**RIGA TECHNICAL UNIVERSITY**
Faculty of Power and Electrical Engineering
Institute of Energy Systems and Environment

**Aiga BARISA**
Doctoral Student of Doctoral Study Programme “Environmental Science”

# MODELLING TRANSITION POLICIES TO A LOW-CARBON ROAD TRANSPORT IN LATVIA BY 2030

**Summary of the Doctoral Thesis**

Scientific Supervisor
Professor *Dr. sc. ing.*
MARIKA ROŠĀ

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**DOCTORAL THESIS**
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To be granted the scientific degree of Doctor of Environmental Engineering, the present Doctoral Thesis will be publicly defended on 22 September 2016, at 14:00, Room 115, at the Faculty of Power and Electrical Engineering of Riga Technical University, Azenes iela 12/1.

OFFICIAL REVIEWERS

Professor *Dr. habil. chem.* Māris Kļaviņš
University of Latvia

Assoc. Professor *Dr. sc. ing.* Jūlija Gušča
Riga Technical University

Senior Scientist *PhD* Kenneth Karlsson
Technical University of Denmark

DECLARATION OF ACADEMIC INTEGRITY

I hereby declare that the Doctoral Thesis submitted for the review to Riga Technical University for the promotion to the scientific degree of Doctor of Environmental Engineering is my own and does not contain any unacknowledged material from any source. I confirm that this Thesis has not been submitted to any other university for the promotion to other scientific degree.

Aiga Barisa ……………………………. (signature)

Date: ………………………

The Doctoral Thesis is written in the English language and consists of an introduction, six chapters, conclusions, two annexes, and a bibliography with 294 reference sources. It is illustrated by 59 figures and 23 tables. The total volume of the present Thesis is 165 pages.

# Table of Contents

## Research Background and Topicality

In the second half of 2014, European leaders agreed on a new framework for climate and energy policies to be introduced by 2030. The new commitment foresees a reduction in greenhouse gas emissions by at least 40 % below the 1990 levels by 2030. A contribution is expected to come from all sectors, including transport. According to the Transport White Paper of 2011, the target is to reduce greenhouse gas emissions from the transport sector by at least 60 % in 2050 compared to the 1990 level.

Transport is responsible for one fifth of the European Union greenhouse gas emissions. While emissions from other sectors are generally falling, those from transport have continued to increase over the recent decades. Although the transport sector is becoming more energy efficient, energy savings only partially offset the increasing transport energy demand.

Observed trends and future projections indicate that in the transport sector significant changes are not expected without political interference. These trends call for new, effective strategies helping to move towards a low-carbon transport system whilst at the same time not limiting mobility.

## Research Scope

The overall objective of the present Doctoral Thesis is to perform an integrated analysis of low-carbon transition policies in the road transport sector in Latvia by 2030. At an international level, the main driver of low-carbon transport is the commitment to reduce climate change; however, in the context of national and local transport policy, the aspect of climate is often left in second place, or is not taken into account at all. The major contribution of the Thesis arises from an integrated multi-scale planning approach that takes into account both the technical and the economic, as well as environmental, aspects.

The following three research questions are raised:

1) To what extent can national transport policy contribute to a reduction in transport carbon dioxide emissions in the long-term, as stipulated by international commitments?
2) What is the potential of local governments to support transition to a low-carbon transport system?
3) What is the interaction between transport policy planning at national level and the biodiesel market in the country, taking into account that biofuels are considered to be the major mid-term solution for greenhouse gas emission reduction in the transport sector?

## Research Methodology

The research methodology is based on four interconnected parts according to the proposed multi-level approach for modelling transition policies to a low-carbon transport system. The proposed methodology is approbated to the case study of Latvia and used for transport policy design at three different levels: national level, local level, and sectoral level.

The first part uses the method of semi-structured interviews to collect in-depth qualitative information around the topic of alternative fuel vehicles at European level.

The second part applies the system dynamics theory as a tool for behaviour analysis of complex systems. Based on the system dynamics modelling approach, a new mathematical computer simulation model is proposed and applied for carbon mitigation policy analysis in the road transport sector.

The third part is represented by two case studies applying different research methodologies to analyse low-carbon transport solutions at local level. The first case study is based on a combined material–energy and cash–flow analysis in order to analyse the techno-economic potential of introducing alternative fuel systems in a fleet of municipality vehicles. The second case study uses a survey method to collect the first experiences of the introduction of electric vehicles in Latvian municipalities.

The fourth part applies a system dynamics modelling approach to develop a new mathematical computer simulation model for policy analysis in the biodiesel sector. The model is used to project the share of biodiesel in the final transport energy demand in response to various policy strategies.

## Scientific Significance and Contribution

An integrated multi-level approach has been developed and applied to research the transition potential to a low-carbon road transport sector by 2030. It includes:

- creation and approbation of a new mathematical energy-economy model based on system dynamics theory for national-level carbon emission mitigation policy design in the transport sector;
- creation and approbation of a new mathematical computer simulation model based on a system dynamics modelling approach for policy analysis in the biodiesel sector; and
- development and approbation of a combined approach of energy and material and cash–flow analysis for the waste-to-biomethane concept introduction in local transport systems.

Research results provide a tool for the development of sustainable transport policies at national, local and sectoral levels, including cross-sectoral feedbacks and interactions. The concepts and theories developed and applied in the Thesis have been discussed in peer-reviewed scientific papers highlighting their scientific innovation and significance.

## Practical Significance

Three groups can potentially benefit from the outcome of the present Thesis. National-level government officials should find this analysis useful for understanding the dynamics that are likely to drive carbon dioxide emissions from the Latvian road transport sector over the coming decades and find optimal strategies for reaching national transport, climate and energy policy goals. The results from the Doctoral Thesis are useful for evaluating the effects of support instruments for low-carbon road transport development in Latvia.

Transport industry participants should find this research useful for planning their future investment decisions since it helps to evaluate and analyse the feedback from national-level policy development trends and identifies both the synergies and potential bottlenecks as a result of policy implementation.

Finally, local government authorities can use this research to support decision making in their future energy use in the transportation sector through sustainable energy action plans or urban mobility plans. Moreover, the results of this research can be used as a starting point for discussions and engagement of local actors (public transport operators, fuel suppliers, and the general public), which is essential in moving towards a low-carbon society.

## Approbation of the Research Results

The results of the author’s research have been presented and discussed in 15 scientific conferences, 10 peer-reviewed full text scientific journals, 9 peer-reviewed scientific conference proceedings, and two textbooks.

## Publications

1. Blumberga, A., Lauka, D., Barisa, A., Blumberga, D. Modelling the Baltic power system till 2050. *Energy Conversion and Management*, 2016, Vol. 107, pp. 67‒75 (indexed in SCOPUS, Web of Science).
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2. Blumberga, D., Barisa, A., Kubule, A., Kļaviņa, K., Lauka, D., Muižniece, I., Blumberga, A., Timma, L. *Biotehonomika*. Mācību grāmata. Rīga: RTU Izdevniecība, 2016, 338 lpp. ISBN 978-9934-10-789-4

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## Structure of the Doctoral Thesis

The Doctoral Thesis is written in English and consists of an introduction, six chapters, conclusions, two annexes, and references. The introduction looks at the topicality of the work, the goal of the research and the methods, as well as the importance of the results of the research.

The first chapter of the Thesis gives a theoretical framework for the research. Based on a review of the literature it explains the need for transition to a low-carbon transport system in Europe, the existing framework conditions for this transition, potential pathways as well as transport sector developments in Latvia, which has been chosen as a representative case study of the research.

The second chapter of the Thesis gives an overall description of the multi-scale methodological approach of transport planning applied in the research.

The third chapter of the Thesis deals with an analysis of road transport developments at a European level. In this chapter, results are presented from interviews with seven leading European-level stakeholder organizations responsible for the research and development activities related to renewable energy technologies in the road transport.

The fourth chapter of the Thesis introduces a tool for low-carbon transport policy planning at national level, including a brief resume of the system dynamics modelling approach and describing a newly developed system dynamics model and its application for scenario studies.

The fifth chapter of the Thesis covers two case studies analysing the potential of introducing vehicles with alternative fuel in municipalities. The first part of the chapter is dedicated to an evaluation of the 'waste-to-biomethane' resource efficiency concept based on a case study of a medium-sized city considering technical, economic and environmental aspects. The second part of the chapter attempts to analyse first experiences with electric vehicle introduction in Latvian municipalities.

The sixth chapter of the Thesis is devoted to an analysis of the biodiesel sector in Latvia. It describes the development and application of a mathematical computer simulation tool for evaluation of policy measures for increasing the market share of first-generation biodiesel.

Finally, the conclusions section summarizes the main points of the research.

The Doctoral Thesis consists of 165 pages, including 59 figures, 23 tables, two annexes, and a list of references with 294 sources.

# 1. LITERATURE REVIEW

It is estimated [1] that the European Union (EU) transport sector in 2010 was 9-% more energy efficient than the previous decade. However, energy savings only partially offset the increasing demand for transport energy. In 2013, a total of 6,465 billion passenger kilometres or, on average, around 12,700 km per person were travelled by motorized means of transport in the 28 countries of the EU. Passenger transport activity has shown a 1.0 % annual increase on average during the period 1995–2013, or 20.4 % in absolute numbers. Meanwhile, the number of goods transport activity reached 3,481 billion ton kilometres in 2013, which was a 22.3 % increase compared to 1995, or 1.1 % per annum on average [2].

Transportation fuel demand relies 94.0 % on fossil fuels [3]. Besides the economic effects, the large dependency on fossil fuel underpins the fact that transport is a significant and ever growing source of greenhouse gas (GHG) emissions. According to the latest estimates [4], GHG emissions from the transportation sector in EU-28 amounted 887.5 million tonnes of carbon dioxide ($CO_2$) equivalent in 2013, which is a 12.9 % increase compared to 1990.

These figures point to unsolved issues in the transport sector, which arise from a strong underlying causal relationship. Economic growth, which is the ultimate goal of both macro-economics and micro-economics, as well as individuals cause the increase in demand for transport services. In today's circumstances, this demand is mainly ensured with fossil energy resources. This in turn is the reason why the transport sector is a significant emitter of greenhouse gases. The increasing energy consumption and GHG emissions in the transport sector require immediate action, which has been acknowledged by the European Commission. At the same time, the complex nature of the transport sector poses a great challenge to decouple the growth in mobility from fossil energy consumption and the associated negative impact on climate.

A framework for transition to a low-carbon transport sector in Europe is created through three important initiatives:

1) The Transport White Paper [5];
2) The Renewable Energy Directive [6]; and
3) The Clean Power for Transport Package.

The Transport White Paper (2011) shapes the role of the transport sector in contributing GHG emissions in the long-term. The long-term goal foresees that transport GHG emissions should be cut by at least 60 % by 2050 compared to the 1990 level. The major emphasis is put on alternative fuels, increased efficiency, and optimised performance of transport systems. The White Paper delivers 40 specific actions and lists 131 specific initiatives to develop a competitive, less oil-dependent transport system with a reduced impact on the environment throughout the European Union.

