used for process heat (transport equipment production). Nevertheless, there are subsectors where even more than 90 % of heat has been used for production processes – non-metallic minerals production and mining.

The quality of the model results is highly related to assumptions that are made in the area outside the model structure. One of the key assumptions for the industrial sector is the energy demand trajectory of the sub-sectors up to 2050. Energy demand in sectors of the national economy depends on several drivers, e.g., GDP, economic growth of sectors, population, floor area, etc. The energy demand of the industrial sector is based on the sectoral value added forecast for Latvia (Capros et al., 2016). There is more specific demand in industries defined by energy services, e.g., energy for process heat, machine drive, building heat and hot water, feedstock, and others. According to research done and projections of industry development pathways, the overall demand for energy services in the industry sector is expected to increase by about 31 % in 2050 compared to 2017. The increase in demand for energy services in the wood sub-sector is around 30 %, in the food sub-sector, circa 21 %, but in the minerals sub-sector, around 56 %.

## Commercial sector modelling

The commercial (COM) sector has different buildings and resulting energy resource consumption levels. Therefore, it has been divided into seven subsectors based on the building classification (CM, 2018).

Resource consumption for almost all COM 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 add more precise PaM directly to the energy efficiency of specific buildings. To ensure correct process development in the TIMES model, heating and cooling processes have been separated as pre-processes for heating and cooling areas, which are now defined as end demand (see Fig. 2.5).

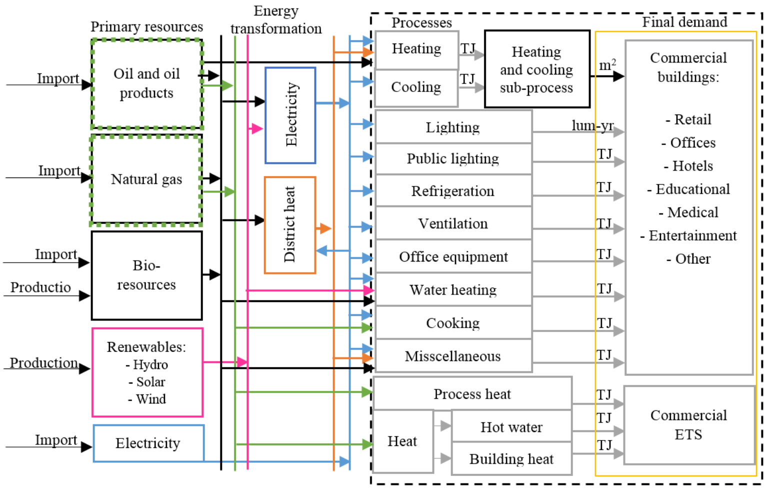



Fig. 2.5. Process scheme of the COM sector.

Like other demand processes, demand for heating and cooling area ($m^2$) has been affected by demand drivers like GDP growth and elasticity for evolution with GDP. Specific plants appear in the COM sector as ETS participants. Those mainly ensure different manufacturing processes. In the TIMES model, they have been divided separately with similar processes to the IND sector – process heat, building heat, and hot water.

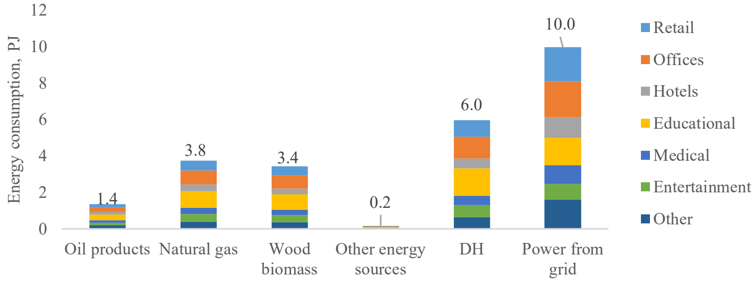



Fig. 2.6. Resource consumption structure in COM sub-sectors in 2017(CSBL, 2021).

The COM sector used 15 % of the total final energy in 2017, equal to 25 PJ. The COM sector has been divided into seven sectors based on building classification (CM, 2018). Power is the main resource used in the COM sector, reaching almost 10 PJ and making up 43 % of the total final electricity consumed in 2017. Also, 27 % of the total final natural gas consumption, equal to 3.8 PJ, was used in the COM sector, where most of it was consumed in educational buildings and offices (see Fig. 2.6).

Electricity consumption structure differs in COM sub-sectors (see Fig. 2.7). In retail buildings as well as in buildings for medical facilities and entertainment, most of the electricity is spent on lighting. In office buildings, the office equipment consumes the most power, but in hotel and educational buildings, most of it is used for water heating.

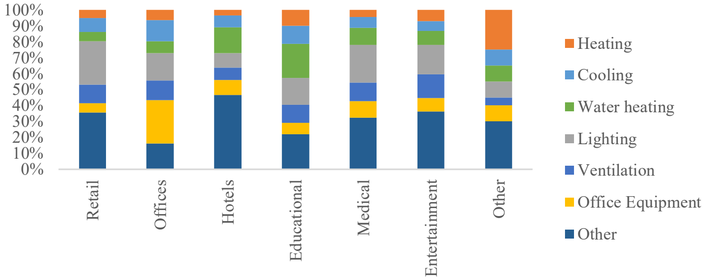



Fig. 2.7. Electricity consumption structure in the COM sector.

DH and primary energy sources have been used for three processes: water heating, space heating, and other processes like cooking. In almost all COM subsectors, heating has mainly been used for space heating and only a small share for water heating.

**Residential sector modelling**

The residential (RSD) sector was divided into two sections – single-family houses and apartment buildings, as both use different energy resources and differ in their consumption. It is assumed that the single-family houses are not connected to the DH network, but some of the apartment buildings are connected to a centralised heat supply.

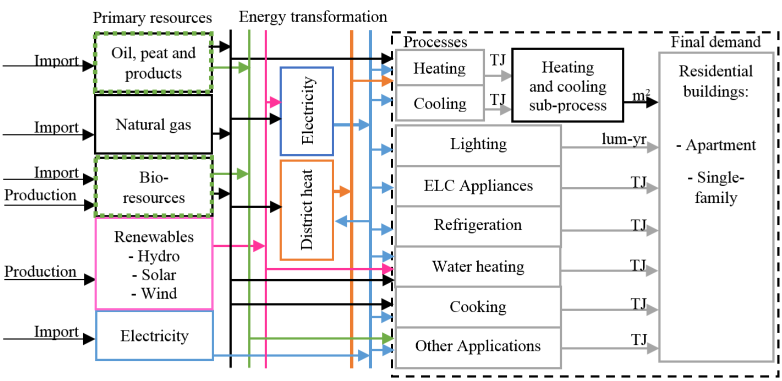



Fig. 2.8. Process scheme of the RSD sector.

Processes analysed in the TIMES model for the RSD sector are heating, cooling, water heating, refrigeration, lighting, cooking, electrical appliances, and other applications. New heating and cooling sub-processes are created similarly to those in the COM sector. This helps to overcome technology linking to a specific type of building and allows the addition of PaM related to the energy efficiency of buildings more precisely. The process scheme for the RSD sector is presented in Fig. 2.8.

In addition, heating and cooling processes have been defined as pre-processes, whereas the rest of the processes, like cooking, lighting, and others, are marked as the final demand and will be analysed in different scenarios.

The second largest part of the final consumption is dedicated to the RSD sector, reaching 29 %. Most of it was wood biomass consumption, equal to 21 PJ, of which 38 % was used in single-family houses and 62 % in apartment buildings (see Fig. 2.9 a)).

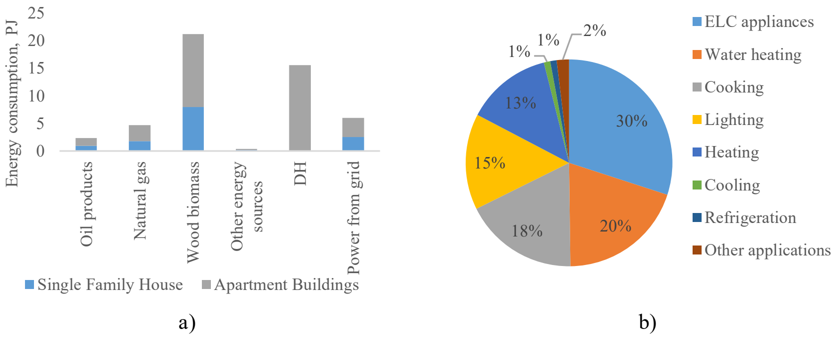



Fig. 2.9. Resource consumption structure (a) and structure of power consumption (b) in the RSD sector in 2017.

The structure of electricity consumption is similar in single-family houses and apartment buildings, as consumer behaviour does not depend on the building type. According to Eurostat (2019), largest share of electricity, i.e. 30 %, is consumed for different electrical appliances (TV, radio, mobile charging, etc.), 20 % is used for water heating, 18 % for cooking, 15 % for lighting, and 13 % for heating (see Fig. 2.9 b)).

**Modelling the energy transformation sector**

District heat (DH) in Latvia is mainly produced in heating plants (HP) and combined cogeneration plants (CHP), where power is also generated.

The modelled energy sector includes district heating and electricity production. In order to better model trends in the energy sector, it is divided into two geographic sub-sectors – Riga and the rest of Latvia.

Data on the consumption of primary energy resources and amounts of heat produced are obtained from reports on air pollution (2-Gaiss, 2019) and publicly available annual reports (RS, 2017; Latvenergo, 2017). Data from the Central Statistical Bureau of Latvia and emission permits are used to determine installed capacities of technologies in boiler houses, hydropower plants, wind power plants and cogeneration plants (SES, 2019).

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 in households, commercial, and industrial sectors mainly for self-consumption coverage. Therefore, calculations on the proportion of electricity produced by solar panels in the energy transformation sector are made in the model. Due to the lack of data regarding solar electricity not being transferred to the power grid, the information available from permits issued by the Ministry of Economics for the construction of new generation capacity was used (MoE, 2019). The total amount of solar electricity produced in different sectors was estimated to be around 5.65 TJ in 2017.

In the TIMES Latvia model, the structure of DH is built based on the division in energy balance, including CHP and HP technologies, as well as emission trading system (ETS) and non-ETS plants to model the $CO_2$ emission costs (see Fig. 2.10) because Latvia is a part of the European Union ETS (EC, 2003). Additionally, the structure has been divided into two regions – Riga and the rest of Latvia, because Riga, with the two high-capacity CHPs, is significantly different from the rest of Latvia. The heat from plants in Riga (LTHR) and the rest of Latvia (LTHL) is transferred to the grid and finally to the industrial, residential, commercial, and agricultural demand sectors.

