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

Reinis Āzis
Doctoral Student of the Study Programme "Environmental Science"

A Breath of Fresh Air for the European Green Deal: Energy Efficiency and Climate Neutrality Factors

Doctoral Thesis

Scientific Supervisor
Professor Dr. habil. sc. ing.
DAGNIJA BLUMBERGA

Professor Dr. sc. ing.
ANDRA BLUMBERGA

RTU Press
Riga 2021

ANOTĀCIJA

Darba rakstīšanas laikā Eiropas "Zaļais kurss" ir viena no apspriestākajām tēmām vides, enerģētikas un ekonomikas jomās. Neraugoties uz to, akadēmijā un publiskajā diskusijā pietrūkst visaptveroša, strukturāla, dinamiska un izmērāma skata vienuviet par klimata neitralitātes mērķu sasniegšanu. Tas ir šī promocijas darba virsmērķis un malks svaiga gaisa tēmas ietvaros.

Eiropas Savienība līdz 2050.gadam ir apņēmusies kļūt klimata neitrāla. Lieki teikt, šis uzdevums būs izaicinošs. Vairāk kā 50% tehnoloģiju, kas būs vajadzīgas, lai sasniegtu klimata neitralitātes mērķi, būs tehnoloģijas, kas vēl nav izgudrotas. Turklāt nekad pasaules vēsturē ekonomikas izaugsmi nav izdevies atdalīt no energoresursu patēriņa pieauguma. Taču ceļa uz klimata neitralitāti fundamentālais ietvars ļaus izmantot tehnoloģiskos un finanšu resursus saskaņoti un tādā mērogā, kāds iepriekš nav pieredzēts. Tāpat arī pēc-pandēmijas pārvarēšanas instrumenti tiek organizēti pakārtojot tos klimata neitralitātes mērķiem. Šie faktori un fosilā kurināmā cenu pieaugums ilgtermiņā liks arī industrijai kļūt energoefektīvākai – vai nu ar mērķi lai virzītos pretim klimata neitralitātei, vai lai saglabātu izmaksu konkurētspēju.

Darba mērķis ir (I) izvērtēt dažādus faktorus un pilnveidot novērtēšanas indikatorus, kas ļauj enerģētikas sistēmai un ekonomikai virzīties uz klimata neitralitāti, kā arī (II) izvērtēt bioekonomikas lomu šīs virzības ietvaros. Tas darīts vienlaicīgi apskatot gan dažādus enerģijas patērētāju līmeņus un savstarpējo mijiedarbību, gan dažādus vides un enerģētikas indikatorus, gan dažādas akadēmiskas metodes un to savstarpējo mijiedarbību, gan izveidojot jaunus inženiertehniskos modeļus. Mērķa sasniegšanai izvirzītie uzdevumi ietver siltumnīcefekta gāzu indikatoru novērtējumu un salīdzināšanu, Latvijas apstrādes rūpniecības energoefektivitātes rādītāju un kopējās energoefektivitātes politikas vērtējumu, faktoru analīzi un modeļu izstrādi veiksmīgai energoefektivitātes politikas ieviešanai, kā arī bioekonomikas jomas ietekmes vērtējumu, virzoties uz klimata neitralitāti.

Promocijas darbs ir veidots kā publikāciju kopa, kas sastāv no 5 tematiski vienotām zinātniskajām publikācijām, kas tapušas doktorantūras laikā. Tās ir publicētas enerģētikas tēmai veltītos akadēmiskos žurnālos ar augstu ietekmes faktoru un indeksētas starptautiskajā datubāzē SCOPUS.

Promocijas darbs sastāv no ievada un piecām daļām. Ievada daļā iekļauta tēmas aktualitāte, hipotēze, mērķi un uzdevumi, darba struktūra un informācija par darba aprobāciju. Promocijas darba pamatdaļā sniegts ieskats izmantotajā literatūrā, metodoloģijā un atainoti būtiskākie rezultāti, kas arī iztirzāti diskusijas daļā. Darba noslēgumā veikti secinājumi par izstrādāto promocijas darbu un apspriesti tālākie soļi konkrētās jomas pētniecībā.

ANNOTATION

At the time of writing, the European Green Deal is one of the most debated topics in the fields of environmental engineering, energy, and economics. Arguably, academia has been lacking research on a singular, comprehensive, structural, dynamic, yet measurable view on achieving climate neutrality objectives. This is the main aim of the dissertation and a breath of fresh air for the climate neutrality debate.

The European Union is committed to becoming climate neutral by 2050. This task is daunting. More than 50% of the technologies that will be needed to meet the climate neutrality targets will be technologies that have not yet been invented. Moreover, never in history has economic growth been unbundled from the increase in energy consumption. However, the fundamental framework for the path towards climate neutrality will allow to use technological and financial resources in a coherent and unparalleled way. Also, long-term fossil fuel price increase will arguably push industry to become energy efficient to remain competitive.

The aim of the research is (I) to assess various factors and to improve assessment indicators enabling energy systems and the economies to move towards climate neutrality and (II) to assess the role of bioeconomy in such transition. This is done by examining: the different levels of and interaction between energy consumers, different environmental and energy indicators, different academic methods, and their interconnectedness, and creating new engineering models. The objectives for achieving the target include: the assessment and comparison of greenhouse gas indicators, the assessment of the energy efficiency performance of the Latvian manufacturing industry and the assessment of the overall energy efficiency policy, the analysis of factors and development of models for successful implementation of energy efficiency policy, as well as the assessment of the impact of the bioeconomy towards climate neutrality.

