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A BREATH OF FRESH AIR FOR THE EUROPEAN GREEN DEAL: ENERGY EFFICIENCY AND CLIMATE NEUTRALITY FACTORS

Summary of the Doctoral Thesis

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RIGA TECHNICAL UNIVERSITY
Faculty of Electrical and Environmental Engineering
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DOCTORAL THESIS PROPOSED TO RIGA TECHNICAL UNIVERSITY FOR THE PROMOTION TO THE SCIENTIFIC DEGREE OF DOCTOR OF SCIENCE

To be granted the scientific degree of Doctor of Science, the present Doctoral Thesis has been submitted for the defence at the open meeting of RTU Promotion Council on 28th October 2021 at 14.00 at the Faculty of Electrical and Environmental Engineering of Riga Technical University, 12 k-1 Azenes Street, Room 115.

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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 Science is my own. I confirm that this Doctoral Thesis had not been submitted to any other university for the promotion to a scientific degree.

Reinis Āzis …………………………… (signature)
Date: ………………………

The Doctoral Thesis has been written in English. It consists of Introduction; 4 chapters; Conclusions; 36 figures; 10 tables; the total number of pages is 175. The Bibliography contains 142 titles.

Contents

Introduction

At the time of writing the Thesis, the world is undergoing a generational change of the global economy due to the turmoil caused by the Covid-19 pandemic. It is vital to acknowledge the generational opportunity that comes alongside with it.

Already in 2018, the European Commission announced its intention for the European Union to become climate neutral by 2050. In the case of the EU – an economy with net-zero greenhouse gas emissions. It is hard to comprehend the scale of such ambitious vision. The world's largest market is arguably embarking on a journey of "climate rush", compatible with gold rush and oil rush of the past. And even though strategic goals and operational tactics are in place, including the European Green Deal and the EU 2030 Climate Target Plan, the task is daunting. According to the International Energy Agency, more than 50 % of technologies that will be needed for meeting the climate neutrality goal by 2050 will come from technologies that have not yet been invented. Furthermore, never in history has economic growth been decoupled from an increase in energy consumption. In addition, most of the EU member states and conventional industries are ill equipped and there is a professional consensus about the lack of energy efficient, optimal and sustainable projects despite the widely available green financing. Yet, the setting offers an unseen opportunity.

The complexity of the climate neutrality transition enables using intellectual and financial resources coherently and, on a scale, unwitnessed before. At the core of the European Green Deal lies not only energy-efficiency thread, but it is enriched with significant green financing mechanism structure, as well as ambitious investment strategies in research and development. In addition, the EU Recovery and Resilience Mechanism, initiated to overcome the economic havoc caused by pandemics, is the first of any EU macro level policies where climate goals have been tagged, and the investment expenditure is capped outside the scope of the Green Deal and corresponding to the climate agenda. In addition, sustainability is at the core of largest finance institutions and there is a professional consensus about the general benefits of energy-efficiency as such.

However, steps including (I) in-depth benchmarking of climate neutrality factors, (II) evaluation of the most appropriate energy-efficiency measures on various levels, (III) interlinked policy and engineering solutions' analysis of energy-efficiency and (IV) macroeconomic evaluation of a shift towards sustainable economics have not yet developed a coherent roadmap for arriving at climate neutrality. This dissertation fills this gap.

The complexity of the question calls for multi-dimensional and multi-method-based approach. Investigation undercuts the aforementioned pillars of the European Green Deal by focussing on different levels of energy consumers and market actors via four key academic methods. In turn, analysis allows to create engineering models of a practical relevance, in combination with an in-depth academic understanding of barriers hindering the shift towards climate neutrality. It is up to the successful implementation of the proposed steps in the research and an efficient, optimal and sustainable joint effort from all stakeholders for the shift towards climate neutrality to be met.

The Relevance of the Topic

The topics covered and the research framework as such provide multiple level takeaways regarding academic landscape. First, The European Green Deal and the EU 2030 Climate Target Plan is at the forefront of both academic and professional debate regarding energy efficiency. The research, therefore, elaborates on concepts central to the academic debate at the time of the writing and undercuts patterns and proposals relevant for multiple actors within the local and global energy market. In fact, the research develops broader discussion regarding any strategic energy-efficiency related goal and the complexity and multiple threads that meeting such a goal would entail.

The research also explicitly elaborates on the role of energy efficiency in both climate transition and energy system transformation. In addition, it uncovers the scope of various policies implemented on a local level and discusses their role in meeting the climate targets in medium and long-term. Furthermore, the research also elaborates on the role of bioeconomy and climate neutrality, and how making steps towards climate neutrality implementation does not simply increase the energy efficiency of the system, but also serves in providing additional positive externalities in local economies, i.e., health care and education.

The Aim of the Investigation

The main aim of this investigation is to uncover (I) various factors that allow energy system and economy, including sub-sectors of economy, companies, as well as individual energy consumers, to strive to and eventually arrive at climate neutrality and (II) the role of bioeconomy and unintended externalities that such transition may have on the economy.

To fulfil the aim of the investigation the following tasks were outlined:

1. To evaluate the GHG emission performance indicator of Latvia and make a comparison with other EU member states.
2. To analyse historical and current energy efficiency performance of the Latvian manufacturing industry and the role it plays in meeting the Green Deal targets and larger energy and economic transformation as such.
3. To assess the energy efficiency policy of Latvia and to deduct potential factors for its successful implementation in the future.
4. To create a policy-making analysis tool in the field of energy efficiency and validate it in reference to a particular energy efficiency policy implementation instrument.
5. To evaluate the role of bioeconomy sectors regarding overall energy and economic transformation, as well as climate neutrality. To assess the ex-post and ex-ante role of various factors, namely, energy consumer behaviour, technological innovation, overall energy system transformation and GHG emission reduction opportunities, regarding climate neutrality and deriving economic shift.

The Novelty of the Research

The novelty of the research is the cross-cut analysis of climate neutrality implementation on four distinctive, yet interconnected levels: (I) para-state and state; (II) sub-sectors of economies, with an overarching emphasis on energy, industry and bioeconomy; (III) manufacturing; and (IV) individuals. Throughout the research unique set of sustainability indictors, energy-efficiency and bioeconomy models, and unique adapted energy-efficiency methods was developed.

First, GHG emission performance indicator via TOPSIS method was developed to significantly improve the analytical evaluation of various EU member states' GHG emission impact, beyond the conventional carbon footprint. Second, by using decomposition analysis method it was analytically proved that current energy-efficiency measures are unbundling from proportionally increasing energy savings due to the expansion of industrial production. Third, theory-based analysis and application of system dynamics were used to both have an in-depth evaluation of the EU and Latvia based energy-efficiency policy implementation. In particular, the implementation of the EEOS has resulted in enabling 95 % of national savings via informative measures and hence, significantly limiting the role of the EEOS and indicating the shortcoming of a policy measure. Fourth, system dynamics modelling was used two folds – for the creation of energy-efficiency implementation tool and the transformational change and positive externalities of the drive towards climate neutrality. While the tool is of a unique academic importance as such for dynamic modelling of shift towards the EEOS proper functioning (eventually leading to climate neutrality), nationwide system dynamics model highlights both the multiple dimensions required for a successful transformation towards climate neutrality to take place, and also the additional realms, including, research and development, education and healthcare which can unintentionally benefit from the climate neutrality transition via bioeconomic sub-sectoral development and therefore serve as a driver for the change per se.

Similar to the climate change debate as such, the phenomenon of climate neutrality has lacked an analytical and engineering research to quantify the multiple risks, observations and more importantly – potential avenues for successful implementation. The overarching unique novelty of the research is to cross-cut the climate change transition and Green Deal implementation via the means of elaborating on unique and compatible climate indicators, assessing particular industrial inputs, calculating the role of particular policy approaches and limiting those inputs, resulting in system dynamics models both for the modelling of inputs and policies, as well as the costs and positive externalities that would come to a larger scale economy if climate neutrality and bioeconomy journey would be embarked upon via changing the energy structure and initiating its transformation.

Hypothesis

The progress of Latvia towards climate neutrality within the framework of the European Green Deal can be assessed by GHG emission factor, energy intensity, success of the Energy Efficiency Directive implementation and the positive externalities of bioeconomy introduction.

Practical Relevance

The practical relevance of the research should be considered threefold. First, investigation elaborates on the methodology for broader and better-encompassing assessment of greenhouse gas emissions. This, in turn, may lead to significantly improved assessment of GHG inventories in other academic research per se. Furthermore, it also allows to assess more in-depth the impact of GHG emissions on macro and micro levels by avoiding the misconceptions of GHG emissions and carbon emissions. Such considerations should be considered vital for incorporation in energy-efficiency measures and policy planning.

Second, via system dynamics modelling a practical energy-efficiency policy evaluation tool has been developed, allowing to assess the potential impact of the policy on structural level and implemented separate measures on various consumer levels. By allowing key actors of the energy market to assess individual roadmaps, the tool serves as a direct feedback tool, arguably, increasing the quality of energy-efficiency solutions on various levels. In addition, practical relevance is enriched by energy-efficiency policy evaluation, indicating the need for policy change and particular details it fails to cover.

In addition, system dynamics model has also been developed for assessing the role of bioeconomy and the impact what developing new biotechonomy products may bring to the energy-efficiency balance and economy as such. The discussion regarding energy-efficiency and bioeconomy has often been ousted and seen separately from the larger energy market and economic debate. This research reveals practical insights and gains that the development of this segment may bring to the broader energy and market structures.

Structure of the Research

The Dissertation is based on 5 interrelatedscientific publications, with the overarching focus on the economic transformation to climate neutrality and energy-efficiency implementation, within the Green Deal context. The research (I) crosscuts multiple layers of energy consumers and relevant levels of analysis, (II) elaborates on

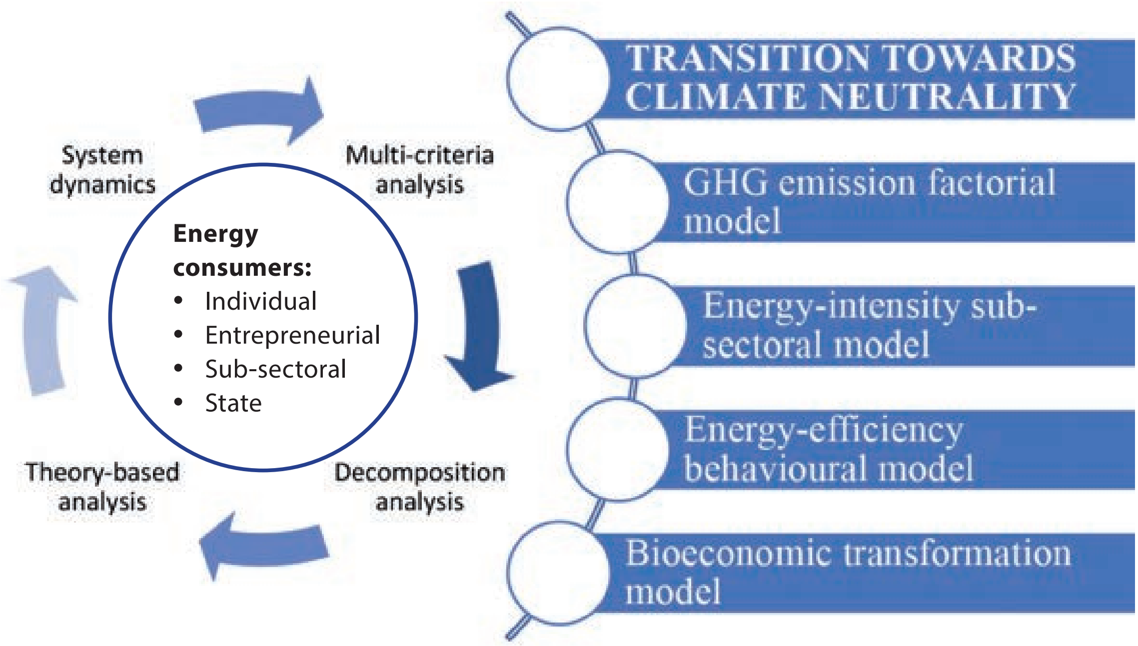

Fig. 1. Research structure.