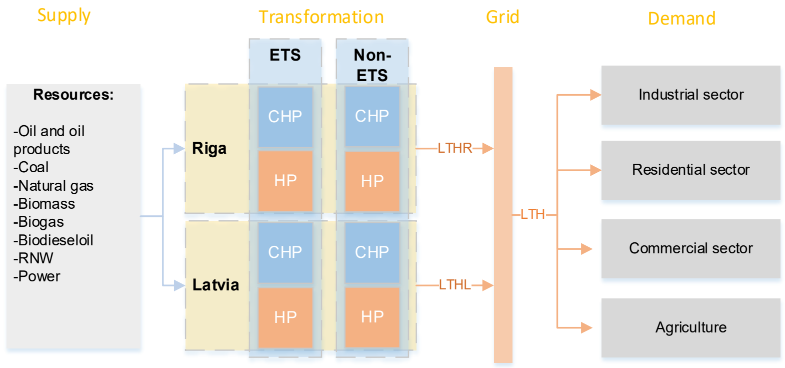



Fig. 2.10. DH structure in the TIMES Latvia model.

The model considers all relevant cost flows – investments, fuel costs, operational costs, and taxes to optimise energy production. One of the essential assumptions is the parameters of available technologies in the energy transformation sector. Therefore, the Danish Technology Catalogue (DEA, 2018) was used to determine the primary technical data of technologies, e.g., operational lifetime, efficiency parameters, capital costs, operational and maintenance costs, and variable costs.

**Passenger transport shift modelling**

The transport sector in the TIMES Latvia model consists of two blocks – passenger travel and freight transport. In this Thesis, passenger land travel has been analysed, excluding traffic by air and water. The road section studied includes road and rail transport as well as individual modes of mobility. Road transport consists of cars, buses, trains, trams, and trolleybuses, while individual transport modes include walking and cycling (see Fig. 2.11).

For more accurate modelling, the 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., in short distances walking, cycling, car, bus, tram, and trolleybus may substitute for each other if the travel destination matches. In contrast, only cars, intercity buses, and trains can be used for distances of 25 km and longer. 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.

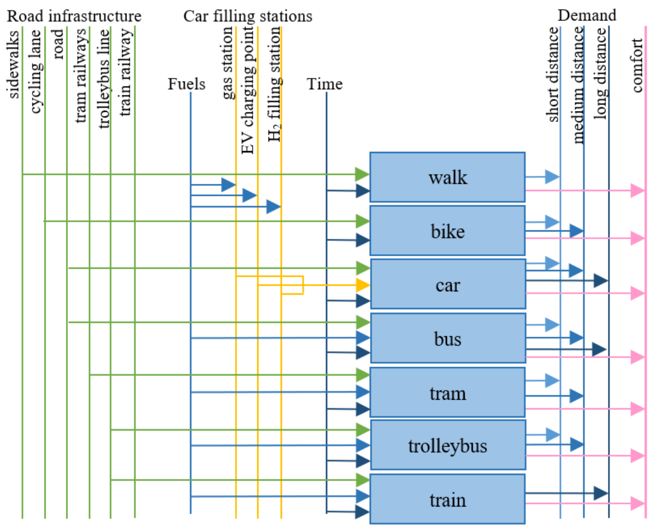



Fig. 2.11. Structure of passenger road transport in the model

The length of the distances in the TIMES model was split up to account for the existing mobility patterns (CSBL, 2018). The limit values for the distances were set to include non-motorised modes of transport – bicycling and walking. Figure 2.12 represents the assumed proportion of transportation modes used in each distance for the base year. These assumptions are based on a study conducted in Denmark (Tattini, 2018) to model the transport sector, which was adapted to the situation in Latvia for the year 2017.

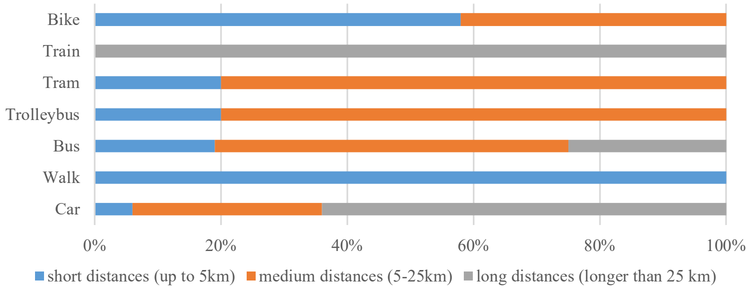



Fig. 2.12. Use of transport modes depending on the distance.

In addition, the level of comfort of different modes has been introduced in the model. As TIMES is an optimisation tool that looks for the most cost-effective system structure, comfort is an essential element that provides more accurate results by including human behaviour. Several experts assessed the comfort level on a scale from 1 to 5 for each vehicle type according to seven factors – safety, noise level, and ability to regulate indoor temperature, ability to travel with family, opportunities to socially distance, accessibility, and barrier-free environment. The availability factor characterises the possibility of immediate use of the vehicle, whether it is available in all conditions (e.g., private car) or whether the vehicle timetable must be followed (for public transport). This parameter does not include the availability of infrastructure, such as cycle lanes, as this parameter is included separately (as road infrastructure) in the model. It was assumed that the highest comfort level is for passenger cars, significantly exceeding the comfort level of other modes of transport (see Fig. 2.13).

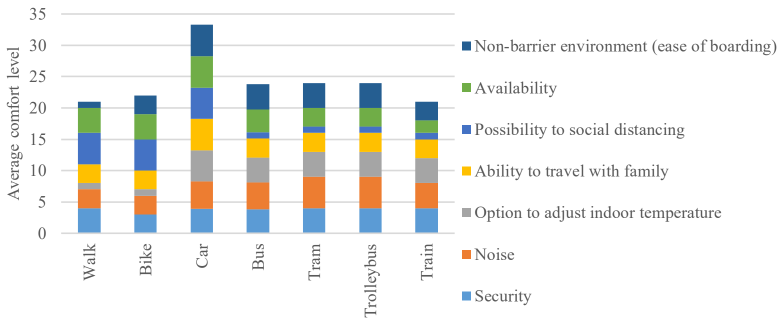



Fig. 2.13. The average comfort level for different types of transportation, based on experts' assessed factors for seven comfort elements on a scale from 1 to 5.

This is not only because the car provides a more comfortable environment but also allows one to travel with family, distance oneself, regulate the indoor temperature, and, most importantly, is always available. The lowest rating is for walking, and the train because it is not so accessible in the whole territory of Latvia due to a lack of railway infrastructure. It is also challenging to get in with a wheelchair or baby carriage in the outdated trains.

### 2.2.2. Input data from other modelling tools

The changes in DH consumption in sectors are derived from the SD model. In the BASE scenario, demand for DH is steady in the RSD sector, where the amount of DH is around 16 PJ, while in other sectors, demand for DH is increasing by 10 % in industrial (IND), about 33 % in agriculture, and for around 9 % in the COM sector (see Fig. 2.14). On the other hand, in the NECP and GHG TARGET scenario, the heat consumption decreases by around 43 % in the RSD sector due to significant building renovation rates and about 8 % in the COM and 7 % in the IND sectors, where the energy efficiency measures are also considered.

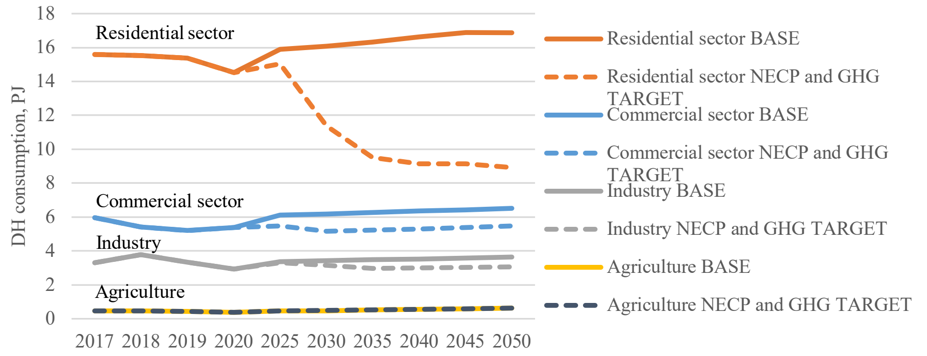



Fig. 2.14. DH demand in sectors.

Results of the forest data processing program "Forest Expert" developed by the Latvia University of Life Sciences and Technologies are used as inputs for the TIMES model. 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 amount of wood pellets available for the energy sector will increase. Still, the availability of other wood biomass will decrease by around 30 % in 2050 compared to 2017 (see Fig. 2.15).

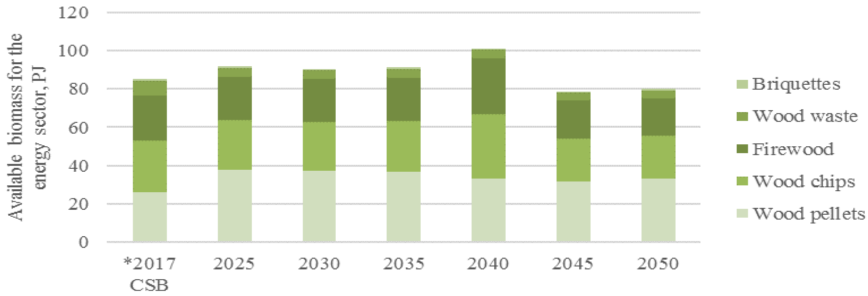



Fig. 2.15. The maximum amount of biomass available for the energy sector (Dubrovskis & Dagis, 2018).

The maximum biomass is achieved in 2040, 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 assortment of this species mostly goes to firewood. The same biomass limitation derived from the "Forest Expert" model is used in all TIME's scenarios without considering different forest management policies.

### 2.2.3. Scenario development

Three main scenario types were developed in the Doctoral Thesis – baseline scenarios (BASE, WEM), which include only existing policies and trends, policy scenarios (NECP, WAM), which include different PaM and target scenarios (GHG TARGET, OPT_Solar and OPT_EE), which include GHG reduction target (see Table 2.1).