The dissertation thesis is designed as a set of publications, consisting of 5 thematically unified scientific publications. They have been published in high-impact academic journals dedicated to the energy topic and indexed in the international database SCOPUS.

The promotion work consists of an introduction and five parts. The introductory part includes the novelty of the research, hypothesis, goals and tasks, dissertation structure, and information about academic approbation. The main section provides an insight into the literature, methodology and presents key results, which are also later discussed. In the end, conclusions are presented and avenues for future research in the specific field are discussed.

PATEICĪBAS

Šis darbs nebūtu tapis bez līdzcilvēku atbalsta, kam vēlējos pateikties.

Paldies Dagnijai Blumbergai par pirmo telefona zvanu Rīgā, 2015.gada vasarā un uzticību, kas pavēra durvis gan jauniem akadēmiskiem un profesionāliem izaicinājumiem, gan atnesa manā dzīvē labus draugus. Atbalsts un motivācija arī promocijas darba tapšanas laikā bija nenovērtējami.

Paldies Andrai Blumbergai par motivāciju domāt sistēmiski un vides ekonomikas jautājumu virzīšanu priekšplānā. Paldies Gatim Bažbaueram par atbalstu vides un enerģētikas cēloņsakarību izzināšanā, tai skaitā, plašākā ekonomiskā kontekstā.

Paldies manam kursa biedram un visīstākajam draugam Tomam Prodaņukam gan par īsiem, nervoziem smiekliem pirms eksāmeniem, gan stundu garām sarunām par enerģētiku un citiem jautājumiem.

Paldies manai ģimenei, kā atbalsts vienmēr ir bijis visa pamatā. Arī šim promocijas darbam.

TABLE OF CONTENTS

ABBREVIATIONS

AHP	-	analytic hierarchy process
BIF (e)	-	biotechonomy improvement factor, excluding additional reinforcing loop
BIF (i)	-	biotechonomy improvement factor, including additional reinforcing loop
BRA	-	the Better Regulation Agenda
CI	-	consistency index
CIT	-	corporate income tax
CO	-	consistency ratio
EBITDA	-	earnings before interest, taxes, depreciation and amortisation
EED	-	Energy-Efficiency Directive 2018/2002
EEOS	-	Energy Efficiency Obligation Scheme
EU	-	the European Union
ETS	-	Emissions Trading System
GDP	-	gross domestic product
GHG	-	greenhouse gases
IDA	-	Index decomposition analysis
ISO	-	International Organization for Standardization
LMDI I	-	Log-Mean Divisia index
MCDA	-	multi-criteria decision analysis
R&D	-	research and development
TOPSIS	-	Technique for Order Preference by Similarity to Ideal Solutions
VAT	-	value-added tax

INTRODUCTION

At the time of the writing, the world is undergoing a generational transformational 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 (EU) 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 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 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 propriate 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, research develops broader discussion regarding any strategic energy-efficiency related goal and the complexity and multiple threads that meeting such a goal would entail.

Research also explicitly elaborates on the role of energy efficiency in both climate transition and energy system transformation. In addition, it uncovers scope of various policies implemented on a local level and discusses their role in meeting the climate targets in medium and long-term. Furthermore, 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 following tasks were outlined:

1. To evaluate the GHG emission performance indicator 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.
6. 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 were 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, via 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. 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 dynamic 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 dynamic 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 dynamic 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

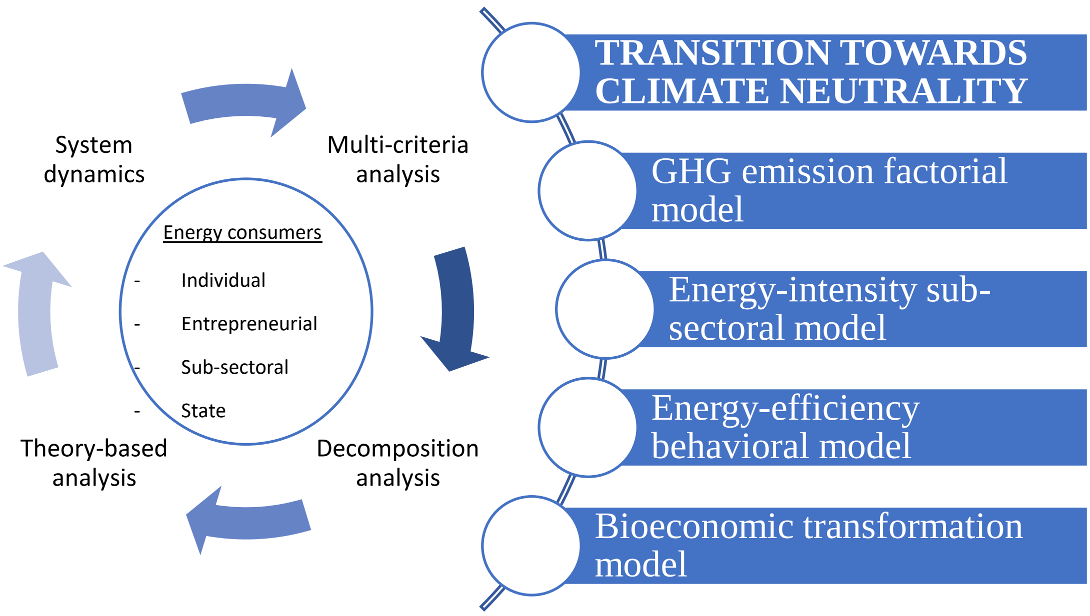
The practical relevance of the research should be considered threefold. First, investigation elaborates on the methodology for broader and better-encompassing assessment of greenhouse gas emissions. This, in turn, may lead to significantly improved assessment of GHG inventories in other academic research 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 dynamic 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 he need for policy change and particular details it fails to cover.