Table 1

Thesis Structure and the Role of Publications

Consumer level	**Method**	**Publication number**	**Publication title**	**Stage of transition**
State and para-state	Multi-criteria analysis	1	*GHG Performance Evaluation in Green Deal Context*	GHG emission factorial model
Sectoral	Decomposition analysis	2	*Importance of Energy Efficiency in Manufacturing Industries for Climate and Competitiveness*	Energy intensity sub-sectoral model
Entrepreneurial and individual	Theory-based analysis	3	*The Bright and Dark Sides of Energy Efficiency Obligation Scheme: The Case of Latvia*	Energy-efficiency behavioural model
	System dynamics			
State (para-state), sub-sectoral, entrepreneurial and individual	System dynamics	4	*The role of forest biotechonomy industry in the macroeconomic development model of the national economy of Latvia: a system dynamics approach*	Bioeconomic transformation model
		5	The role of forest biotechonomy industry in the macroeconomic development model of the national economy of Latvia: an in-depth insight and results	

interrelated research methods, and (III) delivers multiple energy-efficiency and economic transformation models of both scientific and practical relevance. For graphic representation of the structure explore Fig. 1. Fig. 1. Research structure.

The investigation is preluded with a literature review, setting out the discussion regarding the Green Deal goals on multiple levels, strategic and operational tactics for meeting the goals and envisaging lessons learned thus far, as well as paving avenue for more productive implementation steps for the energy efficiency agenda in near future. In addition to the literature review, the dissertation consists of five interrelated scientific publications (Table 1).

With the application of the such research methods as (I) multi-criteria decision analysis, (II) decomposition analysis, (III) theory-based analysis, and (IV) system dynamics, the dissertation evaluates various agents, levels, and interconnectedness of the energy-efficiency system, with the aim of uncovering factors that are enabling for the shift towards truly climate neutral economy to take place. In the end, the results were discussed in order to arrive at a theoretical roadmap for the energy-efficiency implementation agenda and non-field related benefits that the process may bring.

Scientific Approbation

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2. Dolge, K., Azis, R., Lund, P.D., Blumberga, D. 2021. Importance of Energy Efficiency in Manufacturing Industries for Climate and Competitiveness. Environmental and Climate Technologies (25–1), pp. 306–317.
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5. Azis, R., Blumberga, A., Bazbauers, G. 2018. The role of forest biotechonomy industry in the macroeconomic development model of the national economy of Latvia: an in-depth insight and results. Energy Procedia 147 (2018), pp. 25–33.

1. Literature Review

"When it is obvious that the goals cannot be reached, don't adjust the goals, adjust the action steps." Confucius.

1.1. Broader theoretical background

Climate neutrality as a phenomenon should not be considered solely a matter of energy efficiency but far broader. Hence, it is vital to set out the conceptual difference between "climate neutrality" and "carbon neutrality". While the former is a complete phase out of *all* net-GHG emissions within a given system [1] per se, the latter is solely applicable to net carbon dioxide emissions and, arguably, more often associated solely with the energy sector [2]. Therefore, not only the goals, but also the operational tactics for reaching climate neutrality should be conceptionally different and encompass a broader range of actors involved within the system. This, in turn, would lead to a more complex creation of any solutions to be successful in attempting to achieve climate neutrality within a given system. A phenomenon often underestimated by policymakers and academia.

This also has led to the fact that there is quite a wide spectre of academics discussing and attempting to quantify dynamics of energy systems striving to ensure net zero carbon neutrality. However, energy and environmental engineering research focussing on modelling GHG emission neutrality per se can be considered limited. Regarding carbon neutrality, research can be mainly divided into three broad groups of scholars. The first group focussing on systems of energy carriers, the second – on sub-sectors of economy, and the third – on time and space (geographically) based systems.

Regarding energy carriers, a system level research has been focussing on, for example, renewables and renewable gas [3], hydrogen [4], power to methane [5], electric fuels [6], and essentially also natural gas [7]. In reference to economic sub-sectors, notable examples to this investigation include the research of Brand et al. (2012) for transport sector in the UK [8] and others, for example, focussing on buildings [9]. Regarding geographically based systems, several investigations have been focussing on cities, for example, the role of energy-systems in transition of the metropolitan region of Helsinki [10] and regions.

As mentioned before, academia focussing on modelling and combining energy systems driving to achieve climate neutrality also should be mentioned. Notable examples include global aggregated energy system transition analysis for reaching neutrality, for example, (I) focussing on the EU policies from bottom-up approach [11] and macro aggregated approach [12] and (II) focussing on the global energy system shift via global energy and macro-economic discussion.

Furthermore, while in the public policy debate the post-Covid pandemic economic recovery has already been linked to the carbon and climate neutrality debate, there has been lack of theoretical consistency and inclusion of the topic also within the academic discussion in relation to the Green Deal. One of the few notable research underpinning the topic has been carried out by the German Institute of Economic Research, where in the context of future steep electricity demand increase within the EU, modelling and energy system analysis has been carried out for outlining potential avenues for building any economic recovery strategy upon the foundations of the striving for climate neutrality [13]. Nevertheless, the research is focussing solely on the decarbonization of the economy and, arguably, lacks assessment of systemic policy and energy engineering technology type of analysis. This research attempts to fill this gap.

In addition, it can be argued that a simultaneous, multilevel analysis of climate neutrality introduction system, cross-cutting not only aforementioned (I) multiple carriers, (II) economic sub-sectors, as well as (III) time and space, but also encompassing additional various consumer levels; strategy and implementation policy-analysis and post Pandemic dire economic need for investment is among key scientific novelties of the research.

1.2. The European Green Deal targets and local discussion

It can be argued that the European Green Deal serves as platform for wide range of normative regulatory frameworks, growth strategies and implementation tactics on multiple levels, agreed upon by the EU member states and implemented via the European Commission. While the policy spectrum, indeed, is impressive even for such an ambitious venture – ranging from R&D investment packages up to rather conventional regulatory policy proposals to limit GHG emissions and citizen involvement platforms – most notable and widely cited is the “2030 Climate Target Plan” [14]. It includes the revised target of reaching 55 % net GHG emission reduction by 2030, in comparison to 1990. Furthermore, similar attention is also paid to additional targets that should serve to ensure the plan and to make the Green Deal “a real deal” [15] – notably, including the creation of at least 160 000 new “green” jobs, making renewable energy to account for 40 % within the EU energy mix and for the EU to finance one in every three climate change enabling commercial innovation and research & development projects globally by 2030 [16]. Again, also the goals of the plan on the European level in respect to climate neutrality can be seen as demanding instruments in addition to the rather conventional energy efficiency and decarbonisation policies.

The policy initiative in Latvia corresponding to the EU “2030 Climate Target Plan” is the National Energy and Climate Plan of Latvia 2021–2030. The plan sets out ambitious goals, including the following ones:

- To decrease the GHG emissions by 65 % in 2030 (milestone in 2017: –57 %).
- To increase the share of renewable energy in transport energy consumption by 7 % in 2030 (milestone in 2017: 2.5 %, target revised from the initial 14 % in 2030).
- To increase the share of the investment from the GDP in climate neutrality related research and development activities to 2 % in 2030 (milestone in 2017: 0.5 %, target revised from the initial 3 % in 2020).

To continue, the plan also ambitiously refers to the implementation of the “polluter pays” principle as a backbone of any future considerations and supposedly sets out main principles and operational tactics for meeting the targets. The plan arguably completely disregards the numerous difficult theoretical economic, engineering, policy making, cultural aspects and medium- and long-term considerations of such transition in more mature markets [17], needless to say in small and open economies.

Due to the limited scope and role that the analysis of the plan takes in the dissertation, the research underpins arguably the most crucial and sample type of climate target meeting threads, underpinning the general tone and simplicity of the plan. In turn, the relevance of the plan, in coordination with the EU regulatory framework, as well as regarding local market players and the energy market, as well as economic structure has been assessed.

First, it can be argued that the plan clearly lacks the coordination mechanisms to enable a shift towards climate neutrality in the local economy. As discussed throughout this section, a drive for climate neutrality should be considered an initiative underpinning significantly more realms apart from energy or energy-efficiency. Be it in primary financing mechanisms for subsidizing businesses or for the financial instruments of research and development activities. Instead, the instruments should attempt to tackle several realms of economies simultaneously, arguably, it is a mandatory need in the post pandemic EU [18] and climate neutrality is an excellent target for such instruments. Furthermore, recent statistics indicate that from large internationals operating in the Baltic market only 25 % are interested in direct sustainability investment [19]; hence, combination of instruments could attempt to overcome such pattern and, in addition, contribute to the increase of other positive externalities, for example, created "green" jobs and additional financing mechanisms.

Similarly, coordination and inter-disciplinary cooperation should be considered vitally crucial for any research and development related activities. It can be argued that more than 50 % of technologies that will be needed for meeting the climate neutrality goal by 2050 will come from so called "new tech" or technologies that yet have not been invented [20]. This, in turn, should lead to a shift in coordination among the research and development parties, as well as companies from silos-based approach to more encompassing and a structural research and development landscape change. Furthermore, for last 10 years the structure of R&D spending in Latvia has been stagnant, around 0.65 % from GDP [21], indicating both the lack of absolute financial mechanisms and also the lack of champion parties and research internationalization, which should be another way forward.

Second, even though the plan in some realms sets out ambitious goals, it does not do so across the energy spectrum as a whole and lacks clear focus on implementation roadmaps and related measurable deliverables. Regarding realms, standing out is the Latvian transport sector. As such, it comprises around 31 % of energy wholesale consumption, yet the targets have been diminished and even more – no conceptionally new roadmap has been offered. Even though the political rhetoric has argued for the development of biofuels in various means – both addons, as well as new fuels – a significant problem is the coordination between the transport and industrial subsectors of the economy which, arguably, also serves as a barrier for any further developments.

Another aspect of the shortcomings is the general lack of clear roadmap and measurable deliverables. It can be argued that a governmental policy in energy-efficiency and meeting climate neutrality targets in general has been heavily focussing on the approach of "polluter pays" also within the realm of energy, meaning, "consumer pays". However, much of the public rhetoric has been to implement such approach upon large private consumers, according to the Energy Efficiency Law [22] and leave public and separate sub-economic sectors (for example, transport) untouched. A similar policy application for transport sector and public realm, for example, ISO 50001 type of certification or energy audit plan could pave way for more practical and efficient policy implementation tools.

Third, the monetary aspects of the implementation plan are severely underdeveloped and do not provide a clear understanding on how to overcome the existing challenges. Despite the ambitious EU target for every one of three-climate neutrality driving projects to be globally financed by the EU, the lack of financial structure and roadmap for implementation is among the key criticisms of this investigation. Regarding private funding while the global landscape and institutions are touched, there has been lack of project-based restructuring of the Latvian energy-efficiency and climate neutrality landscape. Currently, the global economy is experiencing a lack of efficient, energy efficient and "green" projects, hence, there is an urgent need and a vacuum for developing a strategic local plan.

Furthermore, the emphasis in the local rhetoric is, again, on state budget funds or EU Structural Funds which suffer not only from systemic lack of funding for the Latvian economy, but also from the previously mentioned lack of coordination for fruitful Latvian investment strategy in climate neutrality.

In addition, there has been a systemic lack of corporate funding in the Latvian research and development landscape. There should be a call for structural change, namely, empowering larger corporates to take role and trailblaze the research and development landscape, and such approach should be a part of the national strategy. It is widespread that the budget of research institutions across the globe is mainly comprised 60–70 % of large corporates driven research [23]. In Latvia, the situation is inverse. This should serve as a call for empowering the large corporates – both on facilitation and regulatory level. While facilitation level, indeed, has been partly covered by the recently approved industrial policy – arguably one of few positive aspects of the related regulatory framework – the composition of the Latvian economy is such that most of the large corporates are state owned enterprises (SOEs) and therefore are limited in ability to exercise research and development activities. Namely, research expenditure is relatively often described by the auditing authorities as "using the dominant market position" [24] or potentially unlocking the risk of public fund inefficient expenditure.