Table 2.1

Scenarios Developed in the Thesis

| Name of scenario | Type of scenario | Scientific article | Main additional parameters |
|---|---|---|---|
| BASE | Baseline | 2–5 | n/a |
| WEM | Baseline | 6 | • GDP growth ~3.2 %/year in period 2020–2050<br>• The approved grant program for the planning period until 2027 |
| NECP | Policy | 2–5 | • PaM specified in NECP2030 |
| WAM | Policy | 6 | • GDP growth ~ 3.2 %/year in period 2020–2050<br>• The approved grant program for the planning period until 2027<br>• Additional PaM – EE for buildings, industrial processes, subsidies for electric transport, etc. |
| GHG_TARGET | Target | 4–5 | • Total GHG reduction in 2050 by 70 % |
| OPT_SOLAR | Target | 6 | • Total GHG reduction in 2050 by 90 %<br>• Reduction of primary and final energy consumption by ~ 16 % in 2030 compared to 2020<br>• Prioritised private solar energy production |
| OPT_EE | Target | 6 | • Total GHG reduction in 2050 by 90 %<br>• Reduction of primary and final energy consumption by ~ 16 % in 2030 compared to 2020<br>• Solar energy produced and direct consumption are accounted for in final consumption |

### 2.2.4. Model validation and sensitivity analysis

As an example of the validation process of the model, the comparison of resource consumption in the energy transformation sector of the model BASE results and official statistical data from the Central Statistical Bureau of Latvia for the years 2018, 2019, and 2020 is shown (see Fig. 2.16).

The total resource consumption in the energy transformation sector in statistical data slightly differs from the model results. The total resource consumption in the energy transformation sector in statistical data slightly differs from the model results. The total amount of resources consumed in the energy transformation sector was 949 TJ or 1.7 % less in 2018, 850 TJ or 1.5 % more in 2019, and 588 TJ or 1.2 % less in 2020 than the modelling results.

The primary energy sources used in heat supply (natural gas, wood chips, and biogas consumption) obtained from the model gave no more than a 7 % difference from the statistical data. Natural gas consumption of the model is around 2 % higher than in statistics, biomass consumption is 1 % higher in 2018, 7 % less in 2019, and 1 % less in 2020, while biogas consumption was 6 % more in 2018 and 2020 and 4 % more in 2019 compared to statistical data. Therefore, the results of resource consumption in the transformation sector provided by the model match the statistical data sufficiently well.

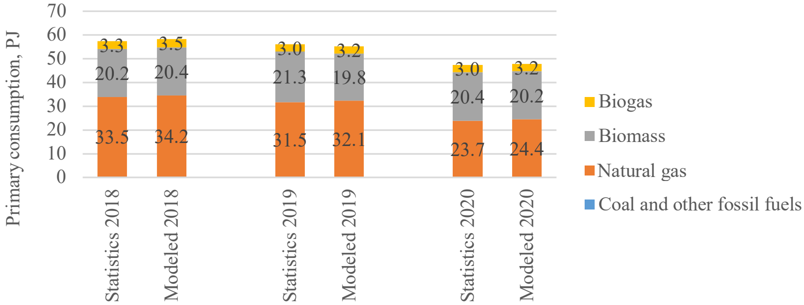



Fig. 2.16. Results of the model and statistical data of primary resource consumption in the energy transformation sector for the years 2018, 2019 and 2020 (CSBL, 2021).

As the sensitivity analysis example is shown by reducing the amount of available biomass for the energy transformation sector for GHG TARGET scenario by an additional 20 % (GHG TARGET+). It could be evident if the export of biomass resources would continue to grow or stricter biomass cascading principles would come into force. However, due to the high impact of heat pumps in the DH sector, such reduction of available biomass does not cause an elevated difference.

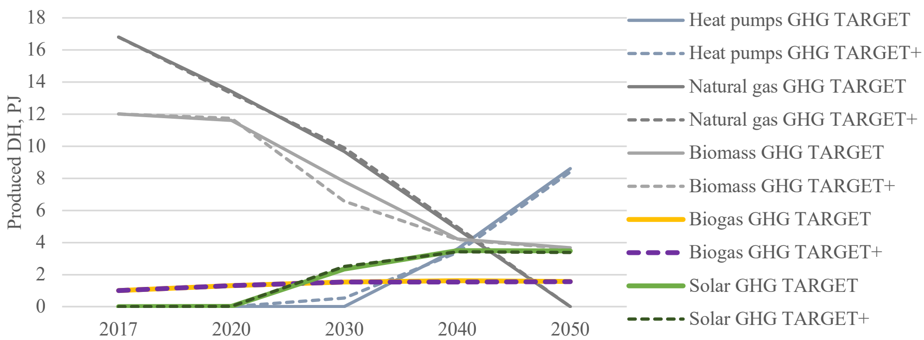


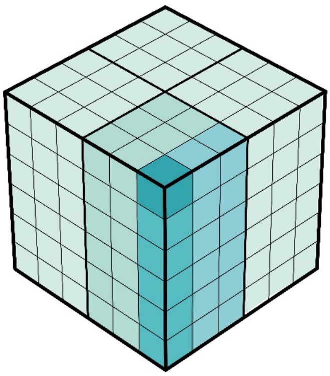

Fig. 2.17. Results of sensitivity analysis – DH produced by the type of resource in GHG TARGET and GHG TARGET+.

Results of heat production rates compared for both scenarios only showed differences in the year 2030 when biomass use decreases by 15 %, substituting it with the help of heat pumps (see Fig. 2.17). If biomass is limited for the energy transformation sector, the use of heat pumps becomes beneficial earlier.

# 3. RESULTS

## 3.1. Representation of energy service provision at different levels of detail

The results of the Thesis are presented using the bottom-up approach of the TIMES modelling tool. This involves first analysing data at the lowest level of detail – technologies – then progressing to processes, subsectors and sectors, ultimately providing results for the entire energy sector. This approach allows different levels of detail to be represented depending on the intended purpose (see Fig. 3.1).



| Level of results | Type of results | Results described |
|---|---|---|
| 1. | Technological | • in the transport sector – types of passenger transport (private car, bus, train, etc.)<br>• in the energy transformation sector – wind turbines, heat pumps |
| 2. | Process | • in the energy transformation sector – provision of thermal energy |
| 3. | Sub-sector | • in the industry sector – wood and wood products, food and tobacco and non-metallic minerals sub-sectors<br>• in the transport sector – land passenger transport |
| 4. | Sector | • industry |
| 5. | Total energy system | • total energy system |

Fig. 3.1. Levels of obtaining and presenting results.

In the next sub-chapters, several examples of the results at different levels are depicted: technological-level modal shifts in the transport sector and renewable technologies in the power sector; process-level resource supply mix in DH; sub-sector and sector-level resource transition; and total energy system total primary and final energy consumption.

### 3.1.1. Modal shifts in passenger transport and renewable technologies in the power sector (1st level)

The restructuring of the transport sector model enables the inclusion and evaluation of PaM related to modal shifts, such as support for public transport improvements and the creation of bike lanes. Transport sector technologies include vehicles such as private cars, buses, and trains. The Thesis further describes the changes in technology for BASE, NECP, and GHG TARGET scenarios, as well as the share of public transport and electric cars in WEM, OPT_EE, OPT_Solar, and WAM scenarios.

In the base year, 77 % of mobility is covered by private cars while 15 % by buses, 3 % by walking and cycling, 2 % by trolleybuses and trams, and another 2 % by train (see Fig. 3.2). Usage of buses is increasing to 20 % in BASE, 23 % in NECP, and 24 % in GHG TARGET in 2030. In 2050, the usage of buses is growing even more, covering 29 % in BASE and around 39 % in NECP and GHG TARGET scenarios. Walking and cycling, usage of trolleybuses, trams, and trains are about 3 % in each scenario in 2050, except in GHG TARGET, where usage of trolleybuses, trams, and trains is increasing to around 16 % in total.

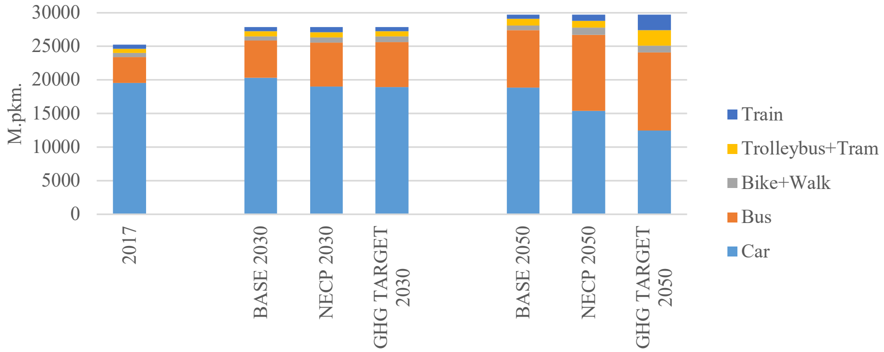



Fig. 3.2. Projection of the use of passenger transport modes for alternative scenarios.

Mainly, private cars are used for mobility in short distances, i.e., up to 5 km, covering around 41 % in the base year (see Fig. 3.3). Also, buses are used a lot, covering 25 % of passenger travel, but walking and cycling provide 28 %. The usage of buses is increasing in all scenarios in 2030, ensuring around 37 % mobility, while it is about 50 % in 2050. Cycling and walking are becoming more popular in NECP and GHG TARGET scenarios, covering approximately 27 % in 2030 and 29 % in 2050. In BASE, only 20 % of mobility will be done by individual modes of transport in 2050.

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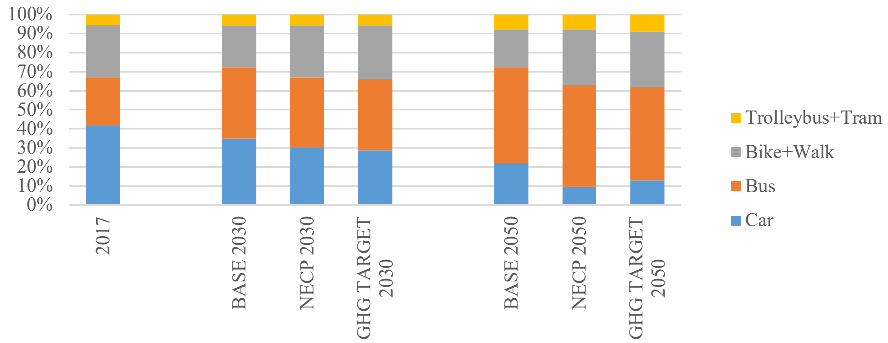
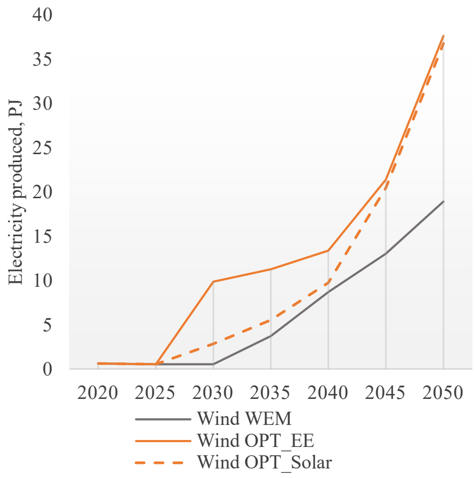



Fig. 3.3. Distribution of passenger transport mode usage for short distances.