In addition, system dynamic 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

Dissertation is based on 5 coupled scientific 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 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 figure below (Fig. 1.).



1. Fig. 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 (tab. 1.).

1. table

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*	

With the application of the following research methods, (I) multi-criteria decision analysis; (II) decomposition analysis; (III) theory-based analysis and (IV) system dynamics, 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

1. Zlaugotne, B., Ieviena, L., Azis, R., Baranenko, D., Blumberga, D. 2020. GHG Performance Evaluation in Green Deal Context. Environmental and Climate Technologies (24-1), pp. 431-441.
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.
3. Blumberga, A., Azis, R., Reinbergs, D., Pakere, I., Blumberga, D. 2021. The Bright and Dark Sides of Energy Efficiency Obligation Scheme: The Case of Latvia. 2021 Energies 2021, 14, 4467. https://doi.org/10.3390/en14154467.
4. Azis, R., Blumberga, A., Bazbauers, G. 2017. The role of forest biotechonomy industry in the macroeconomic development model of the national economy of Latvia: a system dynamics approach. Energy Procedia 128 (2017), pp. 32-37.
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

Arguably, at the time of the writing there are few more often cited concepts within the energy-efficiency debate such as the European Green Deal. Even though, indeed, energy-efficiency is at the core of the plan, it is wrongly assumed that the deal solely focuses on this realm of energy. Consisting of eight interrelated actions, including, (I) climate; (II) environment and oceans; (III) energy; (IV) transport; (V) agriculture; (VI) finance and regional development; (VII) industry and (VIII) research and development [1], the plan truly encompasses broader view and strategy design for a shift towards climate neutrality. In sharp contrast, most of EU member states' plans do not, including Latvia, be it the National Energy and Climate Plan of Latvia 2021 – 2030 [2] or National Industry Policy Guidelines 2021 – 2027 [3].

It can be argued that the rationale behind such an approach is the fact that 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 [4] per se, the latter is solely applicable to net carbon dioxide emissions and, arguably, more often associated solely with the energy sector [5]. 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 while there is quite a wide spectre of academics discussing and attempting to quantify dynamics of energy systems striving to ensure net zero GHG neutrality. However, energy and environmental engineering research focussing on modelling particular carbon neutrality can be considered limited. Regarding GHG neutrality, research can be mainly divided into three broad groups of scholars. First, focussing on systems of energy carriers. Second, focussing on sub-sectors of economy. Third, focussing on time and space (geographically) based systems.

Regarding energy carriers, a system level research has been focussing on, for example: renewables and renewable gas [6]; hydrogen [7], power to methane [8], electric fuels [9] and essentially also natural gas [10]. In reference to economic sub-sectors, notable examples in reference to this investigation include Brand et al. (2012) research for transport sector in the United Kingdom [11] and others, for example, focussing on buildings [12]. Regarding geographically based systems, several investigations have been focusing on cities, for example, the role of energy-systems in transition of the metropolitan region of Helsinki [13] and regions.

As mentioned before, academia focussing on modelling and combining energy systems driving to achieve carbon neutrality also should be mentioned. Notable examples include global aggregated energy system transition analysis for reaching carbon neutrality, for example, (I) focussing on the EU policies from bottom-up approach [14] and macro aggregated approach [15] 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 debate has already been linked to the carbon and climate neutrality debate, there has been lack of theoretical consistency and inclusion of the thesis within an 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 strive for climate neutrality [16]. 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" [17]. 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" [18] – 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 [19]. 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.

For the purposes of academic discussion framework, the relevant threads of the Green Deal shift imperative – both strategic level policy discussion and operational implementation measures – can be arranged in the following way:

1. Primary dimension: decarbonization and energy-efficiency practical measures.
2. Secondary dimension: social cohesion via economic development and financing.
3. Tertiary dimension: research and development advancement, both financial and facilitation measures.
4. Parallel dimension: social inclusion serving as a foundation for the aforementioned.

In turn, each of the dimensions is attributed with several sets of policy tools and initiatives on the EU level that should also be incorporated within the local level. For the purposes of this investigation, just a few can be outlined. For example, (I) the EU strategy on energy system integration [20] and the sustainable and smart mobility strategy [21] – outlining the basis for the primary Green Deal shift dimension; (II) the industrial strategy for a competitive, green, digital Europe [22], as well as the Recovery and Resilience Facility [23] – in reference to the aforementioned secondary dimension; (III) the ambitious financial investment plant "NextGenerationEU" [24], as well as mission oriented approach regarding research and development challenges, responding to separate realms of smart specialization [25]; and even (IV) within the realm of societal policy, for example, the New European Bauhaus initiative [26] – encompassing on the "new ways of living" in Europe for all citizens, in order to target climate neutrality and the Green Deal plans for Europe.