It can be summarized, that there are multiple levels of the dimensions for the analysis – both on the demand (i.e., types of consumers) and supply (i.e., strategy planning, authorities) side. The multiplicity has been also apparent in the threads of action plans persuaded by the EU and locally, in order to arrive at the climate neutrality.

1.4. Literature review conclusion: research relevance to the climate neutrality targets

As discussed before, the literature overview has served to uncover the complex structure that a truly efficient and goal-oriented transition towards climate neutrality should attempt to include. Consisting of multiple dynamic and interrelated pillars – such as energy-efficiency thread, finance and research and development, transition would also touch upon multiple levels of actors – such as geographical, energy system, type of resource. This investigation uses set of methods to uncover the horizontal corelations that seem to be crucial for any truly feasible transition towards climate neutrality to take place.

First, GHG emission performance via TOPSIS method indicates that the conventional carbon-centred evaluation method for exogenous factors falls short for full and thorough analysis of countries' GHG performance. Similarly, to the climate change debate in general, there is an urgent need for the evaluation method to be interpreted broader so that the full spectrum of the climate change transition parameters could be included.

Second, the Log-Mean Divisia index decomposition analysis by using data confirmed that (I) industrial production activity, indeed, is the main driver behind the change in manufacturing energy consumption. More essentially, (II) hence in parallel with economic development, solely energy-efficiency based incentives cannot be catching-up with the expansion of the manufacturing sector. In turn, also data-based modelling points to a more heterogeneous and multiple dimensions inclusive instruments to strive for climate neutrality. This view is upheld also after empirically assessing the Latvian "2030 Climate Targets" plan and should be relevant to all EU member states.

Third, theory-based analysis and application of system dynamics was used to both have an in-depth evaluation of the EU and Latvia based energy-efficiency policy implementation, namely, EEOS in Latvia, and arrive at significant considerations regarding climate neutrality transition and modelling of energy-efficiency analytical tool. Regarding the former, the implementation of the EEOS has resulted in enabling 95 % of national savings via informative measures and incompatible correlation between the savings of the end-consumers and information activities. In turn, only 5 % of savings have derived from technological engineering investment; hence, significantly limiting the role of the EEOS and indicating the shortcoming of a policy measure, solely based in a single dimension.

Fourth, system dynamics modelling was used two folds – for the creation of energy-efficiency implementation tool and the transformational change and positive externalities of the drive towards climate neutrality. While the tool is actually of a unique academic importance as such for dynamic modelling of shift towards the EEOS proper functioning (eventually leading to climate neutrality), nationwide system dynamics model was also built to capture the positive externalities and empirical impact of the climate neutrality driven policies. The model itself highlights both the multiple dimensions required for a successful transformation towards climate neutrality to take place and also additional realms, including, research and development, education and healthcare which can unintentionally benefit from the transition and therefore serve as a driver for the change per se.

2. Methodology

Corresponding to the structure of the dissertation and tasks, the methodology and the results sections will be reviewed sequentially.

2.1. Multi-criteria decision analysis

MCDA (Multi-criteria decision analysis) is a set of processes by which problems are solved when the problem, alternatives and criteria are defined. There are dozens of methods for calculating the best alternative according to a set of criteria. Because of the opportunity to easily compare different alternatives TOPSIS (Technique for Order Preference by Similarity to Ideal Solutions) method was chosen for this evaluation. The basic principle is that the best alternative is at the shortest distance to the ideal solution and at the furthest distance to the negative-ideal solution [25]. For TOPSIS method it is important to define the best and the worst values for criteria. The best alternative is the one with the highest value.

AHP (Analytic hierarchy process) was developed by Thomas L. Saaty and it is one of the most popular methods used for finding criteria weight. With this method all criteria are listed and then compared pair-wise according to their importance (contribution to reaching an objective) [26]. All criteria are compared to each other assigning values from 1 to 9. After calculations are performed each criterion has a weight and it can be used in ranking of alternatives.

Evaluation process of the MCDA application in the dissertation in general consisted of four main steps (Fig. 2.1). First, eight EU countries for the comparison were selected. Next, criteria for GHG performance evaluation were chosen, which was followed by the determination of their importance with application of AHP

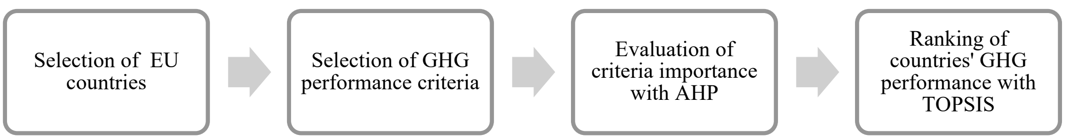

Fig. 2.1. MCDA methodology algorithm.

(Analytic hierarchy process). Lastly, the ranking of countries' GHG performance was made with TOPSIS method.

Based on the information provided in literature as well as considering the available data, six criteria were chosen for the evaluation of GHG performance. First, GHG emissions per capita were chosen as a widely used indicator in many studies and EU reports, as well as a basic representative of countries' emission level. Second, income from environmental taxes was selected as an indicator representing the overall role of environmental protection in the national tax system, and it is expressed as a percentage of the total income from taxes. Third, household energy consumption per capita is expressed as kg of oil equivalent, and it allows easily compare the energy needs of population. Fourth, investment share of GDP is an indicator used to monitor progress towards EU Sustainable Development Goals and represents the level of economic productivity. Fifth, consumption of solid fossil fuels is a basic representative of the amount of the main GHG generating fuels and is expressed in absolute values of thousand tonnes. Sixth, renewable energy consumption represents the achievements towards clean energy and is expressed as a share of consumed renewable energy in gross final energy consumption.

2.2. Decomposition analysis

Decomposition analysis is an analytical tool that is used to measure changes in energy consumption and monitor progress towards energy efficiency and climate neutrality targets. In reference to the tasks of the investigation, the method was used for the analysis of historical and current energy-efficiency performance factors regarding the Latvian manufacturing industry. The method is approved and commonly practiced in the field of energy and environmental studies by numerous international organizations, academic institutions, research centres, and national foundations [27]. Some of them include internationally recognized organizations such as the European Commission [28], the International Energy Agency [29], the European Commission's Joint Research Centre (JRC), the United Nations Industrial Development Organization [30], the Agency's for Ecological Transition (ADEME) project Odysee-Mure, and many others [31].

Index decomposition analysis (IDA) is based on the fundamental principle that changes in aggregate indicator are determined by a list of carefully predefined factors. Theoretical foundation of IDA approaches in energy studies was summarized and described in a study by [32] that presented methodological algorithm for choosing the most appropriate energy decomposition analysis method. The author discusses different aspects and properties of application of either Divisia index or Laspeyres index decomposition techniques. The paper concludes that compared with other IDA approaches Log-Mean Divisia index (LMDI I) decomposition technique stands out and is recommended due to its numerous desirable properties such as complete elimination of unexplained residuals, flexible applicability, comprehensive result interpretation, and others [33]. The advantageous properties of LMDI I method are further demonstrated in numerous energy analysis and climate change assessment studies, including in-depth energy efficiency progress evaluation in manufacturing industry [34]–[37]accounting for 30% of global greenhouse gas (GHG.

Moreover, in recent years, the application of IDA methods has skyrocketed in the field of energy policymaking. LMDI I approach is widely demonstrated in both – academic studies and global energy assessment reports [38]–[40]. Taking into account successful examples of LMDI I utilization and its competitive advantage over other index decomposition methods such as arithmetic mean Divisia index method (AMDI), Fisher ideal index method, Marshall-Edgeworth method [41], LMDI I method was chosen as the most appropriate technique to decompose energy consumption changes in Latvia over the period of 10 years.

Total energy consumption in manufacturing industry is determined as a sum of energy consumption of each industrial sub-sector. Manufacturing industry sub-sectors are selected according to NACE Rev. 2 classification nomenclature and aggregated in groups according to industry sector statistical division as reported in international energy balance statistics [42]. Energy consumption in industry is decomposed according to Equation (2.1).

$$E = i\sum E_i = \sum_i Q\frac{Q_i}{Q}\frac{E_i}{Q_i} = \sum_i QS_i I_i \qquad (2.1.)$$

where
E – total energy consumption, TJ;
Q – total production output expressed as total generated value added, euro;
S – manufacturing activity level in manufacturing subindustry, euro;
I – energy intensity level in manufacturing subindustry, TJ/euro;
i – subsector of the manufacturing industry.

The input of each decomposition indicator is deducted, while using LMDI I decomposition analysis method according to the equations (2.2)–(2.5).

$$\Delta E = E^T - E^0 = \Delta E_{act} + \Delta E_{str} + \Delta E_{int} \tag{2.2.}$$

$$\Delta E_{act} = \sum_i \frac{E^T - E^0}{\ln E^T - \ln E^0} \ln \frac{Act_1^T}{Act_1^0} \tag{2.3.}$$

$$\Delta E_{str} = \sum_i \frac{E^T - E^0}{\ln E^T - \ln E^0} \ln \frac{Str_1^T}{Str_1^0} \tag{2.4.}$$

$$\Delta E_{int} = \sum_i \frac{E^T - E^0}{\ln E^T - \ln E^0} \ln \frac{Int_1^T}{Int_1^0} \tag{2.5.}$$

where
ΔE – change in total energy consumption, TJ;
E^T – energy consumption in the following year, TJ;
E^0 – energy consumption in the initial year, TJ;
Δ – industrial activity indicator, TJ;
Δ – structural change indicator, TJ;
Δ – energy intensity indicator, TJ.

In addition, particular methodology offers a wide-ranging interpretation of results, which is a more desirable factor regarding decision making and policy planning. When indicators are compared, potential role and weight of the structural factors can be explained via industrial activity, structural change and energy intensity. Each indicator is expressed by the equations (2.3)–(2.5), as well as described in Table 2.1.

Data utilized in this study was collected from Eurostat and Central Statistical Bureau of Latvia (CSB) databases [41], [42]. To

Table 2.1

Description of the Decomposition Analysis Indicators

Factor	Notation	Indicator	Description
Activity effect	*Act*	Total industrial value added ($\sum_i EUR_i$)*	Measures changes in overall produced industrial output and impact from economic growth
Structural effect	*Str*	Share of sub-sectoral value added in total industrial value added ($EUR_i/\sum_i EUR_i$)*	Measures the impact from structural change in manufacturing industry (shift from one sector to another)
Energy intensity effect	*Int*	Energy consumption per unit of produced value added (TJ_i/EUR_i)*	Measures energy efficiency and shows how efficiently energy is consumed to produce unit of final product

* in adjusted prices

account for possible industry production output data fluctuations due to price changes, all data on sub-sectoral value added were adjusted according to data on producer price changes in industry sector [43]. Therefore, value added data represent chain-linked volumes of base year 2010. Moreover, a change index was constructed to compare the obtained adjusted value-added data with volume indices of industrial production [44]. The comparison showed that the adjusted value-added data currently represent the overall tendency in industrial production volume changes.

2.3. Theory-based analysis

The part of the research focusing on the ex-post assessment of the energy-efficiency policy of Latvia and, namely, the evaluation of EEOS, was carried out by combining a theory-based policy analysis method to reach the goal of Task No. 3, evaluation of whether new EEOS can reach saving goals without prior experiences with voluntary agreement schemes and emulation of successful EEOS from other countries [45], [46] with the criteria from the Better

Regulation Agenda (BRA) guidelines [47]. This method has several advantages compared to other ex-post evaluation methods. First, it evaluates the whole process of policy implementation, not only focusing on final impacts. Second, it develops indicators for each phase of the implementation process. It helps assess progress and failures as widely as possible. Finally, it helps to determine whether policies are successful or not, why they are successful or fail, and how they can be improved.

A theory-based policy analysis method is intended to systematically assess all phases of the policy implementation process, success and failure factors, and end-effects such as target achievement, the impact of energy savings, and cost-effectiveness. At the core of this evaluation method lies the policy theory. It is an approach to describe how the policy measure is expected to reach energy efficiency goals. The different steps of this method are illustrated in Fig. 2.2.