In OPT_EE and OPT_Solar pathways, the total energy production by the power sector is projected to exhibit a variable trend until 2030, after which a substantial increase in wind capacity is anticipated (see Fig. 3.4 a). Following this, electricity generation is projected to steadily rise until 2050. Due to the availability of low-cost wind power, both optimisation scenarios, as well as the WEM scenario, substantially increase the use of large heat pump (HP) technology in district heating systems (see Fig. 3.4 b).



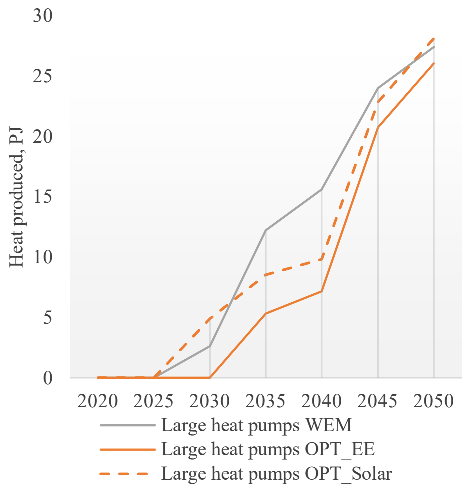




Fig. 3.4. Comparison of wind production rates (a) and heat production with large, centralised heat pumps (b) in different optimisation pathways.

### 3.1.2. Resource supply mix in DH (2nd level)

As an example of the results of the 2nd level, the changes in resource supply mix to ensure the demand of DH for the GHG TARGET scenario are shown.

In the GHG TARGET scenario, the use of biomass is decreasing from around 12 PJ in 2017 to 3.7 PJ in 2050, providing only around 20 % of necessary heat in the DH sector (see Fig. 3.5). The primary energy source for DH in this scenario in 2050 is large scale heat pumps which provide up to 47 %. Modelling results show that solar energy has already become cost-effective in the 2030 scenario and will cover around 19 % of produced DH in 2050. The heat produced by biogas slightly increased from about 3 % in 2017 to about 9 % in 2050.

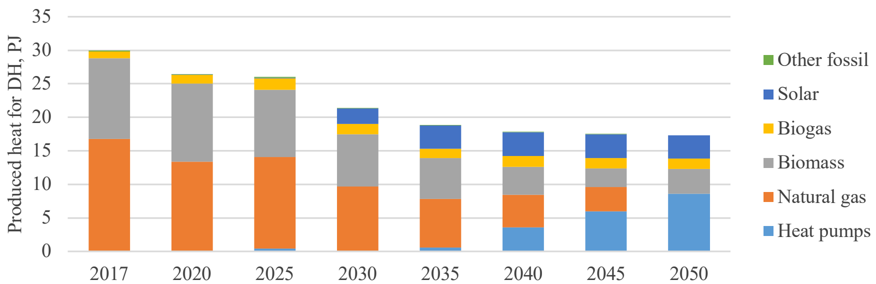



Fig. 3.5. DH produced by the type of resource and technology (heat pumps) in GHG TARGET.

### 3.1.3. Resource transition in specific sub-sectors and sectors (3rd and 4th level)

Changes in resource consumption at the subsector and sector levels are described for the three main subsectors of the industrial sector: food and tobacco, wood and products, and non-metallic minerals. Additionally, the total energy consumption of the industrial sector as a whole is detailed for BASE, NECP, and NECP+ scenarios. In the transport sector, changes in resource consumption are described for the subsector that includes passenger transport on land for the BASE, NECP, and GHG TARGET scenarios.

Results show that in 2030, final energy consumption in the food sub-sector decreases in BASE (3.2 PJ), NECP (3.1 PJ) and NECP+ (2.8 PJ) scenarios while in the REF scenario, consumption remains steady (3.3 PJ) (see Fig. 3.6).

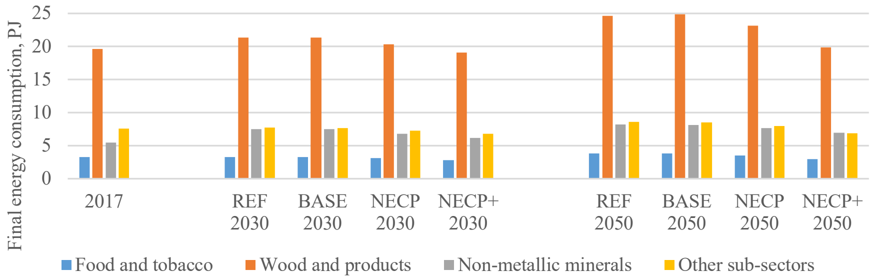



Fig. 3.6. Final energy consumption in the industry sub-sector in the modelled scenarios.

In 2050, the amount of energy consumption increases in all scenarios – REF and BASE scenarios (3.8 PJ), NECP (3.5 PJ), NECP+ (3 PJ). In 2030, energy consumption in the wood sub-sector is increasing in REF and BASE (21.3 PJ), in NECP (20.3 PJ), while decreasing in NECP+ (from 19.6 PJ in 2017 to 19.1 PJ). In 2050, consumption is increasing in all scenarios – REF (24.7 PJ), BASE (24.9 PJ), NECP (23.1 PJ) and NECP+ (19.9 PJ). Energy consumption in the minerals sub-sector in 2030 and in 2050 is increasing in all four scenarios – REF and BASE (7.5 PJ and 8.2 PJ), NECP (6.8 PJ and 7.7 PJ), NECP+ (6.2 PJ and 7 PJ) accordingly. In other industrial sub-sectors, the total final energy consumption increases in REF and BASE (7.7 PJ) and decreases in NECP (7.3 PJ) and in NECP+ (6.8 PJ), while in 2050, consumption increases in all scenarios – REF (8.6 PJ), BASE (8.5 PJ), NECP (8 PJ) and NECP+ (6.8 PJ).

In the wood sub-sector, the main resource is wood biomass, i.e., wood waste and wood chips dominate in energy consumption compiling 7 PJ and 4 PJ, respectively in 2017 (see Fig. 3.7). Wood chips consumption is increasing to circa 7.5 PJ in all scenarios in 2030 and from 11 PJ to 12 PJ in 2050, while wood waste consumption is from 4.8 PJ to 6.2 PJ in 2030 and from 3 PJ to 7 PJ in 2050.

Consumption of electricity remains stable for the whole modelling period and is circa 3 PJ. Amount of used DH in 2030 and in 2050 increases in REF (3.1 PJ and 3.9 PJ), in BASE (2.8 PJ and 3.4 PJ), while decreases in NECP (2.4 PJ and 2.3 PJ) and NECP+ scenarios (2.5 PJ and 2.2 PJ).

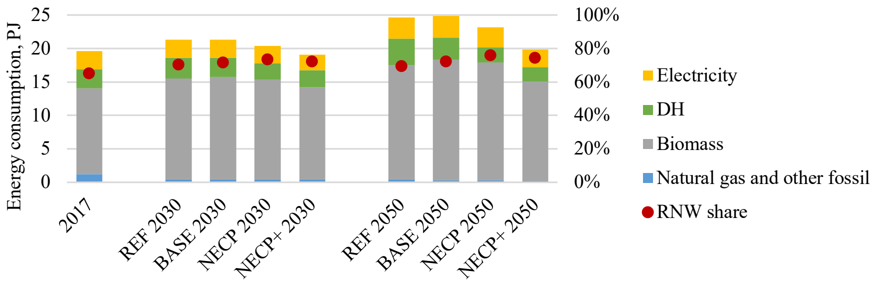



Fig. 3.7. Energy consumption in the wood sub-sector in the modelled scenarios.

The share of renewable energy in 2017 was almost zero, while in 2030 and 2050, the share increased in all scenarios, reaching the highest share in the NECP+ scenario, which was equal to 24 % and 42 %. Fossil fuel dominance in all scenarios is due to the need for high temperatures in industry processes, which cannot be fully ensured by renewable resources.

Total final energy consumption in the industrial sector in BASE and REF scenarios grow steadily from 33 PJ in 2017 to 43 PJ in 2050, and in the NECP scenario, consumption increases to 40 PJ while in NECP+ to 35 PJ in 2050 (see Fig. 3.8). The increase in final energy consumption is due to the planned economic development of the industrial sector in Latvia and the existing PaM to increase energy efficiency and promote the use of RES. Due to the very narrow PaM in NECP2030, the higher efficiency of new technologies alone is not sufficient to compensate for the increase in demand due to economic growth.

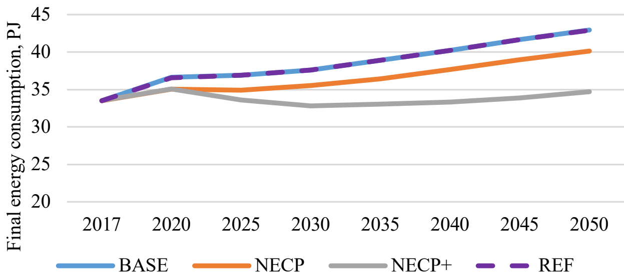



Fig. 3.8. Final energy consumption in the industrial sector in the modelled scenarios.

The GHG TARGET scenario shows the highest reduction in resource consumption, as this scenario requires achieving climate neutrality. The total amount of resources decreases from 23 PJ in the base year to 12 PJ in 2050 (see Fig. 3.9).

Also, in this scenario, diesel oil is the most used fuel, covering around 45 % of the total in 2050. Gasoline, LPG, and natural gas usage decreased from 8 PJ in 2017 to 2 PJ in 2050. 34 % of the total resources used in 2050 is electricity, and 9 % are other alternative fuels, most of which are hydrogen.

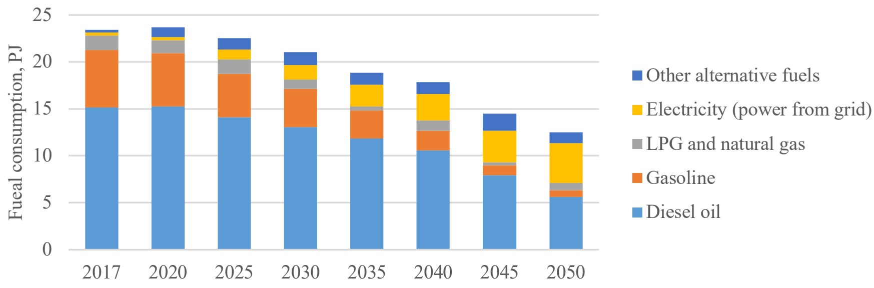



Fig. 3.9. Fuel consumption for land passenger transportation in GHG TARGET scenario.