In order to reduce the transport sector's dependence on fossil fuels, the Renewable Energy Directive (2009/28/EC) requires a common goal for all Member States to achieve a 10-% share of energy from renewable sources in transport by 2020. The current pace of development has shown that this objective is proving difficult to achieve. The European Commission's evaluation [7] showed that 22 out of 27 Member States failed to achieve the indicative 5.75 % renewable energy in transport target in 2010. Five years later, in 2015, only two of the 28 Member States had already fulfilled the 10 % renewable transport energy target [3]. It can be concluded that there are significant barriers in place delaying adoption of alternative fuels in the transport market.

To address this problem, the European Commission adopted the Clean fuels for transport package to contribute to the long-term substitution of oil in all modes of transport. The package incorporates the newly adopted directive on the deployment of alternative fuels infrastructure [8]. According to this directive, all Member States are required to develop national policy frameworks for the market deployment of alternative fuels and their infrastructure. The overall aim is to ensure a build-up of alternative refuelling points across Europe, which is an important step towards market entry of alternative fuel technologies.

There is a variety of policy instruments which are being applied with the aim of reducing $CO_2$ emissions from the road transport sector. These can be classified based on the so called ‘Avoid-Shift-Improve’ principle [9], [10]. The ‘Avoid-Shift-Improve’ concept proposes that $CO_2$ emissions from transport can be reduced in three ways:

- by reducing or avoiding the need to travel (‘Avoid’ strategies);
- by shifting to less polluting transport modes (‘Shift’ strategies); and
- by improving the energy efficiency of transport modes and vehicle technology (‘Improve’ strategies).

A broad research has previously been performed to study the effect of different policy measures on emission reduction. The research showed that travel behaviour is an important determinant affecting mitigation opportunities of transport-related emissions. The choices made by transport users play a key role in transition towards a low-carbon transport system. Private consumers make many choices such as whether to travel, how to travel, how to drive, whether to own a car, and what car to buy [11]. Thus, besides physical (infrastructural), technical and economic issues, the aspect of behaviour is one of the challenges in attaining sustainable travel.

# 2. RESEARCH METHODOLOGY

Transition to a low-carbon transport system is a multi-scale planning process ranging from each of us as individuals up to the global level. The methodology developed and presented in the Doctoral Thesis is based on a multi-level planning approach and incorporates a four-dimensional research covering transport planning at different planning levels:

- international level;
- national level;
- local or municipal level; and
- sectoral level.

As explained by Zermoglio et al. [12], an integrated multi-scale approach allows us to better understand the needs of decision-makers at every scale and the interactions between interested parties. Assessments performed at different levels are focused on the most relevant drivers and impacts at each level, thus allowing arriving at reasonable, comprehensive conclusions.

The research part of the Thesis consists of four stages, which are divided into separate research parts as shown in Fig. 2.1.

**Chapter 3** studies sustainable transport planning aspects from an international (European) perspective. The international scale is considered to be the ‘umbrella’ of the transport policy planning. Transport planning at an international level sets goals and develops pathways for solving global transport issues such as climate change. The international level study was performed to understand the boundary conditions for alternative fuel vehicle deployment in the European Union. The research was developed in two steps. First, it involved a desk research and development of a systematic overview of the actors involved in the research and development of alternative fuel vehicles at European level. In the second step, a qualitative research method was applied – in-depth interviews with identified field experts to examine the current practice and barriers and opportunities for alternative fuels in European road transport.

**Chapter 4** analyses the $CO_2$ emission reduction policy in the transport sector at national level. The transport sector is one of the sectors not covered by the European Union Emission Trading System (except for international aviation). Thus, measures for decarbonisation of the transport sector are in the hands of Member States. The aim of the national level study was to indicate the potential of $CO_2$ emission mitigation from the largest emission source in the transport sector, road and railway transport, by 2030. In order to better understand the driving forces behind $CO_2$ emissions from the road transport sector and to identify the necessary change in the structure of the transport system, a dynamic mathematical model based on the system dynamics modelling approach was developed and applied. The model was approbated on Latvia’s case study.

**Chapter 5** explores the role of local governments in contributing to the achievement of national and international transport policy goals. Municipalities play a major role in implementing national policy strategies and in contributing to the achievement of national targets. The aim of the local-level study was to increase the understanding about the potential of local decision makers to support the transition to a low-carbon transport system. The local level analysis was based on two case studies. The aim of the Case study 1 was to evaluate the techno-economic potential of the application of the concept of waste-to-biomethane in a medium-sized city in Latvia applying cash–flow analysis methodology. The aim of the Case study 2 was to evaluate the first experience of the introduction of electric cars in Latvian municipalities. This was performed based on a qualitative municipality survey.

**Chapter 6** addresses linkages between policy planning at national and sectoral levels. Decisions made at national and local levels have both direct and indirect effects on the micro-economy (service and infrastructure providers, fuels producers and suppliers, etc.). The strategic efforts at national and local governmental levels encourage the development and growth of the particular sector. In contrast, the lack of policies or their inadequacy may lead to unwanted consequences, e.g., industry downturn and inability to achieve the goals set. Biofuels are expected to represent a substantial part of the overall strategy towards diversifying the Europe's energy supplies and curbing GHG emissions in a cost-effective way. The aim of the sectoral level study was to determine the necessary policy support measures to increase the share of biodiesel in final transport energy demand. The research question was addressed by a newly developed mathematical simulation model based on system dynamics modelling approach and approbated on Latvia's case study.

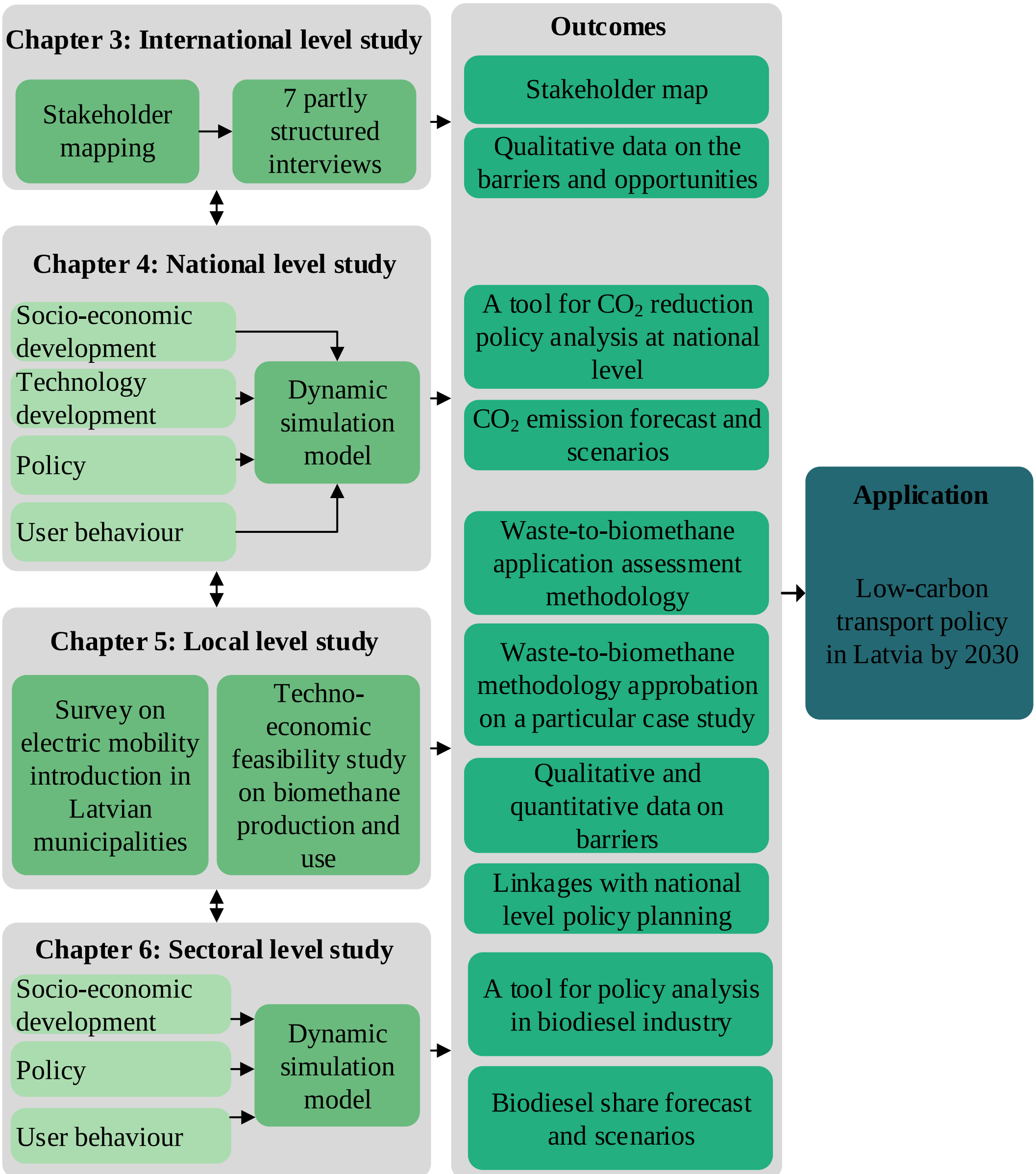



Fig. 2.1. Outline of the research part of the Thesis corresponding to the applied multi-scale analysis methodology for transport sector development analysis in Latvia.

In the light of the ongoing development to low-carbon transport, the choice of the best policy strategies is important to strengthen this transition. The methodology presented in this Thesis combines 'top-down' and 'bottom-up' modelling approaches. On the one hand, the 'top-down' modelling framework described in Chapter 4 (supported by the results of Chapter 3) gives essential understanding of policy mechanisms that can be used to speed up transition to a low-carbon transport system. On the other hand, the 'bottom-up' evaluation (Chapters 5–6) gives a holistic approach, valid also for regional and local scales. In the following sections, the research methods used at each planning level are described in more detail.