First, all steps of the implementation process are listed. It is presented in the form of a cause-impact relationship between different steps of implementation. For each step, indicators are identified to measure the cause-impact relationship and determine whether the change occurred due to the implementation of the policy measure. Both quantitative and qualitative indicators can be applied. Then, the major success and factors of failure in policy implementation are identified for each step of the policy theory. Finally, relation to other policy instruments is determined to understand whether and how they reinforce or balance implementation of the policy measure. If policymakers have clearly described how they foresee implementing the policy measure before implementing it, the explicit theory is available. If the description is not available, the policy theory is implicit, and evaluators have to

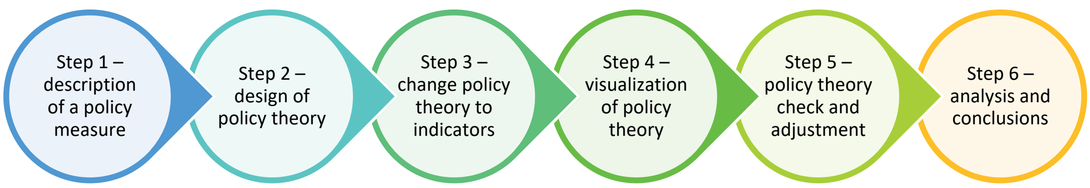

Fig. 2.2. Methodology of theory-based analysis in dissertation.

draw it up. The theory-based policy evaluation is presented as a flow chart.

The verification of the policy theory was carried out with mixed methods in which quantitative and qualitative methods were combined. Quantitative data alone do not fully provide insights and a comprehensive understanding of the causal mechanisms. Therefore, a qualitative method was used to capture essential aspects from the perspective of EEOS parties and to identify non-quantifiable factors that enable to explain the success and failure of the policy measure. This approach enables data triangulation and can limit the bias associated with the application of any single method.

2.4. System dynamics modelling

Throughout the study the application of system dynamics modelling was twofold. First, regarding creation of the policy assessment tool (Task No. 4). Second, regarding the evaluation of the role of the bioeconomy regarding climate neutrality and general economic transformation.

System dynamics as an evaluation method, analysing not only respective input and output flows of a system, but also including feedback provision mechanisms within it, was developed in late 1950s and early 1960s by the Massachusetts Institute of Technology. At the core, method focuses on agents or managers as information convertors who interpret collected new information or feedback of an ongoing process and translate it into corresponding future actions [48]. In respect to particular investigation, among the forefathers of the method should be considered Jay W. Forrester with his paramount research on modelling national economies, for the first time providing an in-depth look into macro-level system dynamics modelling approach [49].

Any system is not entirely based on static action and information feedback mechanisms, but is rather a complex, multi-dimensional, dynamic and interconnected system [50], where decisions of agents are made constantly, at multiple points, and information received regarding any process may affect any decision made throughout an entire system. Regarding system dynamics components there are four central concepts: (I) stocks and flows; (II) feedback; (III) time delays; and (IV) attribution errors and false learning.

System dynamics and the EEOS model

The EEOS model includes several sub-modules developed based on the Energy Efficiency Catalogue. In this study, sub-models were developed for the most popular measures used in the starting and first phases of EEOS in Latvia: one-time or single publications in mass media, one-time or single informative e-mails, E-mail campaigns, mass media campaigns, and individual consultations. Information about energy savings from applying any particular energy-efficient technology is considered part of the information activities. Purchase of any energy efficiency technology directly from the EEOS parties, e.g., light bulbs, is not considered in this model because the costs of bulbs are 100 % covered by the consumers and are not included in the costs of EEOS parties. However, the model has a general sub-model for any energy efficiency technology, which can be easily updated with any technology provided in the Energy Efficiency Catalogue.

The model is developed to assist both EEOS participants and policymakers in determining which activities to carry out if different parameters are changing over time. The stock and flow structure of the mathematical model is supplemented with free

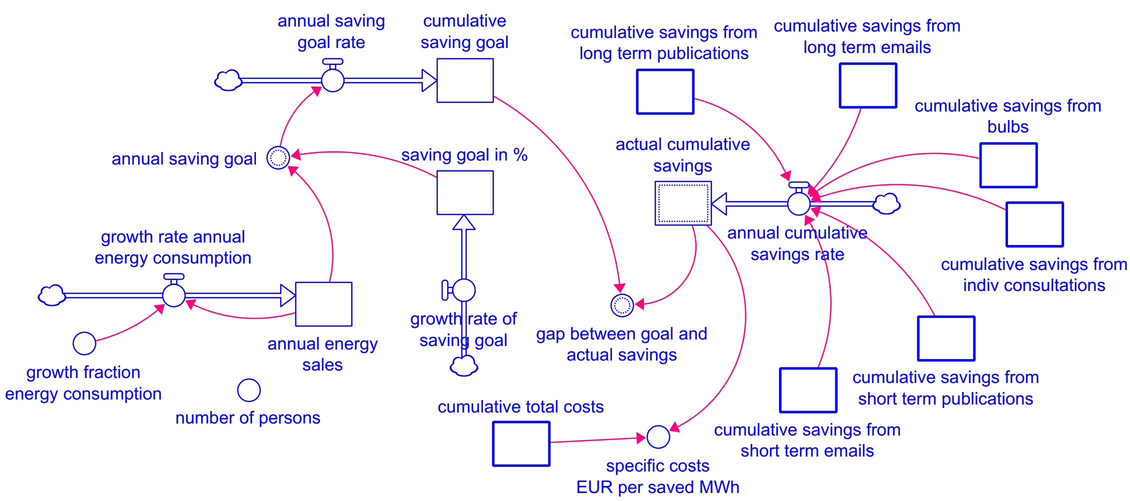

Fig. 2.3. Stock and flow structure of the EEOS savings sub-model.

access Internet-based interface that can be used as a simulation tool by any EEOS party or policymakers. The tool can also be used as an Interactive Learning Environment.

The structure of the model is built as goal-seeking (Fig. 2.3), as the model searches for the most cost-effective solution to close the gap between the savings target set by the legislation for EEOS participants and the actual savings generated by the model. The target function for the optimization is defined as the minimization of cumulative total costs over cumulative energy savings (EUR/MWh). The dependent parameter is the size of the target audience for different measures for information and education activities. The model has a logit function, which is used to calculate the share of each measure in the entire set of measures based on cost-effectiveness, considering limitations set for different activities.

Validation of the model was carried out for both structure and behaviour [51]. Structure validity tests included direct structure tests, structure-oriented behaviour tests. Behaviour tests were carried out after the structure tests were finished.

System dynamics and the evaluation of the role of bioeconomy

On general note, construction of a model combining various biotechonomic forest industry parameters in separate variables (and in the context of macroeconomic development) was possible due to former investigations carried out by Riga Technical University on micro-level biotechonomic forestry segment modelling, namely found in the work by Blumberga et al. (2016). While former investigations clearly elaborate on the environmental engineering aspects of this research, the investigation attempted to draw also significant new aspects of environmental field. One of such aspects will be comparing and contrasting energy intensity of traditional industries today to potential future industries, with biotechonomy included.

The dynamic problem of the research is the overall stumbling Latvian economic growth – 1.5 % to 2.5 % average – and deriving pressures on various macro-level segments as discussed before. Furthermore, to some extent, slowing down of the national economy has recently been attempted to be balanced out by diversifying export markets. The related problem with this strategy is that such tools arguably only prolong the endurance of economies but do not attempt to solve general questions of increasing manufacturing capacity or, more importantly, adding higher added value to particular products (see Fig. 2.4). In addition, the level of biological resource consumption per unit in such cases remains the same; hence, continuing to ensure consistent pressure on climate and environment.

Another aspect of the dynamic problem of particular research and environmental and economic modelling as such is the lack of inclusion of crucial dynamic feedback mechanisms in modelling of macroeconomic scale. In particular, education and healthcare sectors have often been referred to as crucial aspects impacting production output via human capital. Similarly, overall research and

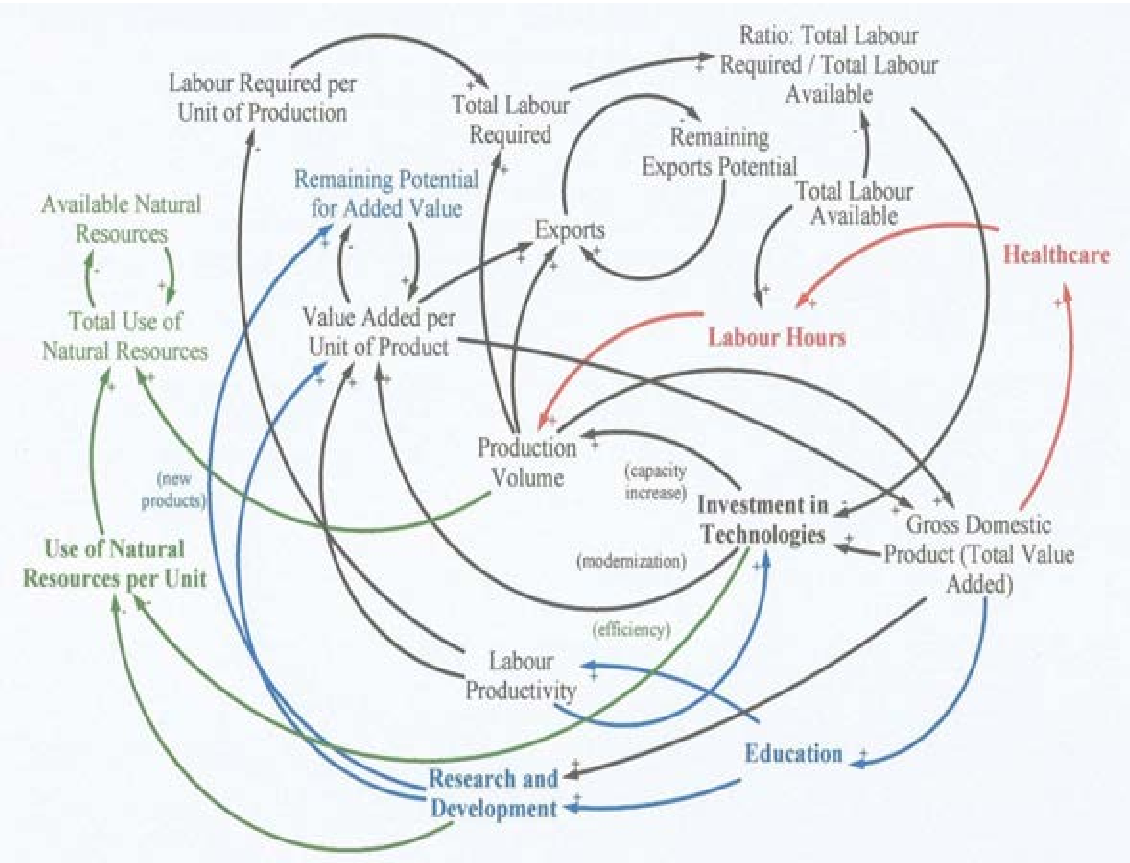

Fig. 2.4. Fig. Macro-level development, environmental, healthcare and education conceptual causal loop diagram.

development capacity, which influences the potential of total added-value via education investment, also should constitute a prominent variable in total production output. However, such feedback mechanisms in dynamic macro-level models have not been included widely, even though while it is clear – as also discussed in the previous chapter – that these aspects can have a significant impact on modifying manufacturing output.

Figure 2.4 presents a conceptual causal loop diagram, explaining the total causalities in the modelled macroeconomic environment and referring to the dynamic problem expressed before.

Overall, additional industries that could be considered environmentally positive or at least neutral would be required to sustain the growing levels of individual economic consumption in parallel to environmental sustainability. This research attempts to evaluate whether forest biotechonomy can bring solution to such a glooming trouble.

3. Results

3.1. Evaluation and comparison of the GHG emission indicator

To begin with, the evaluation of the EU member states in reference to the GHG emission performance indicators was exercised. The statistical data on indicator values for each country were obtained from *Eurostat* database for a time period from 2005 to 2015. Data were normalised after MIN-MAX normalisation. Input data for TOPSIS is presented in Table 3.1.