Literature analysis indicates that not only on a strategic level, but also the implementation level of the European Green Deal is relatively smoothly interlinked, both regarding policy goals, as well as implementation instruments. While fundaments of societal change are seen as a footing for any policy, financial and research and development policies and instruments undercut primarily the larger role of the policy to transform the economy, and only secondary attention is dedicated to instruments solely focusing on decarbonization of business and industry. A similar parallel can be encompassed also assessing the Recovery and Resilience Facility on the EU level, where particular benchmarks and tags have been used for the plan to meet the mandatory quota of investing approximately 40% of the incentives in climate technologies and research. This complex dynamic is also reflected in the fact that multiple Directorates-General are responsible for the implementation of the Green Deal plan, instead of attributing the responsibility to a sole institution. Such sharp differences in the organizational structure for the Green Deal implementation also draw the crucial misalignment between the EU and local policy strategy and implementation levels, even despite the ambitious climate goals brought forward by separate member states. Understanding the role of such differences and based on the theoretical evaluation, potential ways how to bridge them should be considered another significant novelty of the research.

It can be argued that locally even though ambitious climate targets have been set, there is a significant lack of (I) coordination among key stakeholders responsible for the shift towards climate neutrality; (II) practical implementation roadmap, leading to measurable deliverables and (III) financial planning which can be perceived as a critical point, bearing in mind the size and ambition of smaller member states, for example, Latvia.

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:

- 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 [27], needless to say in small and open economies. Nevertheless, some of the considerations for overcoming the challenges in meeting the climate targets (discussed via the dimensions proposed earlier) in the plan are the following:

- Regarding primary dimension (decarbonization and energy-efficiency): (I) to implement the principle of "energy-efficiency in the first place"; (II) to revise of the energy-efficiency obligation scheme; (III) to improve the energy-efficiency monitoring.
- Regarding secondary dimension (economic development and financing): (I) to attract additional private financial resources via state institutions; (II) "not to increase the taxation on climate neutral technologies" and "foster" the discussion of climate taxation.
- Regarding tertiary dimension (research and development incentives): (I) more proactive coordination of climate change goal inclusion within the research and development policy of Latvia; (II) setting up of more effective coordination platforms for the relevant stakeholders within the energy research and development realm.

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 arguably 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 will be 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, small and open economies arguably cannot afford to build tools targeting sole, niche objectives of the economy and expecting to have a lasting impact due to the lack of resources within an economy – both intellectual and financial. Instead, the instruments should attempt to tackle several realms of economies simultaneously, arguably, it is a mandatory need in the post pandemic EU [28] 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 [29]; 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 [30]. 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 [31], indicating both the lack of absolute financial mechanisms, but 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. Moreover, the lack of inclusion of the relevant public stakeholders within the debate and plans brings back the argument of lack of coordination as the core of potential worrisome meeting of the climate targets.

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 [32] 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 policy or energy audit plan could pave way for more practical and efficient policy implementation tools. Again, combining such metrics with financial instruments taking into consideration the footprints of the particular entity may also shift the plan to more valuable asset.

Third, the monetary aspects of the implementation plan are severely underdeveloped and does 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, actually, 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 by systemic lack of funding for the Latvian economy, but the previously mentioned lack of coordination for fruitful Latvian investment strategy in climate neutrality.

Another aspect, and potentially even more worrisome, is the systemic lack of any and, particularly, 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 [33]. 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 do exercise research and development activities. Namely, research expenditure is relatively often described by the auditing authorities as "using the dominant market position" [34] or potentially unlocking the risk of public fund inefficient usage.

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. The aforementioned dimensions, focussing on, but not limited t,o energy realm, financing and R&D. It is therefore vital to shortly elaborate on the research carried out throughout the dissertation, to summarize it and to discuss the role that the dissertation research plays regarding such multi-dimensional analysis.

1.3. Dissertation Research Literature Review

The sub-research field literature overview is presented sequentially, following the dissertation tasks.

1.3.1. GHG Performance Evaluation

In this paper multi-criteria decision analysis (MCDA) is applied to determine the present position of eight selected EU countries (Denmark, Estonia, Ireland, Latvia, Lithuania, Slovenia, Finland and Sweden) in terms of GHG performance. Various indicators are applied, along with GHG emissions considering economic, political, and social and energy consumption factors. This comparison allows determining what the starting points for various countries are and which could take the lead in reaching carbon neutrality. Moreover, taking into account that countries influence each other's energy, environment and economic conditions [35], such comparison can be useful in researching the links between countries. Regarding Latvia, it gives the opportunity to detect its position compared to other EU countries and to judge on the required intensity of the necessary measures. For countries at worse GHG positions, this comparison shows the roadmap for the implementation of successful policies.

Greenhouse gas inventory, prepared by the European Environment Agency, ranks the EU countries according to the total amount of their GHG emissions. On the EU level, progress in GHG emission reduction is mainly measured by the annual changes of the total GHG amount, changes since 1990 and (or) regarding the achievement of national targets [36]. Although, the criterion regarding carbon-neutrality achievement is net GHG emissions, implementation of various indicators allows determining how advantageous countries are in terms of GHG emission reduction.

GHG performance is often evaluated as a part of a broader environmental performance and sustainability assessments [37]–[39]. Along with direct GHG indicators, such as the total GHG emissions per country or GHG emissions per capita, such evaluations often include factors, which do not directly express the GHG emissions while still being closely related. Such factors include: the share of renewable energy, energy consumption, environmental or energy taxes, environmental protection expenditure [40]–[42] and others.