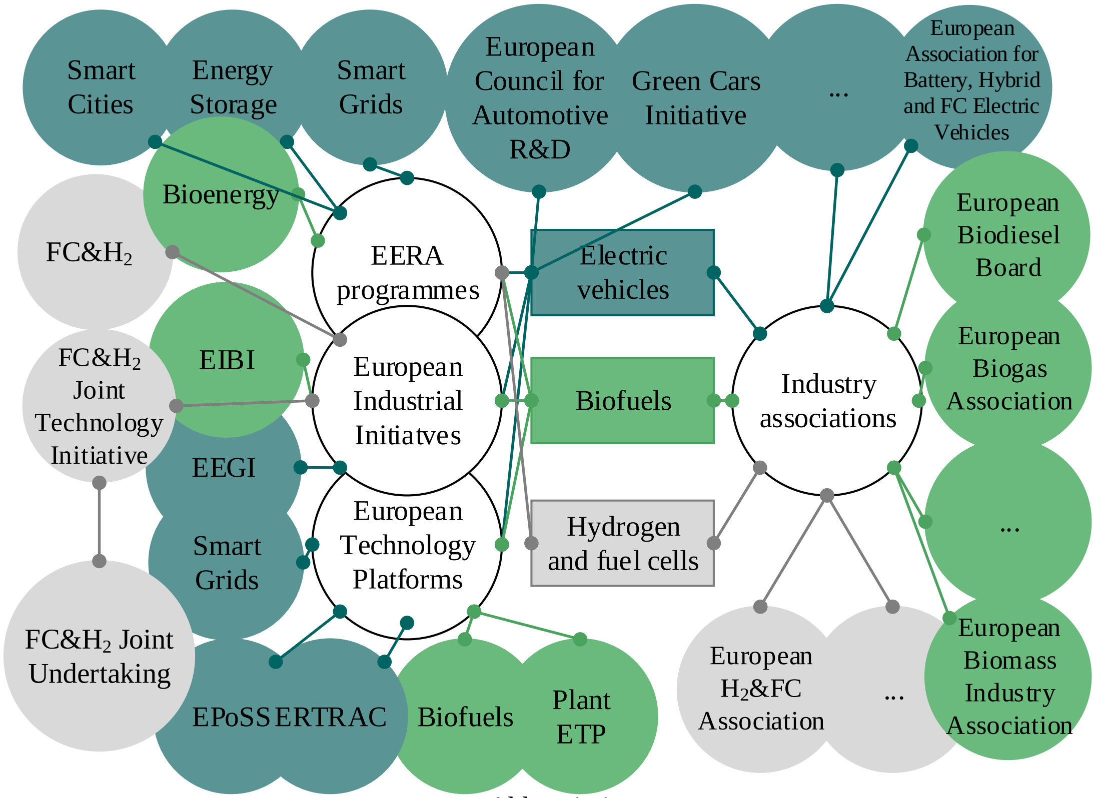
# 3. EUROPEAN LEVEL STUDY ON ALTERNATIVE FUEL VEHICLES

The aim of this study was to increase the knowledge and understanding of the major barriers and opportunities for alternative fuel vehicles at a European level. The research is based on the results from seven in-depth interviews with European-level organization representatives responsible for the research and development of alternative fuel vehicles. The three major alternative fuel technology platforms, namely, electricity, biofuels and hydrogen and fuel cells, are covered by the study.

## 3.1. European network for alternative fuel vehicles research and development

The European network of alternative fuel technologies forms around three major research and technology network organizations (Fig. 3.1):

- European Technology Platforms;
- European Industrial Initiatives; and
- European Energy Research Alliance programmes.




Abbreviations

EEGI – European Electricity Grid Initiative
EERA – European Energy Research Alliance
EIBI – European Industrial Bioenergy Initiative
EPoSS – European Technology Platform on Smart Systems Integration
ERTRAC – European Road Transport Research Advisory Council
ETP – European Technology Platform
FC – Fuel cell
FC&$H_2$ – Fuel cells and hydrogen

Fig. 3.1. European network for alternative fuel vehicles R&D.

The main work of the network is related to the development and updating of strategic research agendas for alternative fuels and technologies, strengthening of the research network, and provision of cooperation among academia and industry. In addition, industry associations and organisations deal with the promotion of alternative fuels at various levels.

Of identified organizations that form the central research network for alternative fuel technology development in Europe, representatives for interviews were chosen. In total, seven organizations were chosen for interviews representing all three technology platforms:

- European Biofuels Technology Platform;
- European Industrial Bioenergy Initiative;
- European Biogas Association;
- Green eMotion project (one of the largest projects launched under the Green Cars Initiative);
- European Green Cars Initiative;
- European Energy Research Alliance Joint Programme on Fuel Cells and Hydrogen; and
- European Hydrogen Association.

### 3.2. Interviews with European Union level stakeholders

The objective of the interviews was to gain information about European-level developments within the transport sector to understand the existing framework conditions, main challenges and barriers for sustainable mobility in Europe. Data were collected in semi-structured interviews via tele-conferences between January–June 2013. Interview questions were targeted to:

- introduce the organization and the person;
- identify the major information exchange networks;
- evaluate EU research in transport;
- determine the main barriers and difficulties;
- identify the opportunities for renewable energy in European road transport; and
- collect information on best practice examples of renewable energy developments in the European road transport sector.

The experts interviewed agree that so far at European level there has been much research in the field of alternative fuels, and it has allowed the first steps to be taken in the market introduction of technologies. Future developments will mainly depend on progress at political level. Experts emphasize that there is a need for a common policy framework as a signal to investors and end-users. This applies to the harmonization of policies between Member States and technology standardization.

# 4. NATIONAL LEVEL DEVELOPMENT: EVALUATION TOOL FOR $CO_2$ EMISSION REDUCTION SCENARIOS

As shown by the literature review and highlighted by Girod et al. [13], scenario studies suggest that $CO_2$ emission savings can be achieved in the transport sector without limiting mobility. The reality, on the other hand, shows an opposite trend of increasing $CO_2$ emissions. This fact highlights the challenging task of decoupling economic growth from climatic consequences, especially if one looks at European countries with less advanced economies, which also includes Latvia.

$CO_2$ emission trends and policy analysis is based on the newly developed simulation model based on system dynamics modelling approach. The aim of the model is to improve the knowledge-base and modelling capacity underpinning policy decision making in transport sector at a country level.

## 4.1. System dynamics modelling approach

System dynamics is a scientific approach where computer based modelling and simulation is used to go beyond the systems structure and to study how and why complex systems develop over time [14]. The theoretical building-up of a dynamic model involves the following steps [15], [16]:

1) problem identification;
2) hypothesis development;
3) model formulation;
4) model testing; and
5) testing policy alternatives.

The analysis of systems structure is based on the concept of two-way causation or feedback (Fig. 4.1.(a)). According to this concept [17], it is considered that decisions derive from information about the state of the system or environment surrounding the decision maker. New information about the changed state of the system induces further decisions and changes. Each such closed chain of causal relationships forms a feedback loop, and many such loops linked together make up system dynamics models [17].

The causal relationships between the elements of the system are transferred to modelling language by using two major types of elements (Fig. 4.1.(b)): state variables or stocks, and flows. State variables represent an accumulation or stock of material or information (e.g. population, vehicle stock, mileage travelled), while flows are used to represent actions that change the state over time. Flows are affected by other elements such as auxiliaries and constants, each of which usually reflects a part of the real world system and is characterized either by mathematical equations or constant values.

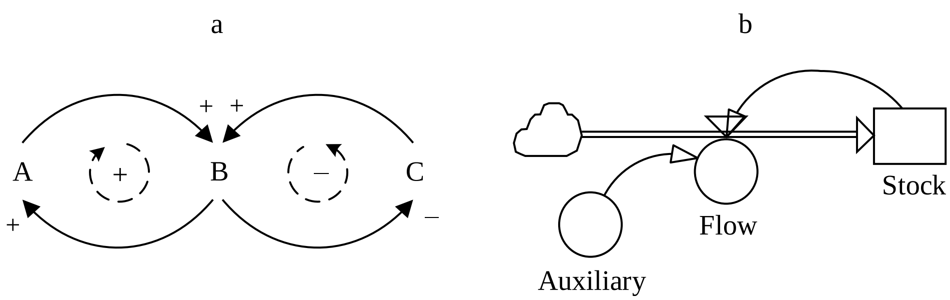



Fig. 4.1. Illustration of system dynamics modelling concepts: causal loop diagram (a); a stock–flow diagram (b).

The principle of accumulation behind the dynamic behaviour of systems states that the dynamic behaviour occurs when flows accumulate in stocks (Eq. 4.1.) [15]:

$$Stock_t = Stock_{(t-dt)} + dt \cdot Flow_{(t,\, t-dt)}, \tag{4.1}$$

where
$Stock_t$ – the stock level at time $t$;
$Stock_{(t-dt)}$ – the stock level at time $t - dt$;
$dt$ – time interval;
$Flow_{(t,\, t-dt)}$ – the flow rate influencing the stock during the time period from $t - dt$ to $t$.

## 4.2. Problem formulation

Past developments in the transport sector are reasonable grounds to believe that greenhouse gas emissions from transport will continue to grow in the future. Historic development trends have shown a good correlation between the gross domestic product (GDP) growth and the transport energy consumption. Decoupling economic growth and increasing energy demand from greenhouse gas emissions in the transport sector has proved to be a difficult task to date, and is a challenge for the future.

Based on the historically observed $CO_2$ emission trends, three possible scenarios were developed:

1) A: Pessimistic scenario – assumes a dynamics growth in $CO_2$ emissions following the economics growth;
2) B: Moderate scenario – assumes that $CO_2$ emissions stabilize during the period 2020–2030 at the 2020 level; and
3) C: Optimistic scenario – assumes that $CO_2$ emissions are reduced 10 % below the 2005 level.

## 4.3. General model description

As shown in Fig. 4.2., the system dynamic model consists of six modules processed in subsequent steps: (i) transport activity modelling; (ii) mode split; (iii) vehicle demand forecast; (iv) technology distribution; (v) energy demand modelling; and (vi) $CO_2$ emission modelling.

The model was created using *Powersim Studio 8* modelling software. It provides a $CO_2$ emission forecast by 2030 with a time step of one year. The model was limited to capture $CO_2$ emissions from road and railway transport modes (excluding domestic navigation and domestic aviation) since they contribute the greatest share of $CO_2$ emissions from the transport sector (95.2 % in EU–28 in 2013 [4]). Moreover, only $CO_2$ emissions related to direct use of fuel in transportation are considered since they form 98.8 % of the EU–28 transport GHG emissions [4].

Annual transport demand projection ($1^{st}$ module) is developed based on the historically observed relationship between GDP, travel activity, and population:

$$\textit{Passenger transport demand}\ (\text{pkm}) = 10\,065.0 \cdot LN\ (\text{GDP}) - 153\,186.0; \tag{4.2}$$

$$\textit{Freight transport demand}\ (\text{tkm}) = 20\,266.1 \cdot LN\ (\text{GDP/capita}) - 154\,709.7. \tag{4.3}$$

The mode split in the $2^{nd}$ module depends on the effect of consumer choice factors. It is assumed that the choice is influenced by five factors: (i) cost of private car use [18], [19], (ii) travel time [18], [19], (iii) accessibility to infrastructure [20], (iv) social acceptance determined by such factors as previous experiences [21], satisfaction with the service [22], and socio-economic position [23]; as well as (v) environmental consciousness [24]. The shift from the initial car user stock to public transport and cycling is the result of changes introduced in consumer choice factors.