Results of the TOPSIS analysis indicate that the best GHG performance is convincingly reached by Sweden, which achieved a coefficient of 0.64 (Table 3.2). Sweden was expected to rank first, as it has showed high performance in other studies evaluating sustainability and environmental performance (e.g. in [52]accounting for 30% of global greenhouse gas (GHG and [53]), as well as it has one of the lowest GHG emissions per capita, and the share of renewable energy is one of the highest. In other indicators Sweden showed average score, except for solid fossil fuel consumption, where it takes the second worst place. Although, it is noteworthy that solid fossil fuel consumption is an absolute value, and therefore Sweden's poor performance in this indicator might be explained by the size of its population and industry or other factors related to consumption of resources.

Despite the highest GHG emissions per capita, Ireland takes the second-best place in GHG performance evaluation (Table 3.2). Ireland's relatively good performance can be explained by its outstandingly high score for the income from environmental taxes, which was the second most important criterion, as well as the significantly low consumption of solid fossil fuels.

Meanwhile, Latvia showed the lowest GHG performance. The main reason for that could be the significantly high score for household energy consumption per capita, where Latvia holds the worst position. Consumption of solid fossil fuels plays a relatively important role as well, while other indicator values are rather average.

Table 3.1

TOPSIS Input Data

Criteria \ Country	Denmark	Estonia	Ireland	Latvia	Lithuania	Slovenia	Finland	Sweden
Greenhouse gas (GHG) emissions per capita	0.481	0.613	0.760	0.602	0.472	0.559	0.741	0.517
Income from environmental taxes	0.282	0.500	0.797	0.494	0.273	0.527	0.614	0.565
Household energy consumption per capita	0.552	0.432	0.575	0.632	0.615	0.558	0.411	0.573
Investment from GDP	0.420	0.470	0.442	0.419	0.355	0.412	0.466	0.319
Solid fossil fuel consumption	0.475	0.469	0.382	0.615	0.484	0.696	0.435	0.612
Renewable energy consumption	0.434	0.530	0.465	0.445	0.388	0.549	0.421	0.539

Table 3.2

Results – Country GHG Emission Indicators

Denmark	Estonia	Ireland	Latvia	Lithuania	Slovenia	Finland	Sweden
0.463	**0.497**	**0.538**	**0.424**	**0.457**	**0.499**	**0.481**	**0.644**

However, it is important to consider that evaluations are made from the average values for a period from 2005 to 2015, therefore, development trends of indicator values are not taken into account. For example, for the share of income from environmental taxes Latvia has a lower indicator value than Ireland, while in 2015 Latvia had a share of environmental taxes of 3.52 % and Ireland had a share of 1.88 % from GDP.

Unexpectedly, Denmark ranks nearly the second worst in GHG performance ranking. Denmark has average values for most of the criteria, without taking any top or bottom positions. However, its resulting score might have decreased because of the low share of income from environmental taxes.

Results indicate that Estonia and Slovenia perform almost equally in terms of GHG performance. Both countries have similar values for most of the indicators. Nevertheless, Slovenia has higher household energy consumption and solid fossil fuel consumption, while Estonia has the second lowest household energy consumption per capita.

In the performed GHG ranking Lithuania takes the second worst place, achieving slightly higher coefficient than Latvia. This result is somewhat surprising, considering that Lithuania had the best score for GHG emissions per capita, which is an indicator of significantly high importance. Still, Lithuania performs the worst in the share of income from environmental taxes and renewable energy consumption, which could be responsible for its low overall GHG performance.

3.2. Evaluation of energy-efficiency of Latvian manufacturing industry

To analyse historical and current energy efficiency performance of the Latvian manufacturing industry and the role it plays in meeting the Green Deal targets and larger economic transformation as such, results regarding decomposition analysis should be explored. Decomposition analysis has been constructed for Latvian manufacturing industry to monitor changes in total industrial energy consumption over the period from 2010 to 2019. The results show that the main driver of energy consumption increase in industry was higher manufacturing activity and economic growth over the period. The obtained results are explained with data from Central Statistical Bureau of Latvia (CSB) and conclusions from Macroeconomic Review of Latvia 2020 [54]. According to CSB data on volume indices of industrial production, manufacturing industry was one of the fastest growing sectors in Latvia over the past ten years [54]. Growing demand in the largest export markets stimulated a rapid increase in manufacturing production volumes [54]. Consequently, the overall manufacturing industry energy consumption increased from 30 562 TJ in 2010 to 34 133 TJ in 2019, indicting 12 % increase over the 10-year period. In 2019, three manufacturing sectors, namely, wood products manufacturing (20 432 TJ), non-metallic mineral manufacturing (6797 TJ), and food,

Table 3.1.

Long-term Decomposition in TJ, 2010–2019

Manufacturing sub-sector	Δ Activity effect	Δ Structure effect	Δ Energy intensity effect	Δ Energy consumption
Chemicals, pharmaceuticals	596	–268	–602	–274
Metals	567	–9521	3461	–5493
Non-metallic minerals	3689	3124	–5652	1161
Motor vehicles, transportation	171	63	–261	–27
Machinery	434	238	–744	–72
Food, beverages, tobacco	2067	–966	–1746	–645
Paper, printing	145	16	–331	–170
Wood products	10243	485	–2281	8446
Textiles, leather, apparel	239	–133	–310	–203
Not elsewhere specified	471	201	176	848
Total	**18622**	**–6762**	**–8290**	**3570**

beverages and tobacco manufacturing (3271 TJ) consumed large majority or 89 % of the overall manufacturing industry energy end-use [54].

The results of decomposition analysis are summarized for long-term (Table 3.1) and short-term (Table 3.2) aggregated values. Long-term analysis includes the whole period of the study, that is period from 2010 to 2019. Short-term analysis includes the period of past five years, from 2015 to 2019.

From both long-term and short-term results, it can be observed that rise in industrial activity was the main factor that drove up total manufacturing industry energy consumption. In terms of sub-sectoral comparison, in the period of ten years, energy consumption significantly increased in wood products manufacturing sector (+ 70 %), non-metallic mineral products manufacturing sector (+ 21 %), and other not elsewhere specified sectors that include rubber, plastics, furniture and other manufacturing (+ 217 %). Significant rise in energy consumption from these sectors determined the rise in the overall industrial energy consumption increase. The industrial activity in wood manufacturing sector was mostly driven by increased demand for wood pellets and chips in global export markets. Moreover, growth rates in the construction sector stimulated demand for cement and glass production, and other building materials [54].

Long-term structural effect was driven by two main factors. First, the bankruptcy and market exit of the largest metal manufacturer in Latvia [55] decreased the overall metal manufacturing sector share in total industrial energy consumption to the historically lowest levels. Second, particularly rapid growth of the wood processing industry stimulated the overall restructurization of manufacturing industry. Over the period of ten years manufacturing industry experienced a shift from one energy intensive sector (metal manufacturing) to other no less energy intensive sector (wood processing). However, the competitive advantage of wood products manufacturing sector is the high share of RES utilization where wood residues and chips, which is a CO_2 neutral fuel, are used in thermal processes.

In 2016, when Energy efficiency Law entered into force, a number of conditions were imposed on manufacturing companies [56].

Large manufacturing companies and large electricity consumers were obliged to implement a certified energy management system or carry out regular energy audits, as well as implement at least three energy efficiency measures with highest indicated energy saving potential or economic return [57]. According to estimated results from the national energy efficiency monitoring system and energy audit program in Latvia [56], [57], manufacturing industry companies have reported achieved and planned energy savings due to different energy efficiency measures such as lighting replacement, improvements in energy management, heating system, ventilation, renovation of buildings and investments in equipment. However, in study [57] it is concluded that initial achieved energy savings from Latvian manufacturing industry within the framework of the program were modest. It was estimated that untapped energy

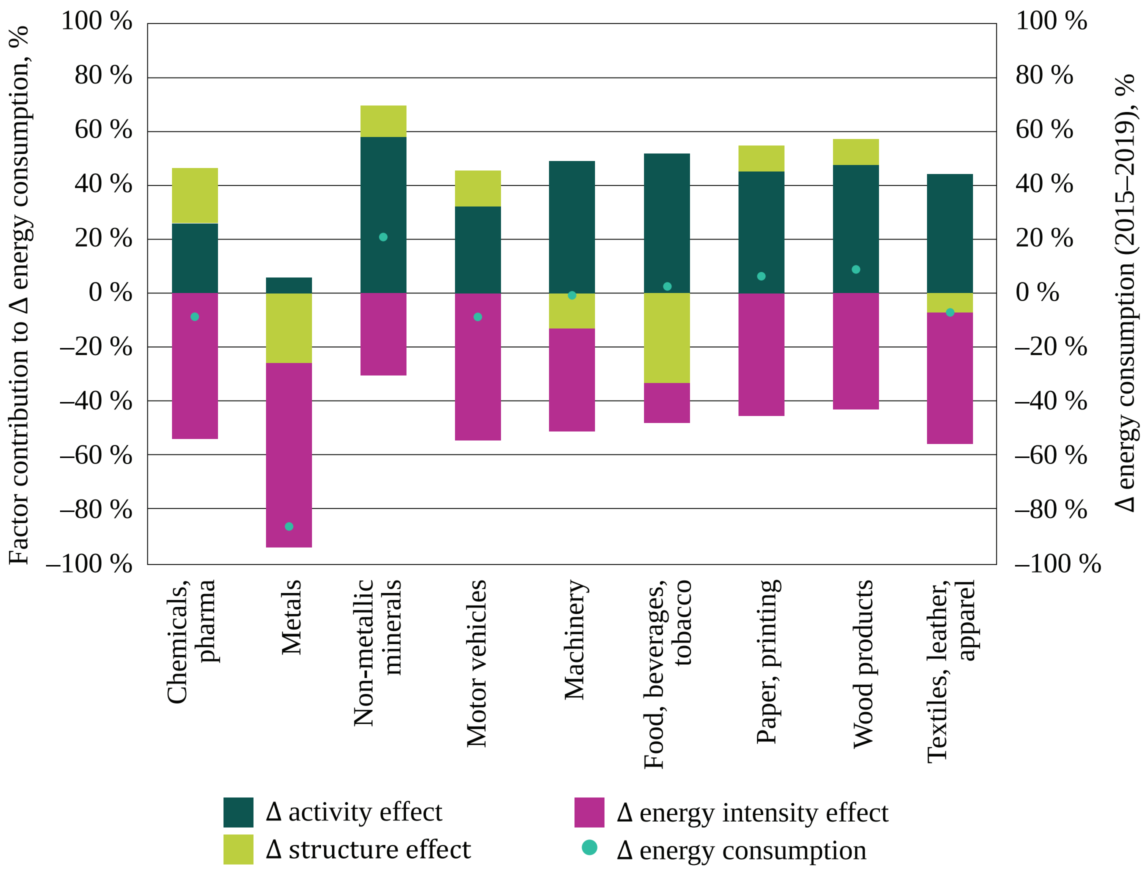

Fig. 3.2. Energy consumption decomposition of the Latvian manufacturing industry, 2015–2019.

efficiency potential in three largest manufacturing industry sub-sectors – wood processing, non-metallic mineral production, and food and beverages processing – reaches 862.6 GWh, if benchmarked with identified technical energy efficiency potentials from similar program in Sweden.

Energy intensity effect was the main driver that contributed to the reduction of energy consumption for all manufacturing sub-sectors (except for not elsewhere specified sectors) in the period of last five years. Figure 3.1 illustrates the contribution of each effect on changes in energy consumption and overall change in consumed energy in each sub-sector in a time period from 2015 to 2019. The results show that despite significant energy efficiency improvements in three largest manufacturing industry sub-sectors, total rise in industrial activity counteracted energy intensity effect. Therefore, current energy efficiency improvements could not compensate the industrial activity effect which drove up the overall energy consumption at much higher pace than implemented energy efficiency measures.

3.3. Evaluation of Latvian Energy Efficiency Policy and factors of its success

In 2016, Latvia committed to contributing 9.85 TWh of cumulative energy savings to the EU's overall energy efficiency goal by 2020. EEOS was one of the policy measures in the broader package of national energy efficiency policies described in the Energy Efficiency Policy Plan for Alternative Measures for the Achievement of the Energy End-use Savings Target for 2014–2020. EEOS parties are obliged to achieve the following amount of energy savings:

for year 2018: $P_{2018}=1.5\ \%\ x\ A_{2018}$;

for year 2019: $P_{2019}=1.5\ \%\ x\ (A_{2018}+A_{2019})$;

for year 2020: $P_{2020}=1.5\ \%\ x\ (A_{2018}+A_{2019}+A_{2020})$,

where

P_n – amount of the EEOS party's annual obligation, MWh;

A_n – amount of electricity sold by the EEOS party in the year concerned, MWh, minus the amount of electricity sold to large electricity consumers (consumption over 500 MWh/year) and large companies, based on a certified auditor's certification.