### 3.1.4. Resource transition in total primary and final energy consumption (5th level)

Changes in total and final energy demand, as well as resource consumption, are described for WAM, OPT_EE, OPT_Solar, and WEM scenarios.

Figure 3.10 represents the comparison of PEC in optimisation and WEM scenarios. By 2030, wind and hydropower are expected to contribute significantly to the overall electricity supply. Like the baseline scenario, hydroelectric power production is expected to remain constant at 10 PJ/year. Biomass, on the other hand, is projected to make only a marginal contribution after 2040.

Both OPT scenarios demonstrate an increasing utilisation of wind power for electricity generation (as shown in Fig. 3.10). However, the OPT_Solar scenario reaches higher overall solar energy production rates because local RES for self-consumption is considered as an EE measure, and therefore, FEC and PEC targets can be achieved with fewer consumption reduction measures. The model tends to install more solar PV panels for self-consumption coverage instead. In the OPT_EE scenario, the most significant reduction in energy consumption within buildings results from an increase in EE due to improved insulation, which leads to a decrease in heat loss.

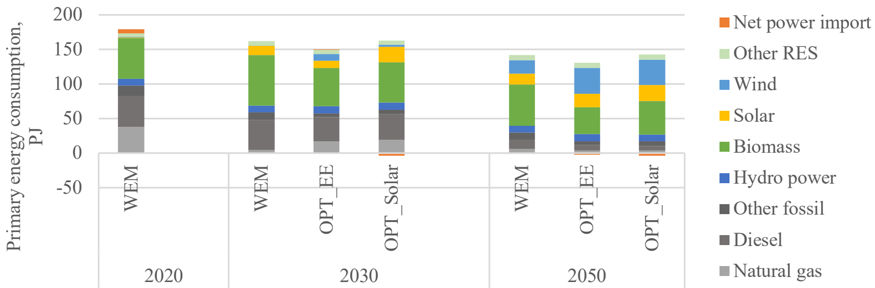
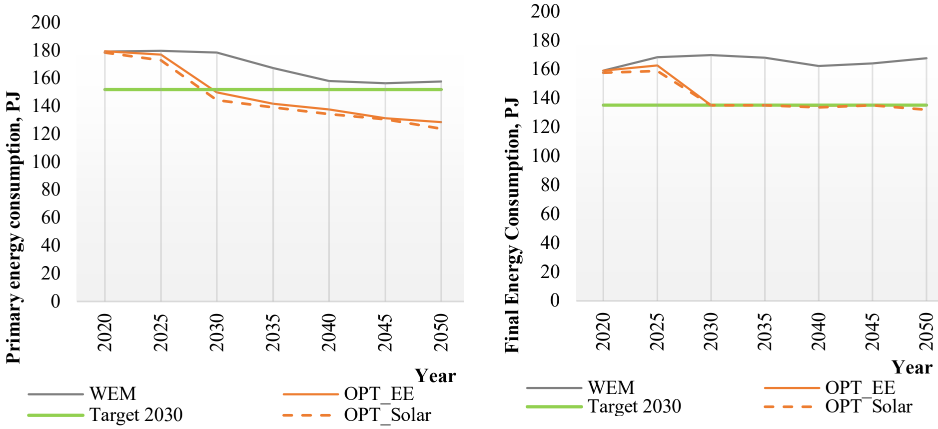



Fig. 3.10. Primary energy mix comparison in different optimisation scenarios.

Optimisation scenarios are designed to reach the REPowerEU FEC and PEC targets in 2030, but as TIMES does not include an annual limit to technology deployment, it switches technology for the target in the last available years. Figure 3.11 shows the PEC and FEC results of the reference scenario (WEM) in comparison with two different optimisation pathways. It can be seen that the WEM scenario with existing policies is far from the 2030 targets.




a) b)

Fig. 3.11. PEC (a) and FEC (b) results in self-optimisation run.

## 3.2. Contribution of sectors and sub-sectors in achieving climate neutrality

Changes in emission volumes are described for the energy transformation sector and for passenger transport on land based on distances across BASE, NECP, and GHG TARGET scenarios. Additionally, the total emissions of the industrial sector for BASE, NECP, and NECP+ scenarios are detailed. A comparison of emission volume changes for each sector under the WEM, OPT_EE, OPT_Solar, and WEM scenarios is also provided.

Total GHG emissions of the energy transformation sector in the BASE scenario are decreasing by around 53 %, while both the GHG TARGET and NECP scenarios reach climate neutrality in 2050 due to the exclusion of natural gas (see Fig. 3.12).

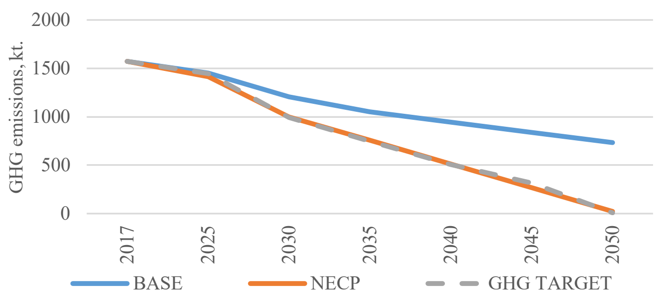



Fig. 3.12. GHG emissions in the energy transformation sector.

In all three scenarios and all distances, the amount of projected GHG emissions is decreasing (see Fig. 3.13). In the BASE scenario, the total GHG emissions will be reduced by

2 % in 2030 and by 14 % in 2050, in NECP by 10 % and 27 %, and in GHG TARGET by 19 % and 69 % for the same period.

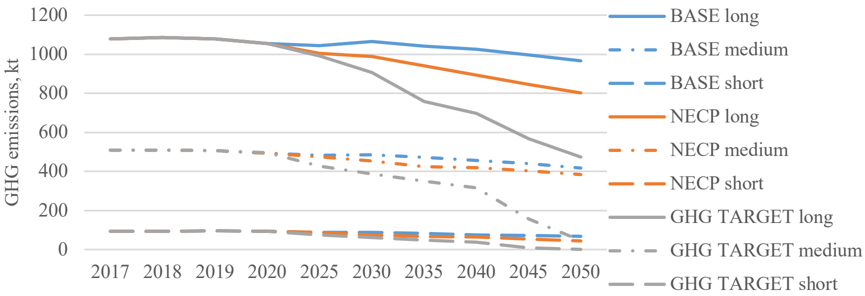



Fig. 3.13. Projection of GHG emissions by distances.

Most of the emissions are released when travelling long distances. Although the amount of GHG emissions is decreasing considerably, from around 1100 kt in the BASE year to 800 kt in NECP and 470 kt in GHG TARGET, the proportion of the decrease is lower than in other distances. Only a 10 % decrease is reached in BASE, 26 % in NECP, and 56 % in GHG TARGET in 2050.

GHG emissions in medium distances are decreasing by 18 % in BASE, 24 % in NECP, and 91 % in GHG TARGET in 2050 compared to the base year. Meanwhile, GHG emissions in short distances are decreasing by 27 % in BASE, 52 % in NECP, and 99 % in GHG TARGET scenarios in 2050.

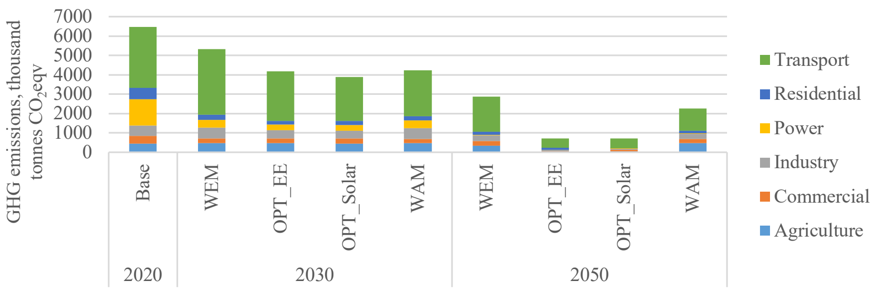



Fig. 3.14. Reached GHG emissions of the analysed scenarios in different end-use sectors.

Figure 3.14 shows the comparisons of reached GHG emissions in the analysed scenarios across different sectors. As can be seen, the set of analysed policies in WAM does not fully reach the GHG emission reduction in 2050 due to the lack of additional policies in the transport and agriculture sectors. In the optimisation pathways, the agriculture sector is decarbonised by integrating more biomethane and hydrogen for machinery, but in the transport sector, higher electrification rates for freight transport are reached. Therefore, additional PaM should be targeted to integrate carbon-neutral solutions in these sectors.

### 3.3. Estimates of specific costs and required investment

Costs and investment volumes for the transport sector are outlined for BASE, NECP and GHG TARGET scenarios. Additionally, total investments for various PaM are detailed for WEM, OPT_EE, OPT_Solar and WAM scenarios.

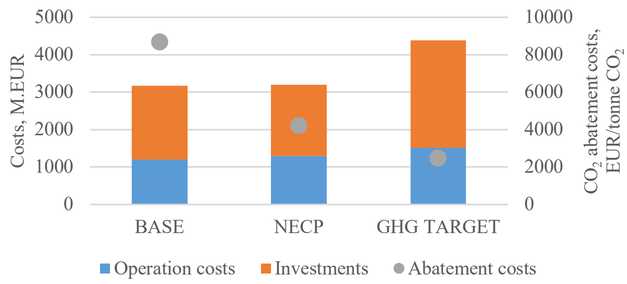



Fig. 3.15. Projection of costs in the transport sector.

Modelling results show that transport decarbonisation in the GHG scenario requires around 2868 MEUR, 38 % more than in the BASE scenario (see Fig. 3.15). However, the $CO_2$ abatement costs for GHG emission reduction are lower in this scenario as the TIMES model optimises the system to reach the lowest GHG emission reduction costs.

The objective of the modelling task is to meet the required energy service demand at the lowest possible total cost. It is clear that achieving climate neutrality requires significant investments in renewable energy (RES) technologies and energy efficiency measures that promote energy conservation and the transition to renewable energy sources.

The results indicate that the target scenario can achieve climate neutrality. However, its total costs are approximately 6 % higher by 2050 than in the policy scenario and approximately 2 % higher than in the baseline scenario when considering the actual reduction in greenhouse gas (GHG) emissions achieved in each case (see Fig. 3.16). Nevertheless, the policy and baseline scenarios fail to achieve climate neutrality, as they do not deliver the necessary GHG emission reductions.

The necessary GHG reductions in the target scenario can be achieved with a total investment of EUR 89 billion by 2050, approximately 8.2 % of the total projected GDP in this period. In contrast, the policy scenario would require EUR 113 billion to achieve the same level of reduction, which is approximately 10.3 % of GDP. In comparison, the baseline scenario would require EUR 134 billion, or approximately 12.3 % of GDP.