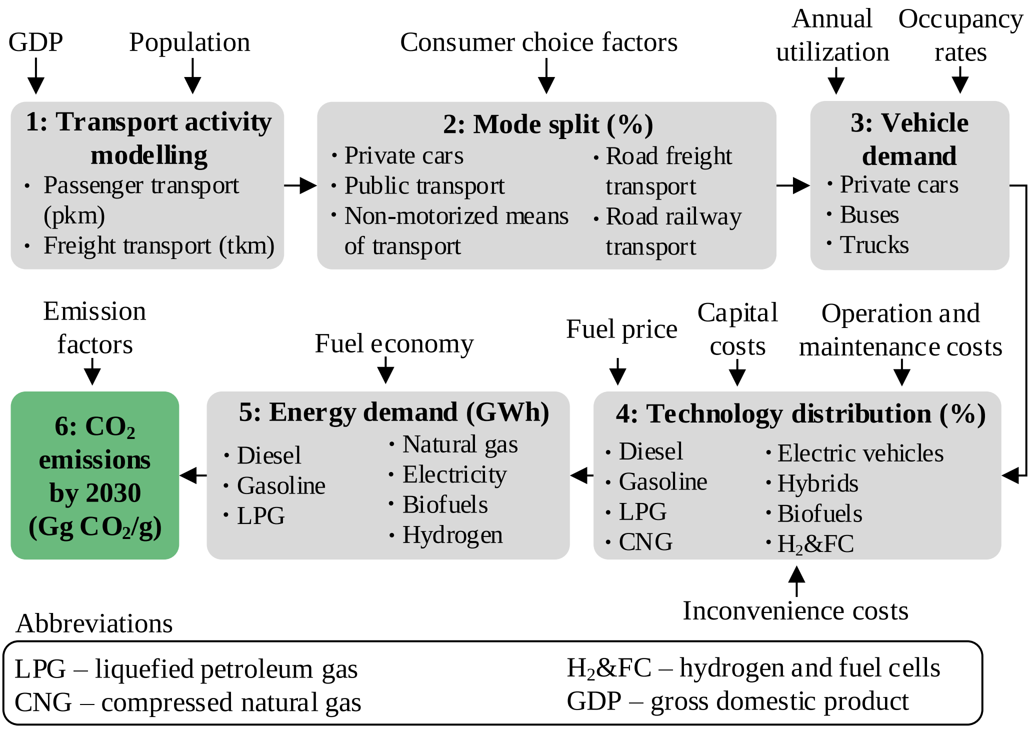



Fig. 4.2. General structure of the road transport system dynamics model.

The general principle of stocks and flows representing the technology distribution module in the *Powersim* modelling platform is illustrated in Fig. 4.3. As an example, the technology choice of electric vehicles is shown demonstrating the dependence of investment shares on total vehicle ownership costs.

Logit function is used to describe technology choice based on cost estimation [25] (Eq. 4.4.):

$$S_i = \frac{\exp^{-\alpha C_i}}{\sum_j \exp^{-\alpha C_j}}, \qquad (4.4)$$

where

$S_i$ – the market share of technology $i$;
$\alpha$ – a coefficient representing the cost sensitivity of market demand;
$C_i$ – the total cost of owning and driving a vehicle of technology $i$, EUR/km;
$C_j$ – the cost sum of owning and driving the vehicles of all technologies, EUR/km.

The total cost of owning and driving a vehicle $C_i$ (EUR/km) is the sum of four components: vehicle cost $C_{\text{veh}}$, fuel costs $C_{\text{fuel}}$, vehicle operation and maintenance costs $C_{\text{O\&M}}$, and inconvenience costs $IC$ (Eq. 4.5.):

$$C_i = C_{\text{veh}} + C_{\text{fuel}} + C_{\text{O\&M}} + IC. \qquad (4.5)$$

The inconvenience cost component relates to alternative fuel technologies, namely electricity, biofuels, natural gas, and hydrogen. Inconvenience costs represent the additional costs to consumers which delay them in choosing alternative fuel technologies. Three types of inconvenience costs are included in the model:

1) cost inconvenience costs (‘Cost IC’) representing higher initial costs of alternative fuel vehicles compared to conventional vehicles;
2) infrastructure inconvenience costs (‘Infrastructure IC’) representing the lack of charging/refuelling infrastructure; and
3) awareness inconvenience costs (‘Awareness IC’) representing a risk factor associated with the low knowledge and experience of alternative fuel vehicle use.

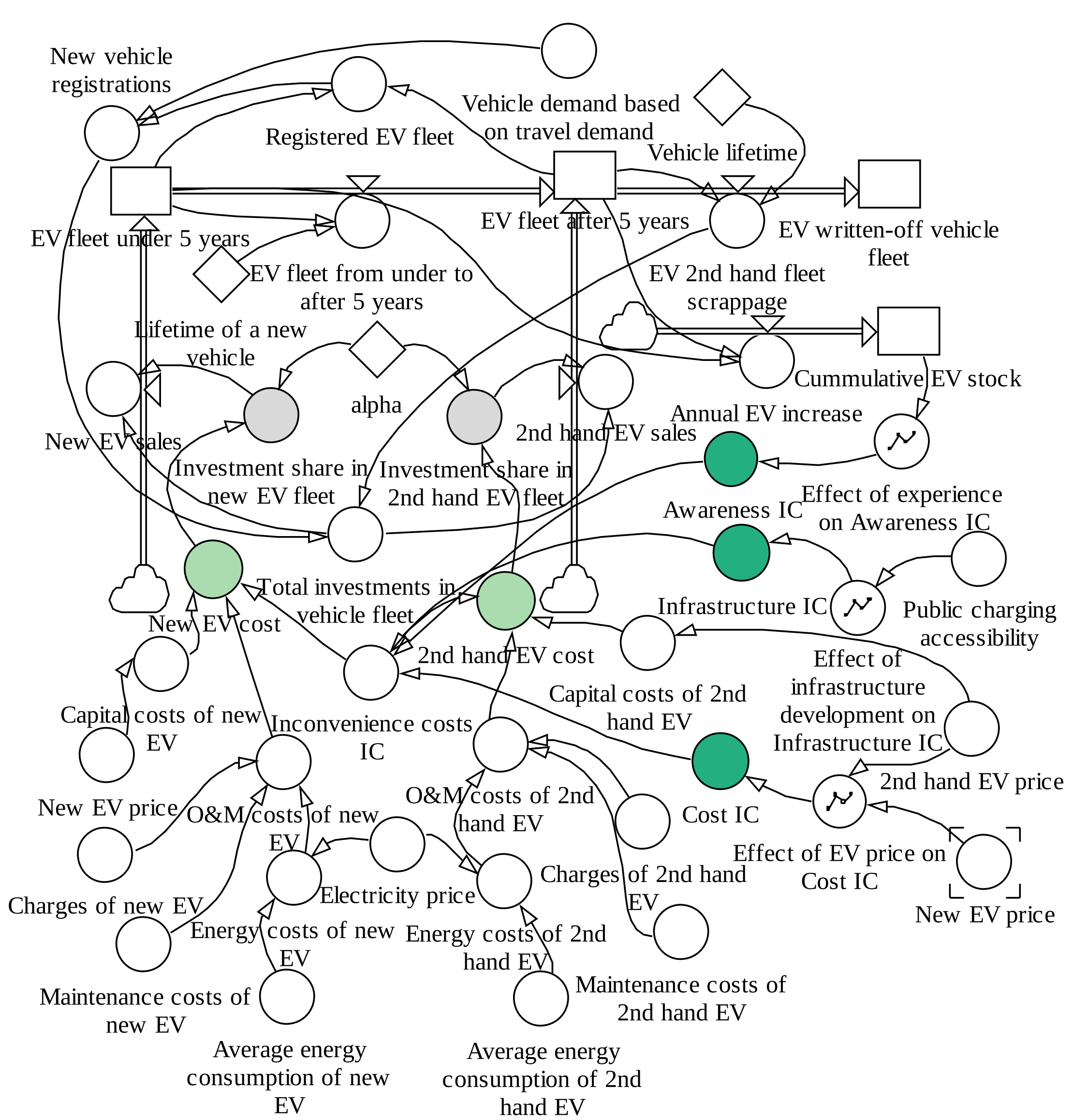



Fig. 4.3. Representation of the technology choice module in the system dynamics model (EV – electric vehicle; IC – inconvenience costs).

Similar stock–flow diagrams as that shown in Fig. 4.3. have been developed for all eight technologies (diesel, gasoline, liquefied petroleum gas, biofuels, compressed natural gas, electric vehicles, hybrid vehicles, and hydrogen) in each of the vehicle types (cars, buses, and trucks). The

$CO_2$ emissions from the transport sector were calculated based on IPCC methodology for national greenhouse gas emission inventories [26]. Total emissions are constructed from road transport sub-categories (cars, trucks, buses) and railway transport.

### 4.4. Modelling assumptions

The following major assumptions regarding macro-economic, economic and technical development are considered in the model:

- transport demand will continue to follow the GDP development as historically observed. Annual GDP increase is assumed to have an average growth rate of 3.1 % between 2015 and 2018 and 1.9 % between 2018 and 2030, in accordance with the national projections [27];
- the demographic indicators will remain negative, i.e., the population will continue to decline with an average decline rate of 1.2 % per year as historically observed;
- fuel prices were assumed to have annual increase rates similar to those observed in the past: diesel – 6.6 %; gasoline – 8.0 %; LPG – 5.2 %; electricity – 8.7 %. For the 'new' fuels (which are not currently used in the Latvian market), the following price increase rates were assumed: 12.5 % for CNG (corresponds to the average price increase rate of natural gas), and 5 % for hydrogen;
- the cost of alternative fuel vehicle technologies will reduce in response to increased global market share [28]; and
- the average fuel efficiency and $CO_2$ emissions of new cars will satisfy the European Union requirements [29].

### 4.5. Scenario development

Policy instruments studied by this model were grouped in five policy instrument sub-categories:

1) policy instruments promoting mode shift from cars to public transport (scenarios PTS1, PTS2, PTS3, PTS4);
2) policy instruments promoting alternative fuel vehicles (scenarios AFV1, AFV2, AFV3);
3) policy instruments aiming to increase the fuel efficiency and the use of biofuels (scenarios B7, B10, *FuelEff*, *NewVeh*, *Electro*);
4) policy instruments promoting the mode shift in passenger and freight transport (scenarios MS-P, MS-G, *MS-Cycle*); and
5) a comprehensive policy scenario with a combination of policy instruments.

Scenario descriptions with corresponding assumptions are summarized in Table 4.1. All policy instruments are assumed to be implemented starting from 2016, if not stated otherwise.

Table 4.1

Description of alternative policy scenarios

| **Scenario** | **Policy measures and results** |
|---|---|
| PTS1 | A gradual decrease in the average travel time per public transport trip by 2030 (−35.0 %) |
| PTS2 | Doubling of private car use costs compared to public transport |
| PTS3 | Informative measures to increase the popularity and acceptance of public transport in society |
| PTS4 | Informative measures to increase the environmental awareness related to transport use in society |
| AFV1 | Development of alternative fuel infrastructure (45 stations/year) |

| Scenario | Policy measures and results |
|---|---|
| AFV2 | Subsidies for alternative fuel vehicle purchase between 2016 and 2021; subsidy rate: 40 % |
| AFV3 | Informative measures to increase the public awareness of alternative fuel vehicles |
| B7 | Increase in mandatory biofuel blend with fossil fuels to 7 % (currently – 5 %) |
| B10 | Increase in mandatory biofuel blend with fossil fuels to 10 % (currently – 5 %) |
| *FuelEff* | Fuel efficiency of used vehicles (cars, trucks, buses) improves 1 % annually (compared to 0.5 % annually in the baseline scenario) |
| *NewVeh* | The lifetime of used conventional fuel cars reduces from 25 years (base scenario) to 10 years starting from 2016 |
| *Electro* | 20 % shift from diesel to electric goods railway |
| MS-P | 2 % annual shift of bus users to railway |
| MS-G | 0.5 % annual shift from road to railway mode in freight transport starting from 2016 |
| *MS-Cycle* | Development of cycling infrastructure (50 km/yr);<br>Policy of raising awareness (informative measures);<br>Additional costs for car users (+30 %) |

## 4.6. Model validation

Structural and behavioural validation tests were performed in this study. In Fig. 4.4., the dynamic behaviour of the key variables generated by the model is compared to the historic data. It can be seen that the behaviour generated by the model is consistent with the historic data. Thus, it is assumed that the model is capable of replicating the structure of the real system and generating meaningful predictions. It is thereby concluded that the model is useful for further policy design aiming to improve the behaviour of the system in the future.