As described above, the EEOS party can fulfil the obligation in several ways. The legislation foresees no financial support activities to energy consumers, and the customer implementing energy efficiency measures bear all costs.

Information and educational measures are defined as campaigns about energy efficiency and energy savings addressing particular target audiences. Four types of information measures are foreseen. First, a single information campaign can include electronic mass media, single activities, and printed materials. Second, a long-term education program or additional information can be included in the bill, non-personalized advice on the EEOS party's web page, single activities, and printed materials. Third, individual activities can include individual consultations in energy efficiency centres, agencies, or exhibitions. Finally, the installation of energy meters with an information feedback function is considered as another information measure.

Energy efficiency improvement in technologies in both domestic and non-domestic sectors include lighting, solar collectors, thermal resistance of the building envelope, change of low-efficiency boilers, installation of biomass boilers, renovation of heating systems, circulation pumps, heat pumps, industrial motors, alternative fuel vehicles, change of vehicles oil, change of tires, heat recovery units for ventilation. Lifetime varies across different technologies. The Energy Savings Catalogue foresees measures in addition to thermal resistance improvements of the building envelope, which goes beyond the current building standards.

The annotation of Regulation No.226 [58] was used to develop the policy theory for this case study, and it was detailed enough to develop an explicit political theory. A theory-based policy analysis chart for the EEOS is presented in Fig. 3.2. The implementation process starts with the climate and energy objectives set by the EU, the requirements of which are embedded in EED. The Energy Efficiency Law takes over the requirements of the EED in Latvia. Based on Energy Efficiency Law, the Cabinet of Ministers issued a regulation which stipulates that the Ministry of Economics determines the EEOS obliged parties, criteria for each commitment period, and the scope of the obligation. The companies included in the EEOS prepare a plan for energy efficiency measures and submit it to the Ministry of Economics. The Ministry performs the verification of the conformity of plans in accordance with regulations and, if necessary, informs the participants regarding the non-compliance of the plan with the requirements. The parties have to resubmit the modified plan of measures and/or the number of contributions to the Energy Efficiency Fund. This is followed by a report from EEOS parties to the Ministry of Economics on the energy savings obtained during the starting period. Each year, EEOS parties report to the Ministry of Economics on the savings achieved. The Ministry of Economics has to include information regarding annual savings in the Energy Efficiency Monitoring System and has the right to perform an audit of the reported savings.

For the most crucial cause-impact relationship, indicators are established to measure whether the cause-impact has occurred and measure whether it is the policy measure that has caused the changes. Success or failure factors increase or decrease the values of the indicators. The number of participants and their total amount of energy sold (GWh/year) are used as indicators for the analysis of the participants and criteria included in the EEOS during each commitment period. The amount of energy savings planned by participants (GWh/year) indicates the EEOS party's duty. The number of energy efficiency plans approved by the Ministry of Economics and planned contributions to the Fund describes the process efficiency. It also indicates what the obliged parties carry out as related to the EEOS obligation and what part of their obligation they entrust to the Fund. The knowledge and understanding of the EEOS party about energy efficiency measures and the possibilities to implement them is a factor of success or failure, which affects the values of both indicators. Two indicators are used to assess the savings of the starting period: annual reduced energy consumption and accumulated savings during the starting period. Similarly, failures/successes are the knowledge of the EEOS party. For an analysis of the savings, reported annually by EEOS parties, several indicators can be used: energy savings (GWh/year), accumulated energy savings (GWh), the ratio of the actual annual energy savings to the expected, estimated savings from awareness-raising activities, estimated savings from other measures, and the amount of planned investment. The values of these indicators are influenced by two success/failure factors: the capability of EEOS parties to convince energy end-users to implement energy efficiency measures and the knowledge about energy efficiency measures and how to implement them. The annual contribution to the Fund reflects the dynamics of the contributions.

The Ministry of Economics controls the reported savings on a random basis, and this process is characterized by the number of reports checked. Therefore, success or failure depends on the resources and capacity available to carry out the verification [59].

The bottleneck in the EEOS scheme is the possibilities and capabilities of the EEOS parties to convince energy end-users of the implementation of energy efficiency measures, as well as the knowledge, understanding of energy efficiency measures and the possibilities to implement them.

Effectiveness

Three main metrics are used to measure and report energy savings in EEOS, namely, cumulative savings, lifetime savings, and annual incremental savings. Deeming of savings over a stated period is commonly used in EEOS in Europe, Australia, and in some cases in the US, Fawcett et al. [60].

In December 2019, information published on the Ministry of Economics website showed 15 EEOS parties in Latvia. Nine parties sell energy to households and small and medium-sized enterprises. Most of the savings planned by EEOS depend on the most significant power market participant, state-owned utility *Latvenergo*.

In the Report on Progress Towards the National Energy Efficiency Target for 2020 [61], the estimated new and cumulative savings achieved by the EEOS during the starting period (2014–2017) are presented (see Figure 3.2. Estimated cumulative savings obtained during the starting phase are 68 % higher (329.2 GWh) than the cumulative savings planned for 2020 (234 GWh).

Interviews with EEOS parties show that the majority of savings are gained through “soft” or information and educational activities, and only a minor part of annual new savings come from the “hard”

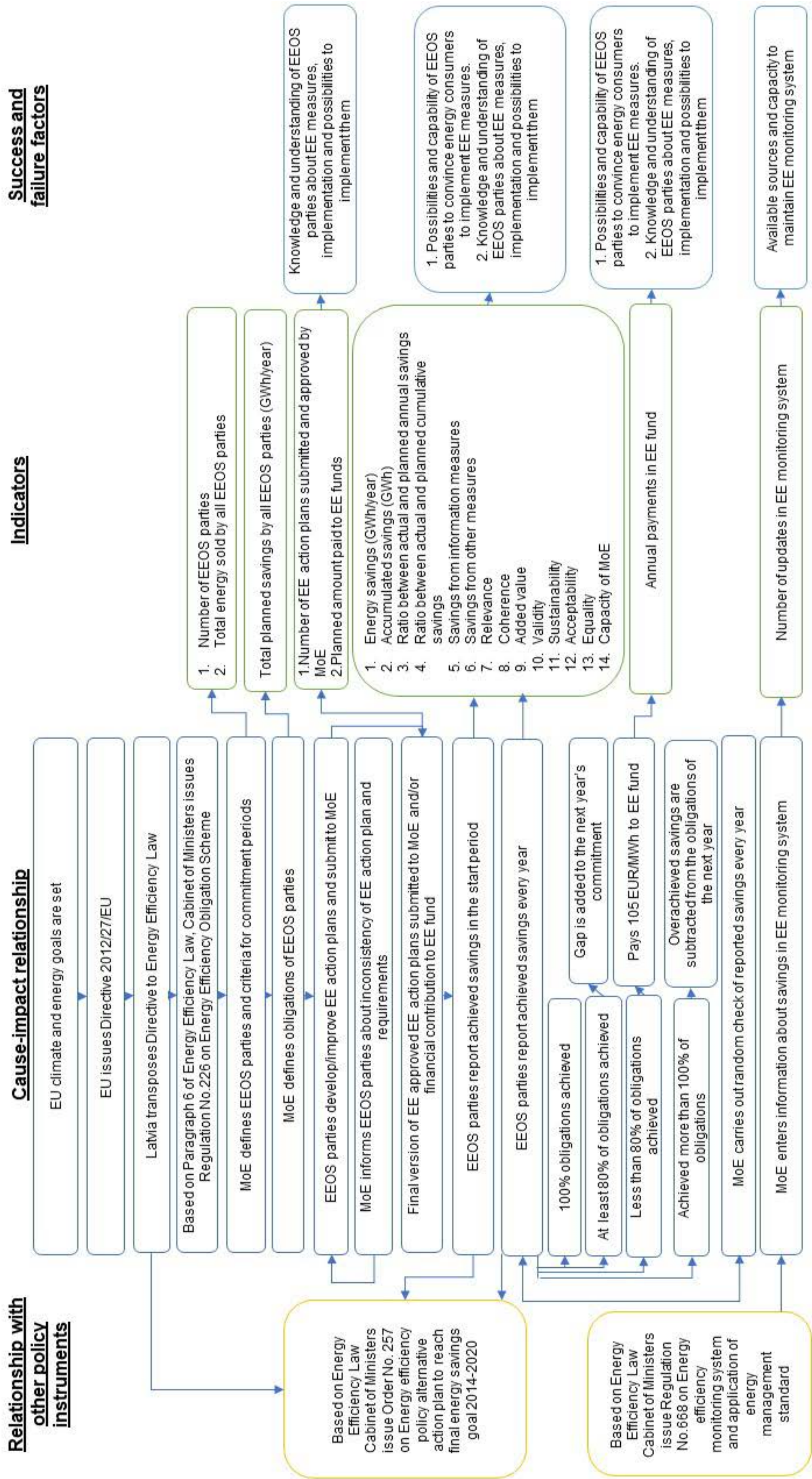

Fig. 3.2. Flow-chart of theory-based policy analysis for the implementation of the EEOS for illustrative purpose (MoE – Ministry of Economics; EE – energy efficiency; EEOS – energy efficiency obligation scheme).

energy efficiency measures implemented by consumers. Responsible parties have not contributed to the Energy Efficiency Fund. The estimated breakdown of actual measures by a group of measures is as follows:

- Information and educational activities (representing around 95 % of total savings): information in mass media, seminars, individual consumer advice, participation in exhibitions, seminars, festivals, etc., home page information, e-mails.
- Sale of energy-efficient technologies in an internet store (representing around 5 % of total savings) as an interest-free loan; direct sale of energy-efficient technologies to energy consumers through a distributed payment, by concluding an agreement that an EEOS member will report energy savings.
- The expertise, understanding, and feasibility of energy efficiency measures and their implementation significantly impact developing and implementing the plan for energy efficiency measures. The interviews indicated that the EEOS parties had employed persons who have expertise in energy efficiency, thereby reducing the risk of not reaching the target. Therefore, decisions are based on cost-efficiency.

Efficiency

The cost of saved energy is a typical metric used to assess energy efficiency costs across different EEOS [62].

Although the legislation demands that EEOS parties publish reports about the costs of measures on their web pages, most EEOS parties have not done so. Information published by energy utility *Latvenergo* shows the following data about 2018:

- Costs of information and educational measures implemented to improve energy efficiency are 327,624 EUR, of which 262,100 EUR applies to households and 65,524 EUR to other users. These costs are included in the operational costs of the utility.
- Households have purchased energy efficiency equipment for a total of 411,803 EUR, while the other users have spent only 4,043 EUR.
- Average cost of savings reported is 4.78 EUR/MWh [63].

When carrying out a cost-effectiveness analysis for each group of measures, EEOS parties have found that the most cost-effective information measures are on social networks, e-mails, mass media, other information measures (the advantage depends on the method of assessing the effect). In contrast, the least cost-effective is individual communication.

Data on the actual costs of the Ministry of Economics of the administration of the scheme have not been obtained.

Coherence

The EEOS has faced several serious challenges rooted in the setup of the policy measure. The dominance of information measures over technological measures is determined by the definitions set by legislation (for more details, see in Discussions).

This policy measure is aligned with other legislation. Thus, energy savings from EEOS are summed up with savings from other policy measures, thus contributing to the national energy efficiency goal. If the EEOS party has to contribute to the Energy Efficiency Fund, the responsibility for fulfilling the EEOS obligation is transferred from the EEOS party to the Ministry of Economics and a state-owned finance institution "Altum," which provides financial support for energy efficiency projects.

The double accounting of savings within EEOS is avoided by parties providing documented evidence for each implemented activity. The Energy Efficiency Monitoring System ensures the double accounting of savings with other policy instruments outside EEOS.