This analysis indicates that although the target scenario requires greater investments than the baseline and policy scenarios, it allows for climate neutrality more economically when considering necessary GHG reductions. Specifically, it results in total costs that are 26 % lower than those of the policy scenario and 50 % lower than the baseline scenario.

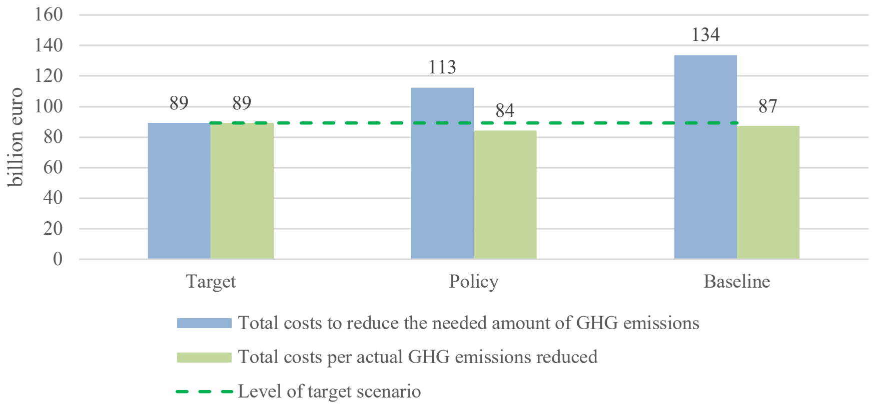



Fig. 3.16. Total system costs for $CO_2$ reduction for different scenarios.

Total investment and the subsidised part of those investments, for different WAM and WEM scenario measures, are shown in Table 3.1. All the investments and subsidies are shown as a cumulative value from 2020 to 2030. As local RES can be used to achieve energy efficiency targets, OPT_Solar has a higher total investment in PV panels than the OPT_EE scenario and a lower total investment in building renovations.

Table 3.1

Cumulative Investments and Subsidies from 2020 to 2030

| | **Total investment, billion EUR** | | | | **Subsidies, billion EUR** | | **Subsidies % of total, %** | |
|---|---|---|---|---|---|---|---|---|
| | WEM | OPT_I | OPT_II | WAM | WEM | WAM | WEM | WAM |
| **Building renovation** | 1.25 | 8.98 | 4.13 | 5.45 | 0.52 | 3.59 | 41.7 | 65.89 |
| **Biomethane production** | 0.02 | 0.02 | 0.02 | 0.06 | 0.01 | 0.03 | 28.62 | 41.22 |
| **PV panels** | 1.84 | 1.16 | 3.35 | 1.51 | 0.02 | 0.02 | 1.33 | 1.63 |
| **Consumer heat pumps** | 0.16 | 0.16 | 0.16 | 0.15 | 0.00 | 0.06 | 0.00 | 40.29 |
| **Industry energy efficiency** | 0.65 | 1.42 | 0.87 | 0.63 | 0.06 | 0.06 | 8.66 | 8.91 |
| **Power sector** | 2.70 | 4.63 | 4.44 | 3.09 | 0.03 | 0.03 | 1.23 | 1.07 |
| **Public transport** | 0.83 | 1.85 | 1.53 | 1.11 | 0.01 | 0.05 | 1.18 | 4.07 |
| **Electric vehicles** | 1.82 | 8.98 | 8.10 | 3.04 | 0.01 | 0.01 | 0.55 | 0.33 |

For both OPT_EE and OPT_Solar scenarios, investments in electric vehicles are equally high. Comparing WEM and WAM scenarios, there is an increase in the subsidised part of the building renovation investments, moreover, there is a significant increase in total investments in building renovations from EUR 1.25 billion in the WEM scenario to EUR 5.45 billion in the WAM scenario, this combination requires a substantial increase in subsidies from EUR 0.52 billion to EUR 3.59 billion (see Table 3.1).

# CONCLUSIONS

The Thesis presents a new methodology for assessing the progress of the Latvian energy sector toward climate neutrality. In the course of the work, a model was developed, and three types of scenarios were formulated.

- Baseline Scenarios (BASE and WEM): These incorporate the current strategy, tax policy, and PaM.
- Policy Scenarios (NECP, WAM): These include various policy instruments, for example, the PaM outlined in the National Energy and Climate Plan until 2030.
- Target Scenarios (GHG TARGET, OPT_EE, OTP_Solar): These aim to achieve climate neutrality by 2050.

The modelling was carried out using the TIMES tool. The main conclusions derived from the Doctoral Thesis are:

1. The model results confirm that, with the current PaM in Latvia, the climate targets set for 2050 will not be achieved. The findings also indicate that the necessary GHG emission reductions for achieving climate neutrality can be attained in the long term with additional targeted PaM.
2. Optimisation results highlight a strong interdependence between the use of heat pumps and wind energy production. This suggests that increasing wind energy utilisation can foster broader adoption of heat pumps and vice versa, thereby ensuring even greater GHG emission reductions.
3. The model shows that final energy consumption in Latvia's industrial sector will increase in all development scenarios, driven by projected economic growth. The existing PaM are insufficient to offset the increase in energy demand in this sector.
4. Biomass is the most important energy resource in the wood sub-sector, gradually replacing natural gas during the modelling period. Similarly, in the food sub-sector, biomass is increasingly replacing natural gas. In the non-metallic minerals sub-sector, natural gas and other fossil fuels, as well as household waste, tires, and rubber products, remain significant energy resources even until the end of the modelling period. At the same time, the share of renewable energy also increases in all analysed scenarios.
5. Centralised district heating consumption remains stable in the baseline scenario. In contrast, in the policy and target scenarios, it decreases by approximately 30 %, thanks to improvements in building energy efficiency, district heating network renovation, and other energy efficiency measures. In the baseline scenario, natural gas and biomass dominate in district heating production, while in the policy and target scenarios, natural gas usage is phased out by 2050. In the target scenario, biomass consumption decreases to about 20 %, with large-scale heat pumps and solar energy producing a substantial share of the heat energy. Sensitivity analysis indicates that stricter biomass availability constraints accelerate the adoption of large-scale heat pumps.
6. Both the policy and target scenarios demonstrate that Latvia's energy transition sector can generate the required volumes of district heat and electricity almost without

emissions, provided that significant investments are made in low-emission technologies. Achieving this requires more than 22 % or more than EUR 326 million in additional investments by 2050 compared to the baseline scenario.

7. An investment of EUR 89 billion is required by 2050 to implement the target scenario. This amount is approximately 8.2 % of the total projected GDP in this period, which is approximately 6 % higher by 2050 than in the policy scenario and approximately 2 % higher than in the baseline scenario regarding the corresponding GHG emission reductions. However, to reach the necessary GHG emission savings for climate neutrality under the policy scenario, an additional investment of roughly 26 % would be needed. In comparison, the baseline scenario would require approximately 50 % more than the target scenario. This is because the target scenario offers the lowest GHG emission reduction cost per ton.
8. The results indicate that targeted policies are crucial for achieving the set REPowerEU and Green Deal goals, as the baseline scenario results, without additional PaM, fall far short of the desired primary energy consumption (PEC) and final energy consumption (FEC) levels for 2030 and 2050. This implies that relying solely on market forces is insufficient; a policy designed to ensure the attainment of climate targets must be implemented. Such a policy could include measures to promote technology replacement, increased carbon taxes, and stricter regulations for market players to facilitate the transition to renewable energy and promote energy efficiency and conservation.
9. A TIMES optimisation simulation, in which only energy efficiency measures are allowed to achieve the 2030 FEC targets, shows that the most cost-effective decarbonisation path largely depends on building renovation and electrification. In an alternative optimisation scenario that allows the installation of solar panels for end-user consumption, the emphasis on building renovation is reduced as solar energy becomes a more cost-effective solution. In cost terms, the optimal decarbonisation strategy thus involves fewer energy efficiency measures but greater investments in renewable energy technologies. Both self-optimisation simulations indicate a shift from fossil fuels to renewables across all sectors after 2030, with the transportation sector exhibiting the slowest transition and retaining the largest share of emissions by 2050.
10. The classic TIMES modelling tool is suitable for general technical-economic analysis. However, introducing innovative solutions into the model is vital for providing a broader analysis of PaM, and for a more accurate determination of the structure of energy consumption, which is an important support for decision-making that contributes to achieving climate goals at lower overall costs. Examples include:
    - Separating the ETS system for the industry and energy transformation sectors in the model allows for the analysis of the impact of emission allowance prices and taxes and the effect of measures directly targeting energy-intensive producers.
    - Including a comfort element in the transport sector accounts for human behaviour, ensuring that results are not based solely on economic profitability.

- Modelling demand for heated square meters in the residential and commercial sectors allows the evaluation of energy efficiency measures. Previously, this was not possible directly, as end demand was based only on heating and cooling volumes.
- The implementation of the industrial waste heat utilisation process in the model allows for analysis of the impact of measures aimed at waste heat utilisation.

# REFERENCES


2-Gaiss ("Database of National Statistical Reports 2-Gaiss.") Accessed: 2019 https://www.meteo.lv/lapas/vide/parskatu-ievadisana/parskatu-ievadisana?id=1039&nid=376.

Alirezaei, M., Onat, N., Tatari, O., and Abdel-Aty, M., "The Climate Change-Road Safety-Economy Nexus: A System Dynamics Approach to Understanding Complex Interdependencies," Systems, vol. 5, no. 1, p. 6, 2017, doi: 10.3390/systems5010006.

Allena-Ozolina, S. et al., "Can energy sector reach carbon neutrality with biomass limitations?" Energy, pp. 123797–123797, Mar. 2022, doi: 10.1016/j.energy.2022.123797.

Allena-Ozolina, S., Bazbauers, G., "System dynamics model of research, innovation and education system for efficient use of bio-resources," Energy Procedia, vol. 128, pp. 350–357.

Andersen, K. S., Termansen, L. B., Gargiulo, M., and Gallachóirc, B. P. Ó, "Bridging the gap using energy services: Demonstrating a novel framework for soft linking top-down and bottom-up models," Energy, vol. 169, pp. 277–293, 2019, doi: 10.1016/j.energy.2018.11.153.

Astudillo, M. F., Vaillancourt, K., Pineau, P. O., and Amor, B., "Can the household sector reduce global warming mitigation costs? Sensitivity to key parameters in a TIMES techno-economic energy model," Appl. Energy, vol. 205, no. July, pp. 486–498, 2017, doi: 10.1016/j.apenergy.2017.07.130.

Balyk, O. et al., "TIMES-DK: Technology-rich multi-sectoral optimisation model of the Danish energy system," Energy Strateg. Rev., vol. 23, no. July 2017, pp. 13–22, 2019, doi: 10.1016/j.esr.2018.11.003.