There are few studies investigating environmental indicators with the aim to evaluate GHG performance. Also, many studies have focused on the drivers of GHG emission reduction. Arguably, the most important are the increase of energy efficiency and renewable energy [43]–[45]. Although in publications was reported that the impact of the share of renewable energy was insignificant in GHG emission reduction, while policies to increase energy efficiency were assessed to have a greater impact.

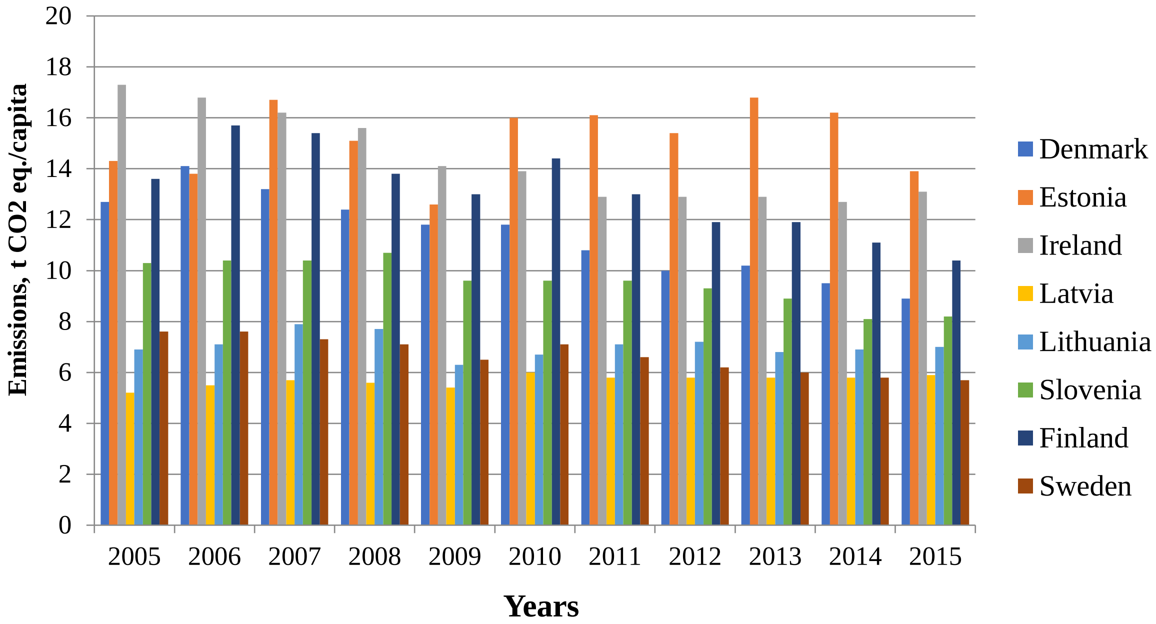
Lately countries are often grouped into categories according to their GHG performance as an attempt to give a general demonstration of similarities and differences and search for correlations. For example, Su M., et al. (2016) established a method of four quadrants to compare the countries' performance in emission intensity, carbon removal rate, and net reduction rate of GHG emissions from 1991 to 2012 [46]. Such division is based on absolute emission quantity, as well as relative emission quantity (the ratio of GHG emissions and GDP) and trends in GHG emissions (the annual net reduction of GHG emissions). According to related calculations, Latvia was the only country in the EU28 to report net GHG removal in 2012. Latvia along with other countries, including Lithuania and Estonia, was grouped in Quadrant I, representing countries with high emission intensities and high carbon removal rates. On the contrary, Germany stood out with significantly high net GHG emissions. However, due to Germany's low emission intensity it was located in Quadrant III representing countries with low emission intensities and low carbon removal rates. Quadrant II grouped countries representing low emission intensities and low carbon removal rates (for instance, Sweden), while Quadrant IV grouped countries with high emission intensities and low carbon removal rates (e.g. Poland).

Meanwhile, Kijewska & Bluszcz (2016) grouped the EU countries into clusters according to their similarities in emissions of four types of GHG to examine the diversity of European countries in terms of GHG emissions [47]. Four clusters regarding the application of k-means algorithm and Euclidian distance have been developed. The clusters were classified according to total emissions. In this evaluation, two approaches were used – the total GHG emissions per country and the GHG emissions per capita. Grouping of the total emissions and grouping of the emissions per capita resulted in different sizes of clusters, which highlighted the question of whether countries should be evaluated by their total emissions or emissions per capita. A similar study [48] grouped countries into clusters by applying agglomeration algorithm. In other investigations countries were evaluated by a narrow set of indicators, and the purpose of such evaluations was to group countries rather than to compare to each other in order to assess the best and the worst performances. The aim of this paper is to rank the selected EU countries according to their GHG performance by offering a set of economic, political, and social indicators.

For the comparison of GHG performance, eight EU countries have been selected, ensuring that different national environmental, economic and political backgrounds are covered. The main point of reference for selecting countries for comparison was the GHG intensity of energy consumption. Latvia was chosen as the main focus of analysis, alongside Ireland and Slovenia, classified as medium GHG intense. Estonia and Lithuania were selected as the countries with high GHG intensity, whereas Finland, Denmark and Sweden were chosen to represent countries with relatively low GHG intensity.

Eurostat data analysis from 2005 to 2015 indicates that Estonia had the highest average GHG emissions per capita (15.2 t CO_2 eq./capita) (Fig. 1.1.), followed by Ireland (14.4 t CO_2

eq./capita), while the lowest GHG emissions were achieved by Latvia (5.7 t CO_2 eq./capita), Sweden (6.7 t CO_2 eq./capita) and Lithuania (7.1 t CO_2 eq./capita).