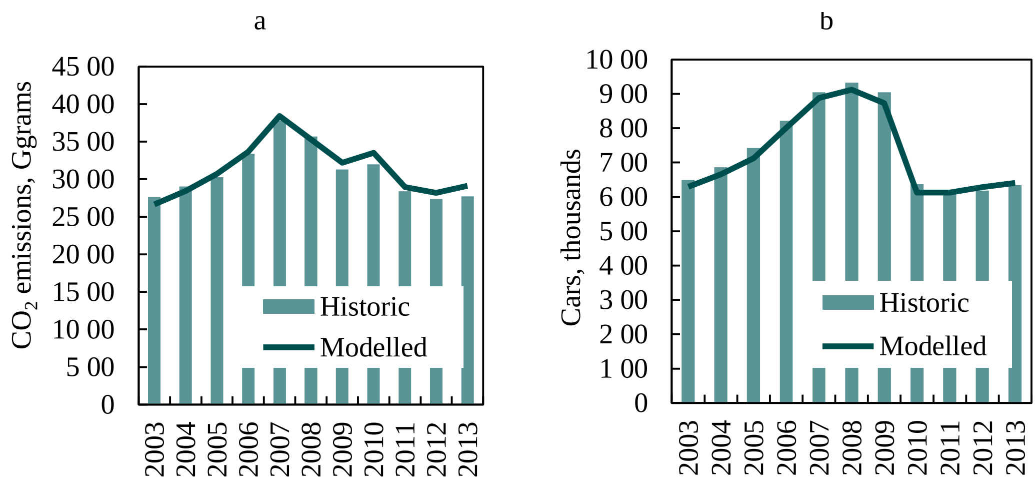



Fig. 4.4. Historical and modelled data on $CO_2$ emissions from the road and railway transport (a) and registered car stock in Latvia (b), 2003–2013.

## 4.7. Results

Baseline scenario results project around 3,480 Gg $CO_2$ in 2030, which is a 25.5 % increase compared to the 2013 level [30]. In the baseline scenario, the car transport will maintain its dominant role as the major $CO_2$ emission source. Car fuel structure will be dominated by three fuel types: gasoline (a decreasing trend), diesel (an increasing trend), and LPG (an increasing trend). The stock of alternative fuel vehicles will increase; however, their overall market share will remain negligible.

The results of the comprehensive policy scenarios are illustrated in Fig. 4.5. Here, the cumulative effect of policy measures is shown. The results show that $CO_2$ emissions from the road transport sector in Latvia could develop following any of the three hypothetical scenarios defined previously (pessimistic, moderate, and optimistic).

A 4.4 % $CO_2$ emission reduction can be achieved due to mode shift from private cars to public transport. However, it should be noted that the increase in public transport use must be relatively large – from 21.0 % currently to around half all passenger travel (53.2 %) in 2030. A combination of technical, economic and informative incentives might lead to this transition. If the shift from private cars to public transport is supplemented with an annual 2 % transition from public transport buses to railway transport (MS-P scenario), the $CO_2$ emission savings increase to 8.1 % compared to the baseline scenario in 2030. Furthermore, a shift from cars to non-motorized means of transport could lead to additional emission savings. A 4.5 % shift would allow achieving additional 1.3 % $CO_2$ emission savings compared to the previous scenario.

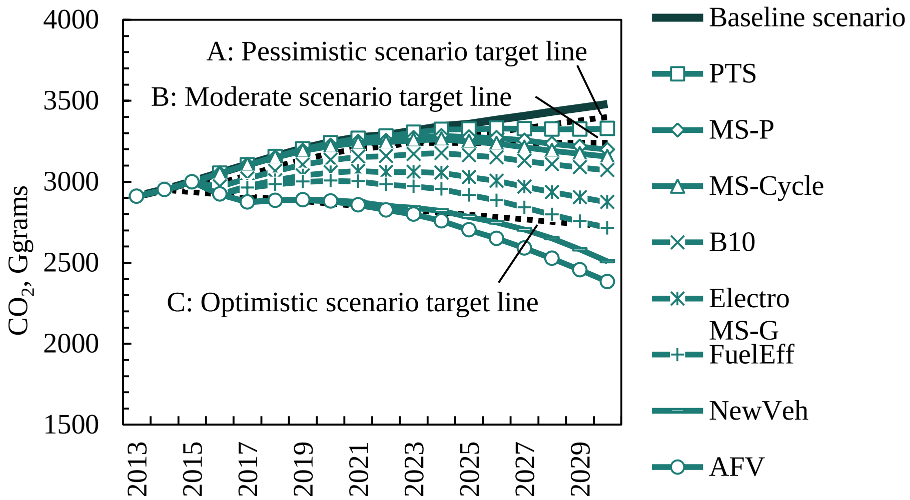



Fig. 4.5. Combined policy results showing the cumulative effect of policy instruments.

In order to achieve the $CO_2$ emissions around the current level in 2030 or decrease, besides the policy measures described above, policy incentives improving the efficiency of the vehicle fleet must be implemented. Fuel efficiency improvements in the vehicle fleet to above average in passenger and freight transport, in combination with a mode shift from road to railway (with electrification of railway transport, scenario *Electro* MS-G) in goods transport, could lead to 22.0 % $CO_2$ emission savings compared to the baseline scenario. In a more environmentally sound scenario, even greater emissions can be achieved. Based on the modelled scenarios, additional emission savings can be achieved by introducing the policies that aim at reducing the average age of the vehicle fleet (e.g. schemes to scrap old vehicles) and increasing the market share of alternative fuel vehicles. In the best case scenario, when all policy instruments are combined, $CO_2$ emission savings could reach 31.5 % in 2030 compared to the baseline scenario. This would allow reducing $CO_2$ emissions by more than 10 % compared to the 2005 level.

# 5. LOCAL LEVEL ANALYSIS

Around 40 % of EU–28 citizens live in densely populated areas [31]. Salvia et al. [32] have pointed out that 'cities are central to achieve the ambitious targets and support the shift towards sustainable growth via a resource-efficient, low-carbon economy'. Further on, a decentralized energy planning and policy design has several benefits [33], [34]:

- it allows for a better fit to local circumstances;
- better interaction between local governments and citizens; and
- being owners of, or owning stakes in, local energy or property companies means that local governments can exert influence over both energy supply and demand.

The aim of this part of the research is to address linkages and trade-offs of the shift to low-carbon transport between national and local planning scales, and it was performed based on two case studies. The first case study evaluates the theoretic techno-economic potential of producing and utilizing biomethane in a transport fleet of a medium-sized city in Latvia. The second case study aims to evaluate the first experience of introducing electric vehicles in Latvian municipalities, based on a survey.

## 5.1. Case study 1: Biomethane use in urban transport

The aim of this research was to perform a techno-economic evaluation of the potential of using biomethane in public transport. The research focuses on the so called waste-to-biomethane (WtB) pathway. The WtB concept is used to describe the utilization of organic waste for biogas production in the process of anaerobic digestion and further upgrading of biogas to biomethane for grid injection or transport/energy applications [35]. The integration of waste management and transport systems is demonstrated in a case study of Valmiera city in Latvia. It represents one of nine major cities of national importance in Latvia thus ensuring a high rate of replication for the proposed concept in Latvia and other countries, especially in Eastern Europe.

A step-by-step methodology was developed in order to investigate the proposed WtB concept in an urban energy system. It consists of three steps as shown in Fig. 5.1:

1) assessment of the waste as feedstock for biogas production;
2) assessment of the biogas and biomethane generation technical options and economic viability; and
3) evaluation of biomethane application alternatives.

At present, municipal solid waste (MSW) (including organic waste) generated in the city is taken to the North Vidzeme municipal waste management site 'Dabe', where landfill gas is collected and further used for electricity generation in a co-generation mode. Latvian legislation does not currently provide any support measures for biomethane production. In addition, since the natural gas market has been monopolized until 2017, possibilities for new suppliers entering the market are limited. Taking into account the existing framework, four potential biogas and biomethane production alternatives were analyzed:

- Alternative 1: Dry fermentation + CHP;
- Alternative 2: Dry fermentation + CHP until 2020 + biogas upgrading from 2020;
- Alternative 3: Wet fermentation + CHP; and
- Alternative 4: Wet fermentation + CHP until 2020 + biogas upgrading from 2020.

Alternatives 1 and 3 assume that the current landfill gas collection and electricity generation in the CHP plant is supplemented by a new anaerobic digestion unit for biologic MSW treatment. In Alternative 1, the anaerobic digestion unit uses dry fermentation technology. In Alternative 3, the anaerobic digestion unit uses wet fermentation technology. Alternatives 2 and 4 assume that both previously described scenarios are supplemented with a biogas upgrading plant using pressure swing adsorption technology. In these scenarios, the CHP unit is in operation by 2020, being replaced afterwards by the biogas upgrading plant.