Barisa, A., and Rosa, M. "A system dynamics model for CO2 emission mitigation policy design in road transport sector," Energy Procedia, vol. 147, pp. 419–427, 2018, doi: 10.1016/j.egypro.2018.07.112.

Barisa, A., and Rosa, M. "Scenario analysis of CO2 emission reduction potential in road transport sector in Latvia," Energy Procedia, vol. 147, pp. 86–95, 2018, doi: 10.1016/j.egypro.2018.07.036.

Barisa A., Kirsanovs, V., and Safronova, A. "Future transport policy designs for biomethane promotion: A system Dynamics model," J. Environ. Manage., vol. 269, no. May, p. 110842, 2020, doi: 10.1016/j.jenvman.2020.110842.

Blumberga, D., Blumberga, A., Barisa, A., Rosa, M., and Lauka, D., "Modelling the Latvian power market to evaluate its environmental long-term performance," Appl. Energy, vol. 162, pp. 1593–1600, Jan. 2016, doi: 10.1016/j.apenergy.2015.06.016.

Bolwig, S. et al., "Review of modelling energy transitions pathways with application to energy system flexibility," Renew. Sustain. Energy Rev., vol. 101, no. June 2018, pp. 440–452, 2019, doi: 10.1016/j.rser.2018.11.019.

Borasio, M., and Moret, S., "Deep decarbonisation of regional energy systems: A novel modelling approach and its application to the Italian energy transition," Renew. Sustain. Energy Rev., vol. 153, p. 111730, 2022, doi: https://doi.org/10.1016/j.rser.2021.111730.

Brown, T., Schlachtberger, D., Kies, A., Schramm, S., and Greiner, M., "Synergies of sector coupling and transmission reinforcement in a cost-optimised, highly renewable European energy system," Energy, vol. 160, pp. 720–739, Oct. 2018, doi: 10.1016/j.energy.2018.06.222.

Brunke, J. C., and Blesl, M., "Energy conservation measures for the German cement industry and their ability to compensate for rising energy-related production costs," J. Clean. Prod., vol. 82, pp. 94–111, 2014, doi: 10.1016/j.jclepro.2014.06.074.

Burandt, T., Xiong, B., Löffler, K., and Oei, P. Y. "Decarbonizing China's energy system – Modeling the transformation of the electricity, transportation, heat, and industrial sectors," Appl. Energy, vol. 255, no. September, p. 113820, 2019, doi: 10.1016/j.apenergy.2019.113820.

Calvo, L. V. Giner-Santonja, G., Alonso-Fariñas, B., and Aguado, J. M. "The effect of the European Industrial Emissions Directive on the air emission limit values set by competent authorities in the permitting procedure: The case of the Spanish cement industry," Sci. Total Environ., vol. 773, p. 145491, 2021, doi: 10.1016/j.scitotenv.2021.145491.

Capros, P. et al. EU Reference Scenario 2016. 2016. [Online]. Available: https://ec.europa.eu/energy/sites/ener/files/documents/ref2016_report_final-web.pdf

Cayla, J. M., and Maïzi, N. "Integrating household behavior and heterogeneity into the TIMES-Households model," Appl. Energy, vol. 139, pp. 56–67, 2015, doi: 10.1016/j.apenergy.2014.11.015.

CE (Copenhagen Economics). "Decarbonisation of the Nordics," no. August 2020.

Cebulla, F., Naegler, T., and Pohl, M. "Electrical energy storage in highly renewable European energy systems: Capacity requirements, spatial distribution, and storage dispatch," J. Energy Storage, vol. 14, pp. 211–223, 2017, doi: 10.1016/j.est.2017.10.004.

Chaudry, M., Abeysekera, M., Hosseini, S. H. R., Jenkins, N., and Wu, J., "Uncertainties in decarbonising heat in the UK," Energy Policy, vol. 87, pp. 623–640, 2015, doi: https://doi.org/10.1016/j.enpol.2015.07.019.

CM (Cabinet of Ministers). "Regulation on building classification in Latvia," Latvijas Vestnesis, vol. 118, no. 118, 2018.

Connolly, D., Lund, H., and Mathiesen, B. V. "Smart Energy Europe: The technical and economic impact of one potential 100% renewable energy scenario for the European Union," Renew. Sustain. Energy Rev., vol. 60, pp. 1634–1653, Jul. 2016, doi: 10.1016/j.rser.2016.02.025.

CSBL (Central Statistical Bureau of Latvia). "Energy balance, TJ, thsd toe (NACE Rev.2)." [Online]. Available: http://data1.csb.gov.lv/pxweb/en/vide/vide__energetika__ikgad/ENG020.px/.

CSBL (Central Statistical Bureau of Latvia). "Travel distance and time of population of Latvia," 2018, [Online]. Available: https://stat.gov.lv/en/statistics-themes/business-sectors/passenger-traffic/press-releases/1753-latvijas-iedzivotaju.

CSBL (Central Statistical Bureau). "Energy balance, TJ, thsd toe (NACE Rev.2) by Indicator, Energy resources, Unit and Time period." Accsessed:2021

Dalla Longa, F. et al. "Wind potentials for EU and neighbouring countries: Input datasets for the JRC-EU-TIMES Model," Jan. 2018, doi: 10.2760/041705.

DEA (The Danish Energy Agency). "Catalogue of technology data for energy technologies." [Online]. Accessed: 2018. Available: https://ens.dk/en/our-services/projections-and-models/technology-data.

Dhar, S., Pathak, M., and Shukla, P. R. "Transformation of India's steel and cement industry in a sustainable 1.5 °C world," Energy Policy, vol. 137, no. November 2019, 2020, doi: 10.1016/j.enpol.2019.111104.

Dolge, K., Kubule, A., and Blumberga, D. "Composite index for energy efficiency evaluation of industrial sector: sub-sectoral comparison," Environ. Sustain. Indic., vol. 8, no. May 2020, doi: 10.1016/j.indic.2020.100062.

Dolge, K., Blumberga, D. "Economic growth in contrast to GHG emission reduction measures in Green Deal context." Ecological Indicators, 130, 2021,108153

Dubrovskis, D., and Dagis, S. "Maintenance of the ' Forest Expert ' model, update on data availability and parameters. Soft-linkage with the System Dynamics and TIMES models," pp. 1–27, 2018.

EC (European Commission). "DIRECTIVE 2003/87/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing a scheMe for greenhouse gas emission allowance trading within the Community," Off. J. Eur. Union, vol. 275, pp. 32–46, 2003.

EC (European Commission). "The European Green Deal", Brussels 2019. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1576150542719&uri=COM%3A2019%3A640%3AFIN [Accessed 11.10.2023]

EP (Commission to the European Parliament and the Council). "Climate action progress report." [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52015DC0576.

Eurostat Source: Eurostat (nrg_d_hhq). Accessed: 2019 https://ec.europa.eu/eurostat/databrowser/view/nrg_d_hhq/default/table?lang=en

Fitch-Roy, O., Benson, D., and Mitchell, C. "Wipeout? Entrepreneurship, policy interaction and the EU's 2030 renewable energy target" J. Eur. Integr., vol. 41, no. 1, pp. 87–103, Jan. 2019, doi: 10.1080/07036337.2018.1487961.

Fleiter, T. et al., "A methodology for bottom-up modelling of energy transitions in the industry sector: The FORECAST model," Energy Strateg. Rev., vol. 22, no. September, pp. 237–254, 2018, doi: 10.1016/j.esr.2018.09.005.

Gravelsins, A. et al., "Modelling energy production flexibility: System dynamics approach," Energy Procedia, vol. 147, pp. 503–509, 2018, doi: 10.1016/j.egypro.2018.07.060.

Green K., Green, R., and Vasilakos, N. "Storing Wind for a Rainy Day: What Kind of Electricity Does Denmark Export?" Energy J., vol. 33, no. 3, May 2012, doi: 10.5547/01956574.33.3.1.

Hache, E., Simoën, M., Seck, G. S., Bonnet, C., Jabberi, A., and Carcanague, S. "The impact of future power generation on cement demand: An international and regional assessment based on climate scenarios," Int. Econ., vol. 163, no. November 2019, pp. 114–133, 2020, doi: 10.1016/j.inteco.2020.05.002.

Han, S., and Kim, J. "An optimization model to design and analysis of renewable energy supply strategies for residential sector," Renew. Energy, vol. 112, pp. 222–234, 2017, doi: 10.1016/j.renene.2017.05.030.

Hof, F., den Elzen, M. G. J., den Elzen, M., and Beltran, A. M. "The EU 40 % greenhouse gas emission reduction target by 2030 in perspective," Int. Environ. Agreem.-Polit. Law Econ., vol. 16, no. 3, pp. 375–392, Mar. 2016, doi: 10.1007/s10784-016-9317-x.

IPCC (Intergovernmental Panel on Climate Change). 2023: Summary for Policymakers. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 1–34, doi: 10.59327/IPCC/AR6-9789291691647.001

Jaunzems, Dz., Pakere, I., Allena-Ozolina, S., Freimanis, R., Blumberga, A., Bazbauers, G. "Adaptation of TIMES Model Structure to Industrial, Commercial and Residential Sectors" Environmental and Climate Technologies, vol. 24, no. 1, 2020, pp. 392–405.

https://doi.org/10.2478/rtuect-2020-0023

Jonkman, J., Castiglioni, A., Akkerman, R., and van der Padt, A. "Improving resource efficiency in the food industry by using non-conventional intermediate products," J. Food Eng., vol. 287, no. June, p. 110198, 2020, doi: 10.1016/j.jfoodeng.2020.110198

JRC (Joint Research Centre), Institute for Energy and Transport. Elbersen, B., Dalla Longa, F., Ruiz, P., et al., "The JRC-EU-TIMES model: bioenergy potentials for EU and neighbouring countries", Publications Office, 2015, https://data.europa.eu/doi/10.2790/39014

Kermeli, K. et al. "The scope for better industry representation in long-term energy models: Modeling the cement industry," Appl. Energy, vol. 240, no. February, pp. 964–985, 2019, doi: 10.1016/j.apenergy.2019.01.252.

Latvenergo AS, "Latvenergo Group consolidated and Latvenergo AS 2017 Annual report," 2017, [Online]. Available: https://latvenergo.lv/storage/app/media/investoriem/en/2017/LE_2017y_ENG_Annual_Report.pdf.

Lerede, D., Bustreo, C., Gracceva, F., Saccone, M., and Savoldi, L. "Techno-economic and environmental characterization of industrial technologies for transparent bottom-up energy modeling," Renew. Sustain. Energy Rev., vol. 140, no. February, p. 110742, 2021, doi: 10.1016/j.rser.2021.110742.