System dynamics tool for Energy Efficiency Policy validation and results

Model input variables and their values

Saving fraction from the end-user consumption is defined by the Energy Savings Catalogue: single publication and e-mail 1 %, publication and e-mail campaigns 2.5 %, individual consultation 3 %. The maximum number of units per year was obtained during the interviews with EEOS parties; it included 24 single publications, 1 publication campaign (5 publications per campaign), 24 single e-mails, 1 e-mail campaign (10 e-mails per campaign), 240 individual consultations. Costs per each information measure were also obtained from the EEOS parties: 800 EUR per single e-mail, 400 EUR per e-mail in the e-mail campaign, 30 EUR per individual consultation, up to 20 000 EUR per single publication (depends on the target audience size), up to 40 000 EUR per publication campaign (depends on the target audience size). According to the Energy Savings Catalogue, the life cycle of information and education measures is 1 year. The E-mail opening rate is 0.2. For the simulation example, the initial values for the model are annual energy sales 1.74 GWh, energy sales growth fraction 1 %/year, initial savings goal of 1.5 %/year, savings goal growth rate 0 %/year (year 1–2) and 1.5 %/year (year 3–5). Simulation time is 5 years, equal to one commitment period for EEOS parties set by the government. A differential evolution algorithm with 10 generations and a population size of 20 is used for optimization.

Two scenarios were developed. Scenario 1 is based on manually set input variables: share of audience from the total number of clients is 0.5 for both e-mails and publications. Scenario 2 is an optimization scenario to minimize cumulative costs for every saved

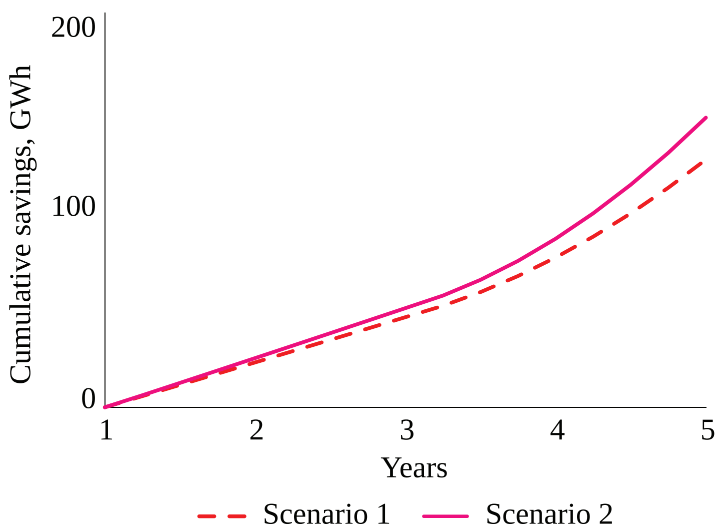

Fig. 3.3. Cumulative savings for both modelled scenarios.

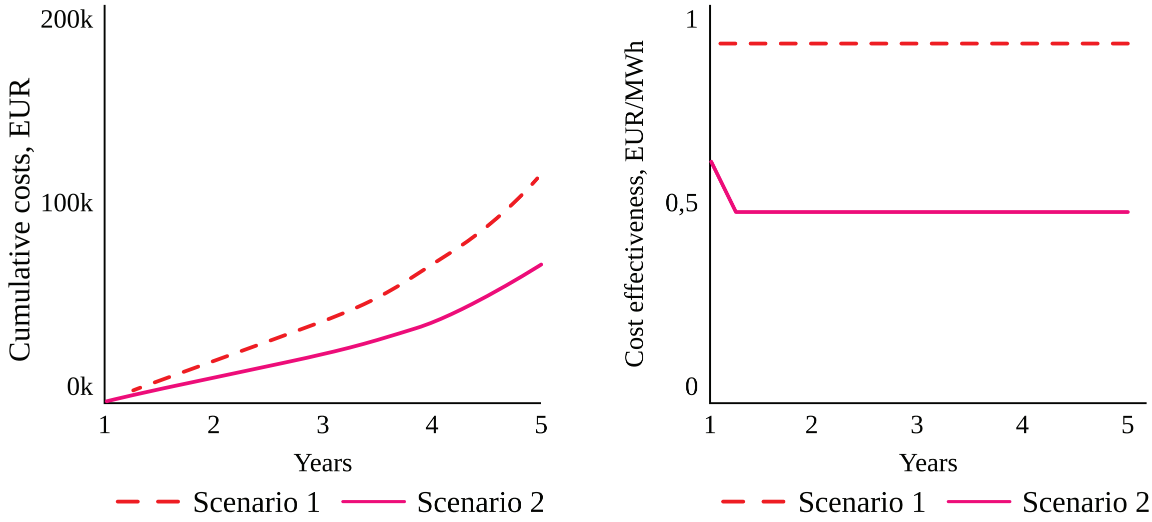

Fig. 3.4. Cumulative costs and cost-effectiveness for both scenarios.

energy unit (EUR/MWh) by closing the gap between savings goal and actual savings.

Figure 3.3 illustrates cumulative savings for both scenarios. Scenario 1 does not reach the savings goal with selected measures, but Scenario 2 reaches the goal set. Both graphs follow a linear tendency in the first two years and then change behaviour as the target increases every year.

Additional simulation results for both scenarios are represented in Fig. 3.4. In Scenario 1, cumulative costs in year 5 reach 114 000 EUR, while in Scenario 2, only 70 000 EUR. The cost-efficiency for Scenario 1 is 0.9 EUR/MWh, while for Scenario 2 it is 0.47 EUR/MWh. In Scenario 1, single e-mails take up a 42 % share (cost efficiency 0.48 EUR/MWh), followed by e-mail campaigns with a 26 % share (cost efficiency 0.96 EUR/MWh), 18 % share for publication campaigns (cost efficiency 1.3 EUR/MWh) and 14 % for single publications (cost efficiency 1.6 EUR/MWh) and no individual consultations (1200 EUR/MWh). For Scenario 2, the share of single e-mails takes up 65 % of total information measures, and the optimal target audience size for this measure is 100 % of the total number of clients, and the publication campaign takes 35 % of the share with 95 % of the target audience.

Types of energy efficiency measures

First, the Latvian EEOS legislation defines that the costs of information and education activities can be included in the energy tariff, whereas energy efficiency measures must be included in the bill of an individual consumer. It leads to the situation whereby retailers have a clear incentive only to do informational programmes, which given their high cost-effectiveness, will only increase average energy prices marginally. Convincing their customers implement energy efficiency measures, on the other hand, means that the individual consumer would need to bear the total investment costs, which contradicts the economic interests of an energy retailer. This incentive structure explains why 95 % of all measures were informational. Second, the reporting on savings relies on the deemed savings. Thus, the EEOS leads to many e-mails being sent and publications printed, without any evidence of whether any real effect on achieved energy savings has occurred.

Saving fraction for different energy efficiency measures

Another critical issue is the saving fraction from the end-user consumption, which is the most critical parameter for cost-effectiveness calculations. This study did not find any information source that would provide evidence on how deemed savings were defined and justified in the Energy Savings Catalogue. It limits analysis of, for example, why sending a single e-mail would induce an energy user to reduce energy consumption by 1 % while an individual consultation only induces an energy savings rate of three times as high (3 %). An individual (targeted) consultation might be more effective than a single e-mail, which will likely be ignored by the vast majority of those who receive it. If the policymakers had built EEOS based on adopted or adapted successful EEOS design from another country, they would have known that information activity alone does not provide actual energy savings [64], [65].

Moreover, no incentives are provided to Latvian EEOS parties to diffuse energy efficiency technologies that would bring actual energy savings. Behavioural and information programs or so-called "nudge" programs are the most cost-effective, but they bring relatively small savings. Financial incentives for technological energy efficiency measures are least cost-effective but have higher energy savings potential [66], [67].

EEOS obliged parties admitted that reaching the savings goal was partly due to reporting measures carried out during the starting phase and reaching savings obligations will become more challenging during the subsequent EEOS phases.

3.4. The role of bioeconomy towards climate neutrality (energy efficiency and economy)

As mentioned before, one of the central dynamic challenges of modelling the role of bioeconomy in energy and economics is that macro-level systems have so far not included financial and socio-economic improvements that could be achieved by introducing a bioeconomy segment into economy. As part of the promotion work, this phenomenon was defined as a biotechonomy improvement factor (BIF) and modelled in two scenarios. The first, where only the financial additional benefits that would be brought to the economy by the development of the bioeconomy, a factor BIF (e), was accepted at the value of the factor. The second factor was modelled, which included additional financial benefits, as well as additional impacts on health and education, which would benefit from additional financial and knowledge transfer, in the context of the introduction of a new sector in the economy – BIF (i). The model was validated using historical data related to base scenarios.

In turn, biotechonomy improvement factor values indicate that by 2047 the largest value is for the BIF(i) scenario – 1.477; while BIF(e) scenario value reaches 1.459, but traditional scenario improvement factor value – 1.447. This indicates that the scenario BIF(i) will encompass the largest education and healthcare improvement factor phenomenon and vice versa.

To continue, healthcare and education annual budget revenue values modelled were the following. In 2047 the traditional scenario values reached EUR 1 067.13 and 249.54 million, BIF(e) scenario values were EUR 1 075.69 million for healthcare and EUR 251.54 million for education and BIF(i) scenario values reached the highest absolute values of EUR 1 088.96 million for healthcare sector and EUR 254.64 million for education sector per year.

The difference between the traditional scenario values and the BIF(i) scenario values in healthcare and education reached EUR 21.83 million and EUR 5.10 million per year, while the difference between traditional and BIF(e) scenario values reached EUR 13.27 million and EUR 2.00 million per year, accordingly.

In reference to annual VAT payments, the BIF(i) scenario reached the value of approximately EUR 153 million per year in 2047, while BIF(e) scenario reached the value of EUR 59.6 million. VAT also should be considered the most influential payment in reference to macroeconomic structure. The annual CIT payments of forest biotechonomy reached the relative value of 11.78 % of total corporate income tax revenues in 2047 in scenario BIF(i) and the value of 4.81 % in the case of scenario BIF(e).

In the case of totally accumulated tax payments by year 2047 from forest biotechonomy sector, the scenario BIF(i) generated approximately EUR 3 006 million accumulated by year 2047, while scenario BIF(e) – approximately EUR 1 672 million in accumulation.

Furthermore, regarding the annual profit after taxes of forest biotechonomy industry in Latvia, by year 2047 in the case of scenario

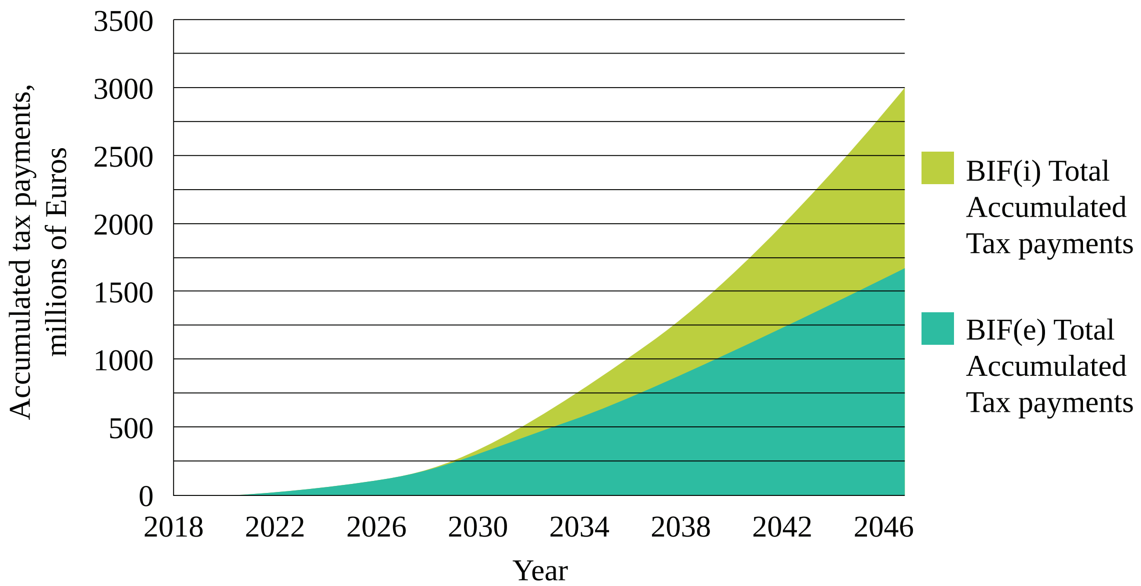

Fig. 3.5. Graphical representation of accumulated tax income from forest biotechonomy in Latvia.