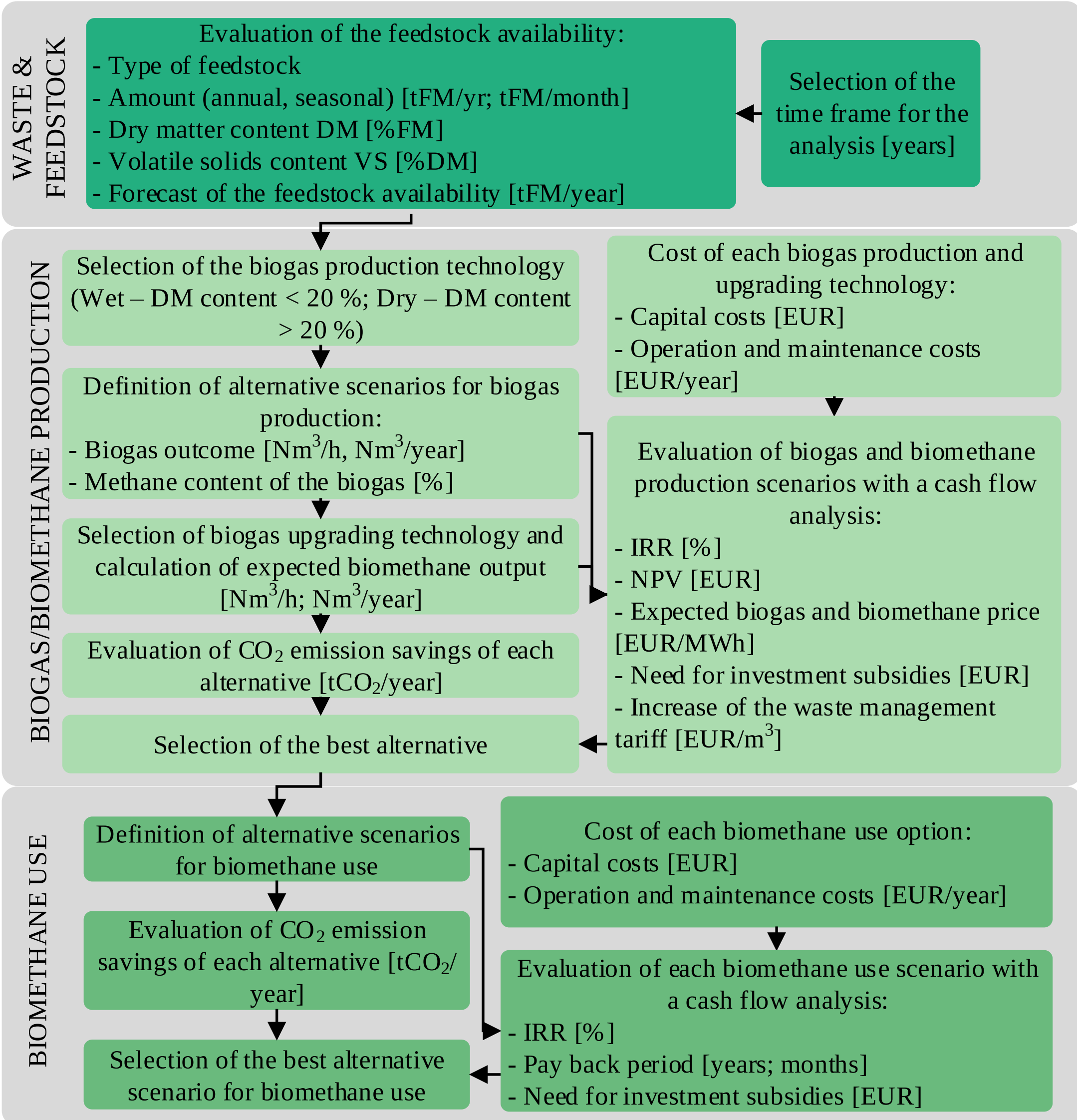



Fig. 5.1. A step-by-step approach for waste-to-biomethane concept in an urban system.

Two alternative scenarios for biomethane utilization in the transport sector were developed, and a techno-economic analysis was performed. The first scenario suggests using the biomethane in waste collection trucks. The second alternative suggests using the biomethane in Valmiera city buses. In the reference scenario which represents the current situation, both vehicle fleets are operated using diesel.

It was found that around 1.1–1.5 million $Nm^3$ of biogas and 608–862 thousands $Nm^3$ of biomethane could be produced annually from municipal solid waste generated in the target region starting from 2020 depending on the technology chosen. In order to get a positive cash flow of a biomethane production unit, the revenues from selling biomethane should be at least 0.35 EUR/Nm$^3$ in the case of biogas production in dry fermentation and 0.74 EUR/Nm$^3$ in the case of biogas production in wet fermentation. The generated biomethane output is sufficient to provide fuel for a fleet of up to 25 vehicles.

In Table 5.1, alternatives are compared in the case of a maximum vehicle fleet that can be converted to biomethane, considering the availability of biomethane in the target region. Considering the mileage and fuel consumption figures of both vehicle fleets, the amount of biomethane produced is sufficient to provide the fuel shift of 21 vehicles in the scenario with biogas production in dry fermentation and 24 waste collection trucks or 25 buses in the scenario where biogas is produced by wet fermentation technology. The investment costs take into account the vehicle conversion costs and biomethane filling station installation costs. The results show that the IRR is positive in the scenarios A1 with dry fermentation technology, which can be explained by the relatively low biomethane price rate in this scenario. Whereas in A2 scenarios with biogas production in wet fermentation technology, the IRR is negative. In order to achieve an economically acceptable IRR (7 %), the project needs external support in the form of subsidies. For example, in the case of 25 buses being converted from diesel to biomethane and considering a 20 % subsidy is provided to cover the vehicle price premium in combination with a 10 % subsidy for the filling station, a 7 % IRR is projected.

Table 5.1

Comparison of biomethane transport alternatives in the maximum utilization scenario (21–25) vehicle fleet

| | Alternative | | | |
|---|---|---|---|---|
| | A1-AA | A1-AB | A2-AA | A2-AB |
| Number of vehicles | 21 | 21 | 24 | 25 |
| Price of the biomethane, EUR/Nm$^3$ | 0.35 | 0.35 | 0.74 | 0.74 |
| Investment costs, thousand EUR | 1,230 | 1,083 | 1,320 | 1,175 |
| Annual fuel cost savings, thousand EUR/year | 509.4 | 491.2 | 258.1 | 259.3 |
| Annual $CO_2$ savings, tons $CO_2$ / year | 1,131 | 1,091 | 1,293 | 1,299 |
| Internal rate of return (IRR) | 66 % | 77 % | Negative | Negative |
| Subsidy needed (IRR = 7 %), EUR | Not needed | Not needed | 40 % vehicle incremental costs + 20 % filling station | 20 % vehicle incremental costs + 10 % filling station |

A1 – Mechanical waste treatment following biogas production in dry fermentation
A2 – Source-separated waste collection following biogas production in wet fermentation
AA – Biomethane use in waste collection trucks
AB – Biomethane use in public transport buses

### 5.2. Case study 2: Electric mobility in Latvian municipalities

Public bodies are acknowledged to be an important driver in achieving energy end-use efficiency [36]. The introduction of electro-mobility in the public sector is one example of how the market introduction of alternative fuels can be promoted.

The goal of this study is to evaluate the first steps of introducing electric mobility in Latvian municipalities. In 2014, the Ministry of Environmental Protection and Regional Development announced a call for electric vehicle purchase and installation of charging stations with a total funding of €5m. The beneficiaries were the direct and indirect administration institutions, derived public persons, and companies. Further in the chapter, experiences from municipalities that participated in the State support programme are summarized. This was carried out with the help of a survey designed to collect users' opinions and attitudes to the new electric cars.

The survey consisted of 21 questions grouped into three sections. The first group of questions dealt with technical data on municipal vehicle fleets including electric vehicles. The second group of questions was designed to clarify user habits and attitudes towards electric vehicles. The third group of questions was targeted at understanding the motivation of municipalities to participate in the State support programme and also to evaluate the existing barriers to a wider penetration of electric vehicles. The survey consisted of open questions, multiple choice questions, and the Likert scale questions.

A request to complete the survey was sent via e-mail to 55 public bodies (municipality administrations, universities, public utilities, etc.) which were granted the State support for electric vehicle purchase. In total, 24 completed questionnaires were received.

Further, the major findings from the survey are summarized.

- The mileage limitation of electric vehicles is more an emotional than a practical obstacle. None of the respondents indicated the average mileage of a trip over 90 km, and the majority of respondents (36 %) travelled under 20 km. Considering that the usual mileage limitation of an electric vehicle determined by the battery capacity is around 120 km, electric cars can be considered an appropriate solution for use in a municipality vehicle fleet. At the same time, 91.2 % of respondents noted that driving an electric vehicle requires more detailed planning of trips due to the limited mileage with one battery charge. 65.3 % also agree that the time spent on electric vehicle charging influences the planning of daily activities.
- Contribution to the 'green image' of the municipality and the possibility of reducing fuel costs are the two most highly rated motivating factors for the purchase of electric vehicles. Overall, 58.3 % of the respondents assessed contribution to the 'green image' of the municipality as a predominant motivating factor for electric vehicle purchase. The possibility of reducing fuel costs by switching from a conventional fossil fuel car to an electric car was evaluated as the second most important motivating factor (45.8 % of respondents marked it as very important). Other motivating factors ranked as important in most cases were reduction of air pollution, contribution to national climate and energy policy goals, as well as local policy goals, and contribution to regional development.
- The major drawbacks of electric vehicles mentioned by respondents included the lack of charging infrastructure, longer time spent on charging compared to the refuelling time of a conventional car, and limited mileage with one charging. When asked to evaluate the importance of various barriers delaying the broader introduction of electric vehicle use, all respondents expressed the view that the price, technical limitations and poor charging infrastructure were the most important or very important aspects. The importance of the barriers was evaluated as being: 34.0 % – lack of charging infrastructure; 25.0 % – higher price compared to conventional cars; 22.0 % – technical restrictions (e.g., charging time); 14.0 % – limited availability of models; and 5.0 % – lack of information.
- Financial support for vehicle purchase is crucial to achieve a higher market share. In total, 91.7 % of respondents rated the financial State support as a very important measure. Other economic motivators, e.g., tax policy, would also be a motivating factor for most respondents. An increase in fossil fuel prices would be an important signal for 75.0 %, similarly as a clear position towards electric mobility at a national level (important for 87.5 %). The State initiated information campaigns were evaluated as

important by 66.6 % of respondents; meanwhile, 25.0 % of respondents evaluated their importance as weak.

In addition to these findings, survey results provide a quantitative assessment of the necessary improvement of existing barriers. Respondents were asked to evaluate the necessary changes in the given barriers so they would not consider this barrier as significant for the introduction of electric vehicle use. This assessment was undertaken to supplement assumptions in the system dynamics model described in Chapter 4 regarding the assessment of inconvenience costs. The results are illustrated in Fig. 5.2.

Based on respondent responses, the results show that each of the identified barriers can be overcome by providing various levels of improvement. As for electric vehicle price, respondents acknowledged that cost reduction above 40 % would result in a significant improvement in the attitudes of potential users. For example, if the price of an electric car would become 41–50 % lower than it is currently, almost 70 % of respondents would not consider it as a barrier to the introduction of electric vehicle use. The price barrier completely loses its significance if costs are reduced by 71–80 %. As for electric vehicle model availability, the bottom line of required improvement is 31–40 % compared to the current situation. With the number of electric car models on the market gradually increasing, this barrier is also gradually being reduced. A similar linearly increasing trend can be observed for improvements in the availability of a fast charging infrastructure (addresses technological limitation related to the time spent on charging) and information availability. These barriers can only be completely overcome in the best case scenario; however, a gradual improvement can be expected in response to continuous infrastructure development and provision of information. Meanwhile, the lack of electric vehicle charging infrastructure requires a significant improvement compared to the current situation to overcome the barrier. Based on the results of the survey, an improvement between 41–90 % would change the attitude of only just under 40 % of potential electric vehicle users. For infrastructure availability to not be seen as a barrier for electric vehicle use, charging stations must be freely accessible on main roads, car parks, and other places.

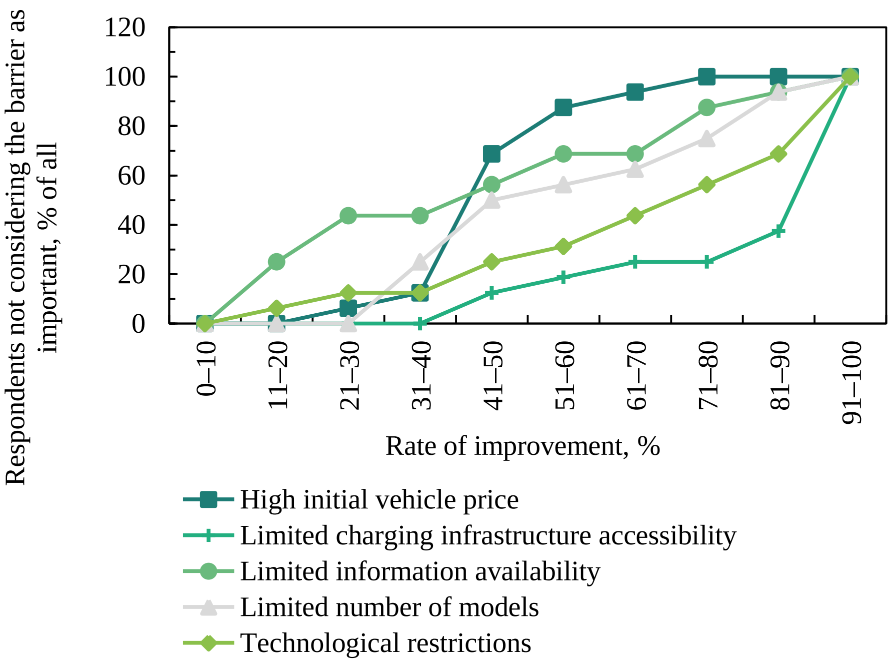



Fig. 5.2. Effect of improvement on barriers for introduction of electric vehicle use.