1.1. Fig. GHG Emissions per capita.

During the studied period, Sweden had the best performance regarding renewable energy consumption. All countries have made improvements in the share of renewable energy. Some countries such as Sweden, Finland, and Denmark have made improvements by more than 10 % in a 10-year-period.

In terms of environmental taxes, Denmark had the highest performance. Denmark has the second highest tax rate in the EU energy sector. Slovenia has been approaching Denmark's environmental tax revenues since 2012, as Slovenia has higher tax rate on transport fuels than on fuels used for energy production – heating or electricity.

From all selected countries, Estonia has the highest CO_2 emissions, which is the second highest value in the EU after Luxembourg. The main reason for the high emissions in Estonia is electricity production from oil shale, which accounts for about 90 % of the total CO2 pollution, and recently oil shale has also been used for liquid fuel (diesel) production [49]. However, Estonia has set ambitious goals to increase electricity production from biomass [50]. Ireland is also a significant source of CO_2 emissions with most of the emissions coming from industry and agriculture [51], and Finland, where emissions from energy sector are mainly generated by utilization of natural gas and peat [52]. Overall, in a 10-year-period, emissions are decreasing periodically, except for Estonia where the trend is uneven.

The total consumption of solid fossil fuel is low in Estonia, Latvia and Lithuania in comparison to other selected countries. Generally, the consumption of solid fossil fuels is decreasing. Finland stands out with significantly high values for this indicator because over half of its heat is generated from solid fossil fuels.

Households hold an important position in the total energy consumption and represent the overall energy consumption image of a population. Household energy consumption per capita is the lowest in Lithuania, while Finland scores the highest. All the selected countries have reduced their household energy consumption over recent years.

Eurostat data indicates that the investment share of GDP was high during a period from 2005 to 2008 for all selected countries, and in 2009 it decreased by 10 % on average, which can be related to the global financial crisis. However, the investment share for all countries started to increase afterwards. The highest average investment share was in Estonia (28.5 %).

1.3.2. Energy Efficiency Performance of the Latvian Manufacturing Industry

"Energy efficiency first" is a strategic priority and one of the key principles of the EU Climate Action Plan and the European Green Deal strategy [53]. The ambitious energy savings targets put a lot of pressure on Latvian manufacturing industry companies, which need to ensure gradual reduction of energy consumption while maintaining competitive economic growth and increasing production output. According to the assessment of the EU Member States' progress in achieving the energy efficiency targets imposed by Energy Efficiency Directive by European Commission [54], in the period from 2005 to 2018, the Latvian industrial sector recorded the highest increase (+ 14%) in energy consumption among the EU-28 Member States. These results require a more detailed study of energy consumption changes in the Latvian manufacturing industry, the main energy efficiency trends and the factors determining changes in energy consumption in manufacturing companies.

There can be distinguished two main motives behind energy efficiency for manufacturing industry companies. On one hand, energy efficiency is associated with reduced environmental impact from production processes through decreased amounts of generated CO_2 emissions from fuel combustion and electricity consumption [55]. On other hand, financial and economic motives that are associated with lower energy costs that significantly impact the overall production costs of manufacturing, as a result determining company’s level of competitiveness in global market.

In the previous studies on energy efficiency in Latvian industry, for example, [56] and [57], the authors started to investigate the differences in energy efficiency of individual subsectors using the composite index methodology. The results of these studies showed that there are sectoral heterogeneities in all dimensions of sustainability of the manufacturing sector, which should be taken into account when designing an effective energy efficiency policy. This paper aims to extend the scope of previous research by examining changes in manufacturing energy efficiency over time. The index decomposition analysis method is applied to measure the changes in energy consumption in all Latvian manufacturing subsectors over a ten-year period from 2010 to 2019.

1.3.3. Energy Efficiency Policy of the EU

The European Union (EU) Energy Efficiency Directive 2018/2002 (EED) has established an energy efficiency target for 2030 of at least 32.5 % (compared to projections of the expected energy consumption in 2030) [58]. EU member states shall achieve the amount of energy savings required by the EED either by establishing an energy efficiency obligation scheme (EEOS) or by adopting alternative policy measures or by combining them both. According to the EED, the obligation can be assigned to energy distributors, retail energy companies, transport fuel distributors, or to transport fuel retailers operating in their territory.

Before the introduction of the EED, five European countries (Denmark, France, Italy, the UK, and the Flanders region of Belgium) were already implementing EEOS [59], subject to about 40 % of the EU population [60]. The first country in Europe that introduced an obligation on suppliers to save energy among final customers was the UK in 1994 [61]. The introduction of EED in 2012 led to a rapid increase in EEOS. As a result, in 2018, already fifteen EU member states had active EEOS (Austria, Bulgaria, Denmark, France, Ireland, Italy, Luxembourg, Malta, Poland, Slovenia, Spain, UK), while another three were intending to start shortly (Croatia, Greece, Latvia) [62]. In April 2020, there were sixteen active EEOS in the EU Member States and the UK, with other countries still planning the implementation [63]. EEOS is used relatively rarely compared to all other policy instruments used to comply with the target, set out in EED. Meanwhile, grant schemes are the most widespread in all sectors. However, the frequency of policy measures used to comply with the EED energy efficiency target does not always represent proportional energy savings. According to the European Commission's report in 2020, EEOS is the most crucial policy measure regarding cumulative energy savings and delivered more than a third (35.59 %) of all cumulative energy savings during the period from 2014 to 2017 [58]. EEOS is delivering more than twice the savings from energy or CO2 taxes (16.07 %), followed by financial instruments (13.12 %) and regulation (9.75 %).