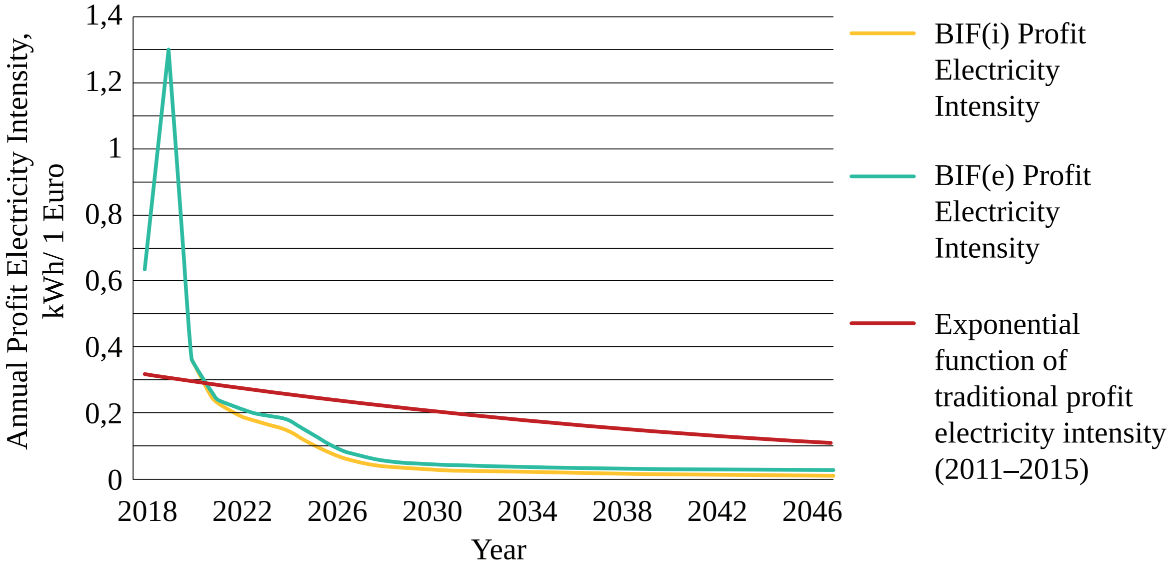

Fig. 3.6. Electricity intensity per EUR generated (sales) in forest biotechonomy and traditional processing industry in Latvia.

BIF(i) the annual profit accounted for almost EUR 0.5 billion (EUR 495 million), but in the case of scenario BIF(e) for approximately EUR 191 million per year.

Last, but not least, in reference to electricity intensity per 1 EUR generated, by year 2047 traditional Latvian manufacturing segment value reached the approximate value of 0.11 kWh/1 EUR, while in the scenario BIF(i) it reached approximately 0.02 kWh/1 EUR, but in the case of scenario BIF(e) – 0.04 kWh/1 EUR.

Discussion and Conclusions

To conclude, the journey of an energy system and economy towards climate neutrality is a complex and a multi-layered one. There are certain aspects which must be in place for any fundamental transformation, for example, the European Green Deal and climate neutrality, to take place. These include: (I) practical, yet well-thought measures of energy-efficiency; (II) related socio-economic and financial developments; as well as (III) a significant untapping of the research and development potential.

Nevertheless, the journey towards goals and climate targets can be considered folly without an enabling roadmap which critically assesses and builds-up particular steps for the climate and energy-efficiency action plan. This investigation is the roadmap and the combination of the academic research methods with practical instruments, which is the unique novelty of this dissertation. It was uncovered in-depth while expanding and concluding in relation to the dissertation tasks outlined:

Throughout the dissertation, the GHG emission performance indicator was evaluated via multi-criteria decision analysis with an aim at arriving at a more complex yet precise evaluation method of a country based GHG emissions performance. While there has been an in-depth discussion regarding GHG emissions and CO2 emissions, other crucial factors of the GHG emission performance have been left omitted. For example, income from environmental taxes and investment share of GDP, to name a few. The dissertation has successfully defined and evaluated GHG emission performance indicator, incorporating some of the GHG emission debate concepts that previously had been disregarded in the academic debate.

Furthermore, to ensure that different energy system structure, political, economic, and cultural factors were incorporated within the analysis, eight different EU countries were selected for the comparison and evaluation. While the analysis revealed that Sweden is most fit for transforming its economy towards climate neutrality from the GHG emissions factor point of view, the investigation revealed that countries championing some conceptions of the GHG emissions, i.e., share of the renewable energy consumed, may, in general, lack fundamental aspects for transforming the energy structure fit for meeting climate neutrality in 2050. Latvia indicated the lowest performance of the countries compared, being behind not only Northern European countries and Ireland, Slovenia, but also its Baltic neighbours. While further research should focus on improving the developed methodology (i.e., expanding the set of indicators, analysing correlations, and applying quantitative data for criteria weights), it also signals the necessity for stronger push for energy-efficiency and rather multi-dimensional approach to the problem.

With the application of the Log-Mean Divisia index decomposition analysis method energy-efficiency performance of the Latvian manufacturing industry and its role towards the climate neutrality was evaluated. Overall, the energy consumption of the Latvian manufacturing industry increased by 12 % during the time period from 2010–2019. In addition, the results indicated that the increase of the industrial production output was the main driver behind the increased energy consumption of the manufacturing segment as such. On one hand, bearing in mind the economic growth of the Latvian economy at the particular time frame constituted roughly 43 %, the increase should not be considered critical, and even more – anticipated. However, within the scope of climate neutrality goal by 2050, arguably ill functioning energy-efficiency implementation policy and the lack of GHG emission and energy-efficiency tools and benchmarking, the conclusion deems additional factors.

Essentially, the Latvian economy has not succeeded in unbundling economic growth from the increase in energy consumption. With an apparent energy-efficiency policy in place, discussed further, the total increase in the industry output outweighed the energy intensity effect. Hence, energy-efficiency measures in Latvia did not compensate the increase in energy consumption. This, in turn, indicates that there is a necessity to accelerate the energy-efficiency measures in the local economy, in order for the energy system and economy to be on track for meeting the climate goals.

Another crucial aspect is that three notable sub-sections of the Latvian industry – wood processing, food processing, non-metallic minerals production – together constitute 89 % of total industrial consumption. Hence, any efficient, optimal and sustainable industrial energy-efficiency measures should take into consideration the heterogeneity of these sectors. For example, extending the ETS scheme to multiple sectors and more extensively including energy-efficiency clauses in manufacturing industry-wide research and development programmes.

Theory-based policy analysis was used for the in-depth assessment of the Latvian energy-efficiency policy, namely, under the energy efficiency obligation scheme (EEOS). Even though the evaluation revealed that the formal EEOS goals have been met, it can be argued that the negative externalities and prospects of the scheme indicate flawed energy-efficiency policy design and implementation measures currently exercised in Latvia. This can severely limit the capacity for reaching climate neutrality by 2050.

A fundamental problem is related with the types of energy-efficiency measures implemented. Whilst the savings have been met, the governmental officials anticipated before the start of the scheme that 50 % of savings would be generated via informative measures and 50 % via energy-efficiency improvement measures. The investigation assessed that 95 % of savings under the EEOS were generated from informative measures, thus introducing two severe obstacles. First, the energy savings depend on "deemed" savings without any evidence of factual energy-saving per se, reliant on the Energy Savings Catalogue methodology, designed locally. Second, deriving from the deemed savings there has been a significant lack of investment into energy-efficiency technologies, while it is proved to be a more sustainable source of energy savings.

This can be explained with the overall cost of energy-efficiency measures for the obliged parties. The three available options in practice have shown that the average cost of information measure for the party reaches 4 EUR/MWh, while the official contribution cost to the energy-efficiency fund is 70 EUR/MWh and penalty for not complying with the EEOS – 125 EUR/MWh. Another aspect is that in an economy which has historically been lacking funds for energy-efficiency measures, such behaviour also does not improve the overall availability of funds for, in turn, incentivising any investment in energy-efficiency technologies via public funds. In addition, as the savings are deemed in the first place, there is a risk of having no energy saving on a systemic basis whatsoever and hinders the development and potential diffusion of energy-efficient technologies.

Throughout the investigation an internet-based simulation tool was developed, with applying system dynamic modelling. The tool provides both the policy makers and the EEOS parties with insights of the scope and deliverables of various potential energy-efficiency policy implementation measures. This, in turn, has also validated the argument of arguably flawed and rather formal policy making approach, but also serves as a separate practical takeaway from the investigation with building a more practical and measurable roadmap towards the implementation of the EEOS and, in turn, climate neutrality agenda.

To assess benefits and positive externalities from following the climate neutrality pathway and introducing new bioeconomy sectors within the energy structure and markets, the role of bioeconomy sectors was evaluated while using system dynamics modelling. The introduction of the forest biotechonomy segment, potential increase of annual governmental budgets in education and healthcare budgets can be assessed. This, in turn, serves to the argument that transformation of the energy and production industry with the development of bioeconomy sub-sectors can lead to an increase of funds available in an economy, with increase in energy-efficiency in the Latvian manufacturing industry. In particular, the modelled increase in education and healthcare sectors has been relatively notable. In the case of scenario BIF(i) it has been EUR 5 million and 20 million accordingly, but in the case of scenario BIF(e) – EUR 2 million and 8 million.

In addition, in reference to the reinforcing aspect of education and healthcare improvement to the forest biotechonomy manufacturing output, the model reveals significant potential increase of annual contributions to the macro-level economy. In terms of annual value added tax payments – from roughly EUR 60 million – in scenario BIF(e) – to EUR 153 million in the case of BIF(i). Regarding corporate income tax annual contributions – from 4.81 % of total annual corporate income tax payments in scenario BIF(e) to 11.78 % in scenario BIF(i). And finally, all accumulative macro-level contributions until 2047 were also increased from EUR

1.61 billion – scenario BIF(e) – to nearly EUR 3 billion in scenario BIF(i). This serves not only as the climate related externality, but as a practical financial gain from the transition towards climate neutrality in 2050. Last, but not least, the introduction of bioeconomy also revealed significant increase of energy-efficiency within the manufacturing industry. In the case of scenario BIF(i) by 2047 the generation of 1 EUR sales profit would require 0.02 kWh of electricity, while in the case of BIF(e) scenario 0.04 kWh, but in traditional industry modelling – 0.10 kWh per 1 EUR generation. Furthermore, if converted to carbon dioxide equivalent per 1 EUR profit, the results would indicate 2 grams, 4 grams and 18 grams of CO_2 equivalent, accordingly.

In the end, the dissertation has assessed and evaluated the role of various factors, including the following ones:

- Energy consumer behaviour – individual consumer level, industries, governments and systemic scale via climate transition debate.
- Technological innovation – regarding separate energy-efficiency measures, as well as systemic innovation via introduction of bioeconomy or three pillars of the transition towards climate neutrality.
- Overall energy system transformation – via system dynamic modelling in regards to energy efficiency, systemic transformation and positive energy-efficiency and macroeconomic externalities regarding introduction of bioeconomy.
- Opportunities and potential for the GHG emission factor expansion and evaluation in terms of emission reduction opportunities.
- A transformative change towards climate neutrality can happen only if *all* multiple dimensions of this dissertation are considered. Starting from an in-depth and broader monitoring of current state of affairs regarding climate neutrality, transparent evaluation of the success and failures of former and current policies & related energy-efficiency measures, as well as multidimensional analysis of takeaways that such system would entail and bring.

- Currently, the ex-post evaluation signals crucial bottlenecks in multiple dimensions to be overcome over the upcoming decade to be on the right road to climate neutrality by 2050. It is up to us to determine whether we are, indeed, ready to embark on this journey.

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