# 6. TARGET SECTOR ANALYSIS

This chapter describes a dynamic simulation model for biodiesel market analysis in Latvia and analyses the effect of various policy support instruments on increasing the proportion of biofuel in total transport fuel demand.

## 6.1. Biofuel market in Latvia

Latvia joined the European Union in 2004, and in doing so the common energy policy of the European Union became binding for Latvia, also in relation to the use of biofuels in transportation [37]. To promote the achievement of the goals outlined in the Directive 2003/30/EC, the Latvian government initiated the development of a national biofuel support programme. Direct support included subsidy payments for the biodiesel and bioethanol producers. In addition to subsidies, a 5 % mandatory biofuel blend with fossil fuels was introduced at the end of 2009 and reduced excise duty rates were introduced.

During the operation of the State support program, the production capacity of biofuels in Latvia increased considerably from 2.3 thousand tons in 2005 to 175.6 thousand tons in 2010 [38]. The growth, however, stopped after the conclusion of the support programme in 2010. The existing biofuel plants have either suffered financial losses or have ceased the production entirely. The situation is risky considering the 10 % renewable transport energy target by 2020.

## 6.2. Methodology

In order to analyse the effect of various policy support instruments on increasing the proportion of biofuel in total transport fuel demand, a new mathematical simulation model was developed. The model was built using the *Powersim* software platform, and it applies the system dynamics modelling approach. The model incorporates specifications designed to examine the dynamics of biofuel demand and supply market interactions.

In Fig. 6.1, important market sectors and interrelationships that directly impact the biodiesel industry in Latvia are illustrated. As seen in Fig. 6.1, the biodiesel industry is considered to cover three major sectors:

- resource supply sector;
- biodiesel production sector; and
- biodiesel demand sector.

The biodiesel vehicle fleet is the motor of biodiesel demand. The model assesses two types of biodiesel consumers: traditional diesel fuel vehicles, which consume biodiesel through the mandatory biodiesel blending, and vehicles that are adapted to use higher content biodiesel (Eq. 6.1.):

$$D_{\mathrm{B}} = Q_{\mathrm{B}} \cdot KM_{\mathrm{av}}^{\mathrm{B}} \cdot F_{\mathrm{av}}^{\mathrm{B}} + D_{\mathrm{blend}}^{\mathrm{B}}, \tag{6.1}$$

where

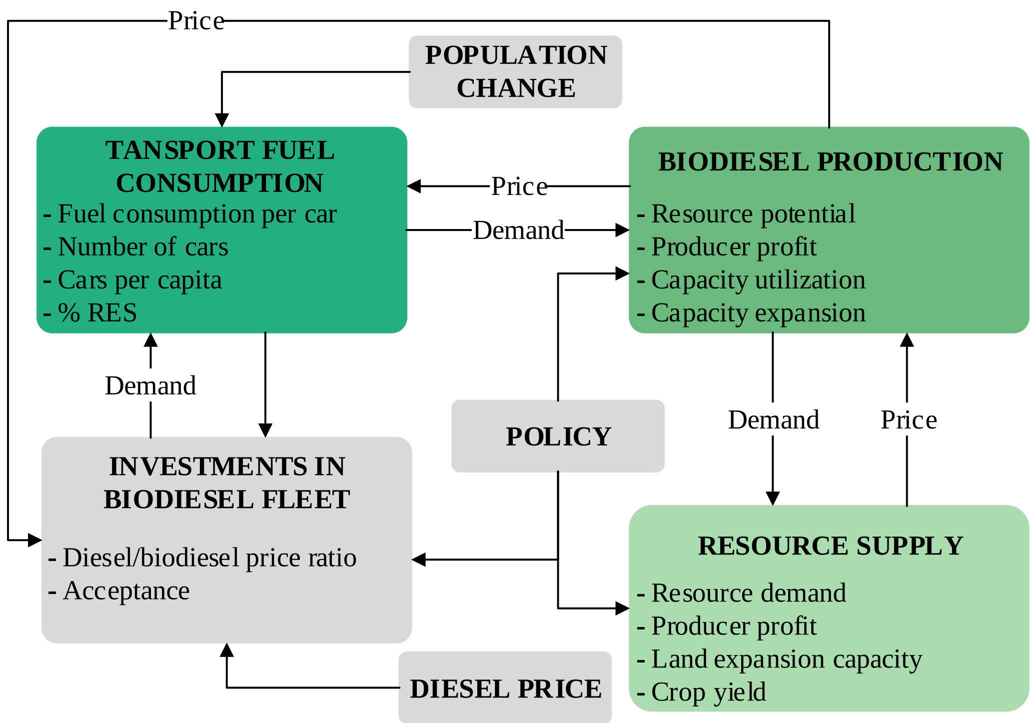
$D_{\mathrm{B}}$ – annual biodiesel demand, l/year;

$Q_{\mathrm{B}}$ – biodiesel vehicle fleet, cars;

$KM_{\mathrm{av}}^{\mathrm{B}}$ – average distance driven by a biodiesel car per year, km/year;

$F_{\mathrm{av}}^{\mathrm{B}}$ – average fuel consumption of a biodiesel vehicle, l/km;

$D_{\mathrm{blend}}^{\mathrm{B}}$ – biodiesel demand due to biodiesel blend with fossil fuels, l/year.




RES – renewable energy sources

Fig. 6.1. Overview of sectoral interactions in the model.

The biodiesel demand directly determines the biodiesel production sector, and, in turn, the biodiesel production impacts the demand for feedstock (in this case, rapeseed) (Eq. 6.2.):

$$Q_{\mathrm{RS}} = S_{\mathrm{RS}} \cdot Y_{\mathrm{RS}}\,, \tag{6.2}$$

where
$Q_{\mathrm{RS}}$ – annual cultivation of rapeseed, t;
$S_{\mathrm{RS}}$ – area of rapeseed, ha;
$Y_{\mathrm{RS}}$ – rapeseed yield, t/ha.

The price of feedstock is the key component determining the biodiesel cost (Eq. 6.3.):

$$C_{\mathrm{prod}} = \left(1 - Subs_{\mathrm{prod}}\right)C_{\mathrm{cap}} + \left(1 - Subs_{\mathrm{farmers}}\right)C_{\mathrm{feedstock}} + C_{\mathrm{fixed}} + C_{\mathrm{op}} - R, \tag{6.3}$$

where
$C_{\mathrm{prod}}$ – the average biodiesel production costs, EUR/ton;
$C_{\mathrm{cap}}$ – equipment capital costs, EUR/ton;
$C_{\mathrm{feedstock}}$ – feedstock price, EUR/ton;
$C_{\mathrm{fixed}}$ – fixed costs, EUR/ton;
$C_{\mathrm{op}}$ – operational costs, EUR/ton;
$R$ – revenue from glycerol sales, EUR/ton;
$Subs_{\mathrm{prod}}$ – subsidies to biodiesel producers, %;
$Subs_{\mathrm{farmers}}$ – subsidies to farmers, %.

From the end-user side, consumer response is driven by the cost competitiveness of the fuels. The consumer will use more biodiesel if the price of biodiesel becomes more attractive regarding the price of diesel. This relationship is described using a multinomial logic model described in [25] which says that the least cost technology gains a relatively larger investment share than its competitors. The existing barriers for a wider use of biofuels [39] are taken into account as inconvenience costs. A virtual biodiesel vehicle stock was created representing the possible number of biodiesel fleets that could be reached if there was no inconvenience among the consumers related to the consumption of biodiesel. The stock is positively affected by an investment flow as described in [14]. The stock outflow in this situation characterizes the loss of investments (foregone investments) in biodiesel vehicle fleets due to the inconvenience related to biofuel purchase and use (Eq. 6.4.):

$$Q_B = +dt\left(I_T \cdot I_B^S\right) - dt(Q_B^V \cdot ISD), \tag{6.4}$$

where

$Q^B$ – biodiesel feet, vehicles;

$I_T$ – total annual investments in a new fleet, EUR/year;

$I_B{}^S$ – biodiesel investment share;

$Q_B{}^V$ – price-based annual biodiesel vehicle fleet (virtual biodiesel fleet), vehicles;

*ISD* – total investment slowdown due to inconvenience costs, %.

The total investment slowdown is assumed to be a sum of three components:

1) investment slowdown related to the price ratio between fossil fuel and biofuel ($ISD^{price}$, %);
2) investment slowdown related to fuel availability ($ISD^{availability}$, %); and
3) investment slowdown related to the necessity of vehicle modification to be able to use high-level biofuels ($ISD^{modif}$, %).

The investment slowdown (*ISD, %*) is calculated using the Eq. 6.5:

$$ISD = E^{price} \cdot ISD^{price} + E^{availability} \cdot ISD^{availability} + E^{modif} \cdot ISD^{modif}, \tag{6.5}$$

where

$E^{price}$ – effect of fuel price on investment slowdown, %;

$E^{availability}$ – effect of biodiesel availability on investment slowdown, %;

$E^{modif}$ – effect of the necessity to modify the vehicle on investment slowdown, %

### 6.3. Results

The modelling results are shown in Fig. 6.2 and reflect the share (%) of biodiesel in the final consumption transport fuel in different scenarios. The business as usual scenario (scenario A) describes the future effectiveness of the current biofuel policy in Latvia. It considers the continuation of the existing 5 % mandatory biodiesel blend policy in combination with a 0.3 EUR/l fossil fuel excise tax. Such a policy allows increasing the share of biodiesel of the final transport energy consumption from the initial 3.4 % in 2012 to 4.0 % in 2020 and 4.2 % in 2030. The consumption of biodiesel can be increased by raising the mandatory blend of biodiesel with the diesel from the current 5 % to 7 % (scenario C) or by promoting end-consumers with subsidies to cover the costs related to vehicle modifications necessary to be able to use high blend biofuels (scenario D). These policy instruments provide up to a 1.5 % additional increase in the biodiesel share of the total transport fuel consumption by 2030.