The summary about EEOS in selected EU countries and the UK compiled by Duzgun & Komurgoz, 2014 [64] represents the differences between EEOS. Regarding obligated parties, all energy suppliers were set as obligated in France, while in Belgium, for instance, only electricity distributors are obligated. In Italy, energy-saving measures refer to all sectors, including transport, while only residential customers are eligible in the UK. In Denmark, France, and the UK, savings are attributed to the delivered energy. Meanwhile, in Italy, Belgium and Poland, it is primary energy. The target amount of energy savings is difficult to compare as the final consumption of energy is an important factor [65]. Denmark, France, and Belgium have set a fixed penalty per kWh for the shortfall of savings, while in Italy and Poland, the penalty can vary widely, but in the UK, the government holds a possibility to impose a penalty, yet does so rarely [66]. Nearly all selected countries allow some trading of the white certificates, except for Belgium. Overall, costs are passed on to the end-users through energy bills, and this is the primary source for funding the programs among these countries [67].

The success of EEOS implementation depends on various factors, such as policy design, implementation, governance, market structure and conditions [68]. Bertoldi et al. [69] concludes that although supplier obligations seem to be well-suited for the residential sector, end-user saving obligations may also offer advantages to the industrial and commercial sectors. Often EEOS are coupled with a trading system, and one of the leading trading options is white certificates [70].

Fawcett et al. [68] provides evidence that a good quality EEOS may deliver significant, cost-effective energy savings over many years. The overall benefits of EEOS are distributed over different domains, such as energy end-users, utilities, and society [71]. However, these benefits are not automatically guaranteed with every launch of EEOS. For example, while theoretically, energy savings under the EED should be about 10.5 % by 2020 (1.5 % per year for seven years), in practice, these savings are expected to be about half that amount. In addition, the European Commission reported that thirteen EU Member States risk not meeting their national energy savings obligation by December 2020, including Latvia.

The most important disadvantages of EEOS are transaction costs and administration costs. Furthermore, it is suggested that the accredited savings during the scheme are likely to be higher than the actual savings achieved due to possible bargains during negotiations between stakeholders. Another view suggests that efficiency measures might not deliver the theoretically estimated range of efficiency because of the rebound effect [72], [73]. Finally, the duration of the policy is shown to be more important than the mere existence of the policy in demonstrating the policy's effectiveness [74].

Another study [75] has analysed the distributional effects of EEOS derived by analysis on delivery and financing of measures and concluded that high-income households and large enterprises are the beneficiaries. In contrast, low-income households and small enterprises are the ones to pay. Other studies have also found that the effects of EEOS may be regressive for low-income households [76]. The previous statement suggests that such schemes are usually not well balanced, and thus its success might be questionable in some cases.

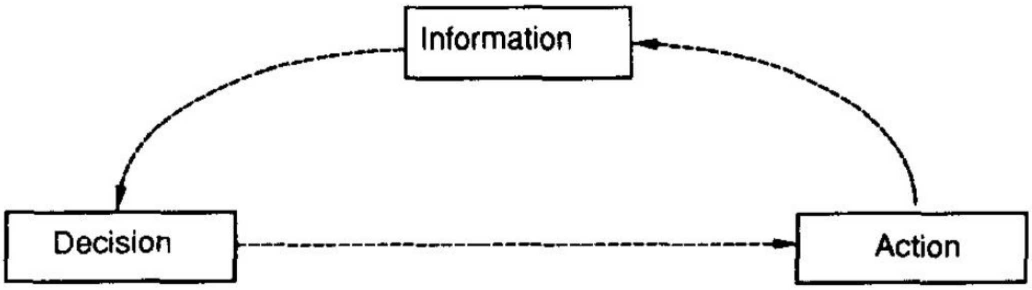
Despite many studies on the evaluation of energy efficiency policy impact that have been carried out over the past several decades, there is a gap of knowledge about the role of policy and market interventions in delivering energy savings and emissions reduction [77].

Following the introduction of EED in 2012, the Latvian government has conceptually decided to introduce EEOS in 2013 [78]. The scheme officially started in 2017. A forecast on the implementation success of EEOS in Latvia presented by [68] predicted that Latvia is at high risk of savings shortfalls because it may not deliver savings at the predicted rate. This statement was built on the arguments that the Latvian scheme originally was neither built on the existing experience of a voluntary scheme for obligated parties nor adopted (and adapted) a successful EEOS design from another country.

1.3.4. Energy Efficiency Implementation and Transformation via System Dynamics

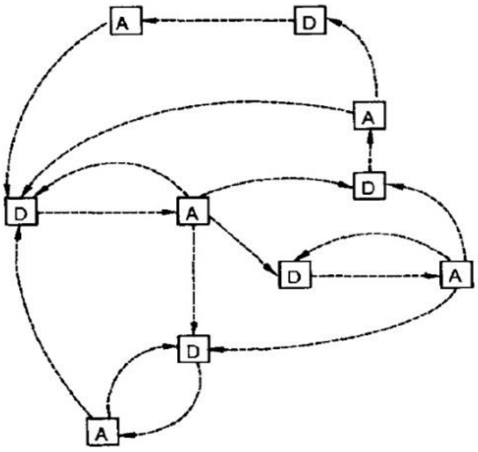
System dynamics as an evaluation method, analysing not only respective input and output flows of a system, but also including feedback provision mechanisms within it, was developed in late 1950s and early 1960s by the Massachusetts Institute of Technology. At the core, method focuses on agents or managers as information convertors, who interpret collected new information or feedback of an ongoing process and translate it into corresponding future actions [79]. 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 dynamic modelling approach [80].