Li, P. H., Keppo, I., and Strachan, N. "Incorporating homeowners' preferences of heating technologies in the UK TIMES model," Energy, vol. 148, pp. 716–727, 2018, doi: 10.1016/j.energy.2018.01.150.

Li, S., Li, L., and Wang, L. "2030 Target for Energy Efficiency and Emission Reduction in the EU Paper Industry," Energies, vol. 14, no. 1, p. 40, 2020, doi: 10.3390/en14010040.

Lima A., "Electricity Storage as a Matching Tool Between Variable Renewable Energy and Load," SSRN Electron. J., May 2019, doi: 10.2139/ssrn.3389673.

Loulou, L., Goldstein, G., Kanudia, A., Lettila, A., Remme, U., and Noble, K., "Documentation for the TIMES Model PART I – Concepts and Theory," no. July, p. 151, 2016.

Lund, H., Möller, B., Mathiesen, B. V., and Dyrelund, A. "The role of district heating in future renewable energy systems," Energy, vol. 35, no. 3, pp. 1381–1390, 2010, doi: https://doi.org/10.1016/j.energy.2009.11.023.

Marques, C., Fuinhas, J. A., and Tomás, C. "Energy efficiency and sustainable growth in industrial sectors in European Union countries: A nonlinear ARDL approach," J. Clean. Prod., vol. 239, 2019, doi: 10.1016/j.jclepro.2019.118045.

McCallum, P. et al. "A multi-sectoral approach to modelling community energy demand of the built environment," Energy Policy, vol. 132, no. June, pp. 865–875, 2019, doi: 10.1016/j.enpol.2019.06.041.

Meessen, J., Pestiaux, J., Schobbens, Q., Jossen, Q., Martin, B., Linden, C. V., Lemmens, P. W."Analysing the impact assessment on raising the EU 2030 climate targets" 2020. Available online: https://www.ecologic.eu/sites/default/files/publication/2020/eu2030-ia-analysis_final.pdf

MoE (Ministry of Economics). "Permits for the implementation of new electricity generation facilities." [Online]. Accessed: 2019 Available: https://www.em.gov.lv/lv/nozares_politika/atjaunojama_energija_un_kogeneracija/atlaujas_jaunu_elektroenergijas_razosanas_iekartu_ieviesanai/.

Obrist, M. D., Kannan, R., Schmidt, T. J., and Kober, T. "Decarbonization pathways of the Swiss cement industry towards net zero emissions," J. Clean. Prod., vol. 288, p. 125413, 2021, doi: 10.1016/j.jclepro.2020.125413.

Ollier, L., Metz, F., Nuñez-Jimenez, A., Späth, L., and Lilliestam, J. "The European 2030 climate and energy package: do domestic strategy adaptations precede EU policy change?" Policy Sci., Feb. 2022, doi: 10.1007/s11077-022-09447-5.

Papadogeorgos, I., Papapostolou, A., Karakosta, C., and Doukas, H. "Multicriteria Assessment of Alternative Policy Scenarios for Achieving EU RES Target by 2030," pp. 405–412, Jan. 2017, doi: 10.1007/978-3-319-56288-9_54.

Pavičević, M. et al., "The potential of sector coupling in future European energy systems: Soft linking between the Dispa-SET and JRC-EU-TIMES models," Appl. Energy, vol. 267, no. May, p. 115100, 2020, doi: 10.1016/j.apenergy.2020.115100.

Rafiee, A., Karimi, M., Safari, A, and Abbasi Talabari, F., "The Future Impact of Carbon Tax on Electricity Flow between Great Britain and Its Neighbors until 2030," Appl. Sci., vol. 11, no. 21, p. 10460, Nov. 2021, doi: 10.3390/app112110460.

Ramea, K., Bunch, D. S., Yang, C., Yeh, S., and Ogden, J. M., "Integration of behavioural effects from vehicle choice models into long-term energy systems optimization models," Energy Econ., vol. 74, pp. 663–676, 2018, doi: 10.1016/j.eneco.2018.06.028.

Resch, G. et al. "Assessment of Policy Pathways for Reaching the EU Target of (At Least) 27 % Renewable Energies by 2030," Eur. Dimens. Ger. Energy Transit., pp. 45–65, Jan. 2019, doi: 10.1007/978-3-030-03374-3_4.

Reveiu, A., Smeureanu, I., Dardala, M., and Kanala, R., "Modelling domestic lighting energy consumption in Romania by integrating consumers behavior," Procedia Comput. Sci., vol. 52, no. 1, pp. 812–818, 2015, doi: 10.1016/j.procs.2015.05.137.

RS (AS RĪGAS SILTUMS). "Annual Report 2017." [Online]. Available: https://www.rs.lv/sites/default/files/page_file/rs_gada_parskats_2017.pdf.

Runge-Metzger, A., and Wehrheim, P. "Agriculture and forestry in the EU's 2030 climate target," Clim.-Neutral Eur., pp. 165–179, Oct. 2019, doi: 10.4324/9789276082569-8.

Salvucci, R., Gargiulo, M., and Karlsson, K. "The role of modal shift in decarbonising the Scandinavian transport sector: Applying substitution elasticities in TIMES-Nordic," Appl. Energy, vol. 253, no. February, p. 113593, 2019, doi: 10.1016/j.apenergy.2019.113593.

Salvucci, R., Tattini, J., Gargiulo, M., Lehtilä, A., and Karlsson, K. B. "Modelling transport modal shift in TIMES models through elasticities of substitution," Appl. Energy, vol. 232, pp. 740–751, Dec. 2018, doi: 10.1016/j.apenergy.2018.09.083.

Schmid, E., Knopf, B., and Pechan, A. "Putting an energy system transformation into practice: The case of the German Energiewende," Energy Res. Soc. Sci., vol. 11, pp. 263–275, 2016, doi: https://doi.org/10.1016/j.erss.2015.11.002.

Seck, G. S., Guerassimoff, G., and Maïzi, N. "Heat recovery with heat pumps in non-energy intensive industry: A detailed bottom-up model analysis in the French food & drink industry," Appl. Energy, vol. 111, no. 2013, pp. 489–504, 2013, doi: 10.1016/j.apenergy.2013.05.035.

Selosse, S., and Ricci, O. "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, doi: 10.1016/j.energy.2014.09.014.

SES (The State Environmental Service). "GHG permits," Accessed: 2019 [Online]. Available: http://www.vvd.gov.lv/izsniegtas-atlaujas-un-licences/seg-atlaujas/?company_name=Olaines&org_id=&perm_date_from=&perm_date_to=&s=1.

Shafiei, E., Davidsdottir, B., Leaver, J., Stefansson, H., and Asgeirsson, E. I., "Simulation of alternative fuel markets using integrated system dynamics model of energy system," Procedia Comput. Sci., vol. 51, no. 1, pp. 513–521, 2015, doi: 10.1016/j.procs.2015.05.277.

Shafiei, E., Davidsdottir, B., Leaver, J., Stefansson, H., Asgeirsson, E. I., and Keith, D. R. "Analysis of supply-push strategies governing the transition to biofuel vehicles in a market-oriented renewable energy system," Energy, vol. 94, pp. 409–421, 2016, doi: 10.1016/j.energy.2015.11.013.

Siddi, M. "Coping With Turbulence: EU Negotiations on the 2030 and 2050 Climate Targets," Polit. Gov., vol. 9, no. 3, pp. 327–336, Sep. 2021, doi: 10.17645/pag.v9i3.4267.

Simoes, S. et al. "Impact of different levels of geographical disaggregation of wind and PV electricity generation in large energy system models: A case study for Austria," Renew. Energy, vol. 105, pp. 183–198, May 2017, doi: 10.1016/j.renene.2016.12.020

Steinke, F., Wolfrum, P., and Hoffmann, C. "Grid vs. storage in a 100% renewable Europe," Renew. Energy, vol. 50, pp. 826–832, 2013, doi: 10.1016/j.renene.2012.07.044.

Tash, A., Ahanchian, M., and Fahl, U. "Improved representation of investment decisions in the German energy supply sector: An optimization approach using the TIMES model," Energy Strateg. Rev., vol. 26, p. 100421, 2019, doi: 10.1016/j.esr.2019.100421.

Tattini, J., Gargiulo, M., and Karlsson, K. "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.

Temursho, U., Weitzel, M., and Vandyck, T. "Distributional impacts of reaching ambitious near-term climate targets across households with heterogeneous consumption patterns: A quantitative macro-micro assessment for the 2030 Climate Target Plan of the EU Green Deal," 2020, doi: 10.2760/89463.

Veum, K., and Bauknecht, D. "How to reach the EU renewables target by 2030? An analysis of the governance framework," Energy Policy, vol. 127, pp. 299–307, Apr. 2019, doi: 10.1016/j.enpol.2018.12.013.

Wang, H., and Chen, W. "Modelling deep decarbonization of industrial energy consumption under 2-degree target: Comparing China, India and Western Europe," Appl. Energy, vol. 238, no. January, pp. 1563–1572, 2019, doi: 10.1016/j.apenergy.2019.01.131.

Wiese, F., Thema, J., and Cordroch, L. "Strategies for climate neutrality. Lessons from a meta-analysis of German energy scenarios," Renew. Sustain. Energy Transit., vol. 2, no. October 2021, p. 100015, 2022, doi: 10.1016/j.rset.2021.100015.

Xu, Y., and Szmerekovsky, J. "System dynamic modeling of energy savings in the US food industry," J. Clean. Prod., vol. 165, pp. 13–26, 2017, doi: 10.1016/j.jclepro.2017.07.093.

Zappa, W., Junginger, M., and van den Broek, M. "Is a 100% renewable European power system feasible by 2050?," Appl. Energy, vol. 233–234, no. January 2018, pp. 1027–1050, 2019, doi: 10.1016/j.apenergy.2018.08.109.

Zhu, Y., and Ming, J. "Lagrangian decomposition for stochastic TIMES energy system optimization model," AIMS Math., vol. 7, no. 5, pp. 7964–7996, Jan. 2022, doi: 10.3934/math.2022445.

**Signe Allena-Ozoliņa** was born in 1989. She received a Bachelor's degree (2012) and a Master's degree (2014) in Social Sciences in Management (program "Environment and Business Management") from the University of Latvia and a Master's degree in Environmental Sciences (2016) from Riga Technical University (RTU). From 2019 to 2023, she was a researcher at the RTU Institute of Energy Systems and Environment. Currently, she is a senior expert in the Climate Policy Department of the Ministry of Climate and Energy of the Republic of Latvia. Her research interests are related to energy system modelling, renewable energy sources, and GHG emissions reduction.