The scenarios E–G illustrate several policy instruments which can be used to increase the share of biodiesel in final transport fuel consumption by 2.5–3.5 % compared to the baseline scenario. In the best case scenario (G), a combination of policy instruments allows reaching a 7 % biodiesel share in 2030. From the model simulations, a confirmation was found that promoting biofuel acceptance among end-users is critical. Promoting biofuel end-use by certain support measures such as subsidies to cover vehicle modification costs or refuelling infrastructure development costs allows ensuring a moderate growth of biodiesel consumption. The policy instrument ensuring the greatest increase in biofuel consumption in the moderate growth scenario is the development of the biodiesel refuelling infrastructure. The results confirm that the adoption of alternative fuel vehicles is highly dependent on refuelling availability [40], which should be primarily addressed by policy makers. In combination with the subsidies for vehicle owners for adapting their vehicles for high-blend biodiesel fuel (scenario F), this policy instrument can increase the local demand of biodiesel considerably: 5.5 % in 2020 and 6.8 % in 2030 out of the final transport fuel consumption. Alternatively, good results can be achieved by a combination of policies focused on all target groups involved in the biodiesel supply chain. One such example is a combination of four policy measures illustrated in the G scenario: increased biodiesel blend with fossil diesel from 5 % to 7 %; a 50 % increase in excise tax on fossil fuels; a 50 % subsidy for feedstock suppliers to cover the net per-hectare payments; and 50 % subsidy for vehicle owners.

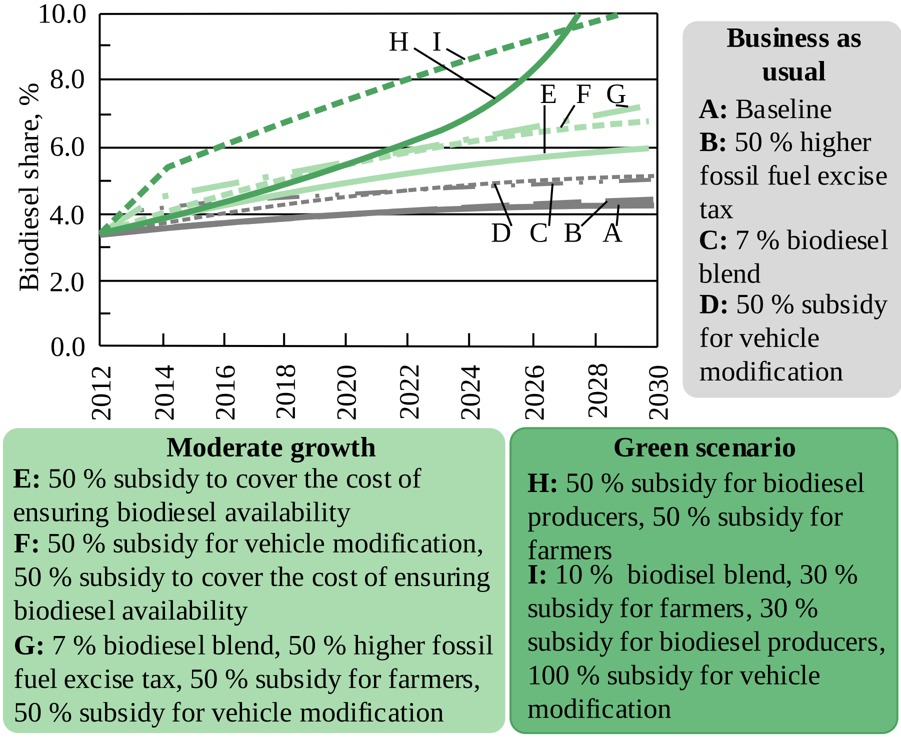



Fig. 6.2. The effect of policy instruments on biodiesel share.

The results indicate that the policy instruments discussed do not allow reaching a 10 % biodiesel share of transport energy demand. In order to achieve a more rapid consumption of biodiesel, two cases are considered. The first case (H scenario) considers a combination of two policy measures under which the subsidies for biodiesel producers and feedstock suppliers are applied to compensate the costs of biodiesel production and rapeseed production. The second case (I scenario) considers a mix of four policy measures under which the support for both rapeseed and biodiesel producers and consumers is provided in combination with an increased biodiesel blend with fossil fuels. Both cases allow a relatively fast and noticeable increase in the share of biodiesel in transport fuel consumption, reaching 10 % before 2030.

# CONCLUSIONS

1. The research topic of the Doctoral Thesis is transition policies to a low-carbon transport system as an integral part of the move towards a low-carbon society. Research in the field has shown that existing transport systems are difficult to change due to many factors and complex interactions between them. Meanwhile, the high dependency on fossil fuels and negative environmental effects call for rapid action to develop framework conditions for transition to a more sustainable transport system. This research contributes to the existing knowledge in the field by providing the missing insights as to how different levels of government can contribute to the development of future transport systems with a reduced negative impact on climate without limiting mobility.
2. The research of sustainable transport transition policies was based on an integrated top-down and bottom-up analysis approach linking four planning levels: international, national, local, and sectoral level. The following major findings can be highlighted based on the outcome of the research.
    - **International level.** The European Commission has taken a strong position on the development of sustainable transport systems, including technological progress, optimum use of transport modes and infrastructure, and demand-side management. Much effort is being made at a European level to strengthen the link and cooperation between research and industry. This has allowed Europe to become one of the leading regions in the field of alternative fuel vehicles. A survey of seven leading European-level organizations forming the network of alternative fuel vehicle research and development, however, shows that further progress is needed. A major issue to be dealt with is the work towards European-level standardization and harmonization of the policies to develop a coherent regulatory framework for alternative fuel deployment in road transport. This is an important precondition to bring the necessary signals for involved parties at all levels: investors, service providers, end-users, etc.
    - **National level.** Demand for transport and energy consumption in the transport sector is strongly linked with GDP growth, and further emission increase can be projected in the future despite energy efficiency improvements in vehicle fleets. A change in the travel structure is unlikely to happen without appropriate policy measures targeted at both infrastructural and behavioural improvements. There is a wide variety of policy instruments at national level that can be implemented to decouple the GDP growth and transport-related negative effects on climate, including the measures promoting mode shift from private cars to public transport and non-motorized means of transport, mode shift from road to railway transport, renewal of vehicle fleets, shift to alternative technologies, etc. Scenario studies suggest that $CO_2$ emission savings range from small up to around a third in 2030 compared to the baseline scenario. This finding was derived from a newly developed simulation model for policy analysis at national level. The model was built using the system dynamics modelling approach and approbated at national level based on Latvia’s case study. It covers the major $CO_2$ emission sources from the transport sector and allows a comprehensive analysis of many $CO_2$ emission mitigation policies. The two major strengths of the model are:
        1. the model is unique in its ability to model the effect of many discrete policy measures unlimited in their numerical values (e.g. the subsidy rate for alternative fuel vehicle purchase), as well as integrated policy packages;
        2. the ‘white box’ modelling approach makes researching the existing causalities more efficient in the transport system and build the understanding and conference of the dynamic behaviour generated by the real system. Moreover,

this approach allows further improvements to be made in the structure of the model and assumptions used, thus ensuring the opportunity for accuracy improvement of the model, as well as its use for transport system analysis from other perspectives or within the context of other country case studies.

- **Local level.** Municipalities have the potential to contribute to the achievement of national transport policy targets in terms of increased share of renewable energy sources in the transport sector and reduction of transport emissions as shown by the analysis of two case studies. The first case study found that the amount of biomethane that can be produced from organic municipal waste generated in a medium-sized city in Latvia can ensure the energy needs of its public transport buses. The second case study showed that electric vehicles are a suitable alternative for a municipal vehicle fleet, but there are significant barriers hindering their wider use. Although both studies applied different methodologies, both of them point to the financial aspect as a major barrier delaying the adoption of alternative fuels in local governments. The capital costs of alternative fuel technologies are high. Considering the priorities and limited possibilities of local government budgets, the savings expected from smaller operational costs compared to traditionally used fossil fuels is not a sufficient motivator. Thus, it can be concluded that the presence of a State support measure co-financing costs of the introduction of alternative fuel vehicles is a predominant precondition for the expansion of alternative fuel vehicle fleets in municipalities.
- **Sectoral level**. The current policies to achieve national biofuel targets in the transport sector complying with the requirements of the European Union have been shown to be ineffective. There are also no preconditions in place that could accelerate the use of biofuels in the 'business as usual scenario', which is not a positive sign for the future. It means that policy support measures are needed to increase the use of biofuels and move towards the 10 % renewable transport energy target by 2020 and beyond. Both, promoting biofuel consumption and production measures are necessary to ensure that there is a demand for biofuels, which is affected by two major obstacles: the cost effectiveness of biofuels compared to traditional fuels, and public acceptance. These results were obtained from a newly developed modelling tool for policy analysis in the biodiesel sector that covered three major sub-sectors of the biodiesel industry: the production sector, the consumption sector, and the feedstock supply sector. The study was specifically addressed to the evaluation of the principle scenarios within the Latvian context in terms of the implementation of state subsidies, increase of excise on fossil fuels and a higher rate of biodiesel blending. The results constitute an important level of innovation within the ongoing debate on the subsidies for biodiesel producer sectors. Although other evaluations of the policy measures effects on the spread of the biofuel industry through system dynamic have already been carried out, the contextualization of the problem to the Latvian condition is an important adaptation respecting the developed models that can better face the main local issues.

3. The research has pointed to several leads for further research:
    - so far, extensive research has been performed and is described in the literature regarding factors that influence travel behaviour within the context of transition policies to low-carbon transport (e.g., conditions affecting modal choices). However, it has been a more qualitative than quantitative assessment. The results of the existing studies allow the relevant factors to be assessed affecting the transport users' behaviour, but they do not provide sufficient knowledge about the degree of behavioural changes that could be achieved in response to the changes in these factors. It can be regarded as a research field of social sciences with a high potential to

complement engineering studies (e.g., such as system dynamics modelling), especially in the transport sector, where transport users' behaviour plays a decisive role in the development of the transport system;

- the achievement of the long-term greenhouse gas emission reduction targets in the transport sector in Latvia is related to responsible decision making that will have an effect on human behaviour as well as patterns of mobility. A large number of measures in the transport sector will require significant investment. In order to plan investments and to take the necessary measures, there is a need for reliable baseline data and evaluation of the current situation. An important part of such research is the study of people's travel habits, population density changes, as well as instruments that motivate transport users to change their habits. The presence of reliable data is also important in the implementation phase (monitoring) when the assessment of the implemented measures is performed;
- the current practice of investment decision making is usually based on direct economic considerations, i.e., the evaluation of the profit and the payback time. However, environmental policy decisions provide a number of indirect economic benefits such as improved public health, local economy growth and rising living standards which are not covered by traditional valuation methods. Therefore, cost-benefit analysis that considers both the direct and indirect costs and benefits can be considered a more suitable valuation method. Studies are needed to demonstrate cost-benefit analysis application in the transport sector. Putting the cost-benefit analysis methodology into practice would improve reflecting the impact of adoption of investment decisions.

4. This work has demonstrated an integrated evaluation of transition policies to a low-carbon transport system. The research of the long-term dynamic behaviour of $CO_2$ emissions originating from the transport sector in Latvia has contributed to a better understanding of the major technical, economic and behavioural drivers behind them, and this has made it possible to design the policies capable of decoupling GDP growth, travel demand and the related negative climate effects. The research of alternative fuel vehicle introduction in municipalities is the first attempt to link national and local level transport planning in Latvia by addressing the issues of national importance at municipality level. And, finally, the systems dynamic model proposed for the biodiesel production chain in Latvia has provided a better understanding of the development of the Latvian biodiesel industry. The model provides a tool for the evaluation of both the current and new policy efforts of the government towards the promotion and use of biodiesel in Latvia.

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