Nevertheless, if we regard system dynamics as an approach, at the core of this method lays inevitable dynamic complexity of a system. As wonderful as the human mind is, the complexity of the world dwarfs our understanding. Our mental models are limited, internally inconsistent and unreliable [81].



1.2. Fig. Decision and information feedback loops [81].

Any industrial or state-level system is not entirely based on static action and information feedback mechanisms (Fig. 1.2.), but is rather a complex, multi-dimensional, dynamic and interconnected system [82], 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 (Fig.1.3).



1.3. Fig. Multidimensional and interconnected system [33].

Regarding system dynamics components there are four central concepts that should be explored in greater depth: (I) stocks and flows; (II) feedback; (III) time delays and (IV) attribution errors and false learning.

In reference to the former, it describes the accumulation and utilization of resources in a given complex system [81]. This is crucial to system dynamics as this concept forms the backbone of the dynamic problem. Flows, to that extent, are the rate of change of the stock. Both input and output flows can be based on various processes with different time, pace and source, so even without any exogenous factors the very core dynamics can be challenging. This can be illustrated by the fact that with sophisticated systems, often business analytics and scholars focus their attention away from tangible stocks (i.e. monetary capital, natural resources) to intangible, such as skills of system agents and various other political, social and normative stocks [83].

To some extent, feedback mechanisms are the crucial factors shaping the dynamic problem and systemic change. In any given system, most of the time agents assess the current situation in comparison to their desired outcome or goal and hence the difference between the goal and given situation seemingly defines their problem to overcome [81]. In order to resolve the situation, agents implement new actions; however, what is not anticipated are related new feedbacks and deriving systemic change implemented by them. Once new solutions are being implemented, new omitted variables may appear, or other agents of the system may act differently and reshape the current problem or create several new ones.

Feedback loops in system dynamics can be positive or negative – reinforcing growth to certain predefined limits or decreasing, goal driven accordingly. In any case, feedback in general interlinks various variables stationed in any given system [84]; but the process elaborated above emphasize the difference of a feedback loop in system dynamics and in static input-output systems. Some of the most well-known feedback loops that will be also incorporated within this investigation include (I) over-investment in production capital, (II) policies or mass actions that extend the expansion of a mechanism and promote excess and (III) increase and dissipation of growth expectations [85].

Time delays appear in system dynamics as the gap between decision-making process and action implementation. This phenomenon is explicitly troublesome as it is the driving factor behind system oscillation [86]. Consider, for example, a situation in a production company. While production process has been relatively constant, market demand for particular type of product all of a sudden increase. Experiencing demand and deriving price increase, company manager decides to significantly increase production volumes. At first, she would experience a time delay in raw material procurement and acquisition, as related production system management cannot be as dynamic as individual decision-making process. Second, even once increased production volumes would be implemented, there would be a time delay from the moment when she saw and defined the market opportunity until products reach market. Furthermore, once the situation would be back to business as usual, it would take additional time for the manager to observe it (i.e. from sales numbers) and deliver information back to her production team. This example elaborates on the two most prominent time delays that can be found in system dynamics: (I) resource delays and (II) information delays [84], which both will be considered throughout this research.

Attribution errors and false learning is the last, but definitely not least, of major system dynamics components influencing various systems and deserving a separate comment. The heuristic approach that individuals use when projecting personal cognitive maps of various processes and systems, tend to ignore nonlinearities, feedbacks, time delays and other elements. Furthermore, in complex dynamic systems causes and effects can be dispersed in place and time [81]; therefore, highlighting nonlinearity of these systems. As a result, individuals tend to apply false judgment regarding system participants or cause-effect principles, leading to attribution errors and false learning. Even though in complex systems different individuals tend to behave similarly; they also most commonly attribute behaviour of other agents to their characters rather than institutional framework they are embedded in [87], which lead to consequences expressed earlier. With time initially minor system misjudgements and deriving behaviour change of agents can cause a snowballing and shatter the very system itself. It is therefore system dynamics is focusing on systems rather than individuals as predominant structures shaping system outputs.

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, via 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 dynamic 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 dynamic model was also built to capture the positive externalities and empirical impact of the climate neutrality driven policies. The model itself both highlights the multiple dimensions required for a successful transformation towards climate neutrality to take place, and also highlights 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

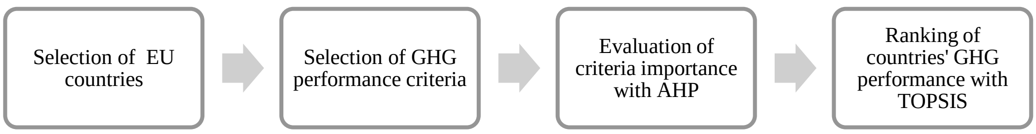
Corresponding to the structure of the dissertation and tasks, the methodology and the results sections will be reviewed sequentially.

2.1. Multi-criteria Decision Analysis

MCDA (Multi-criteria decision analysis) is a set of processes by which problems are solved when 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 [88]. 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.

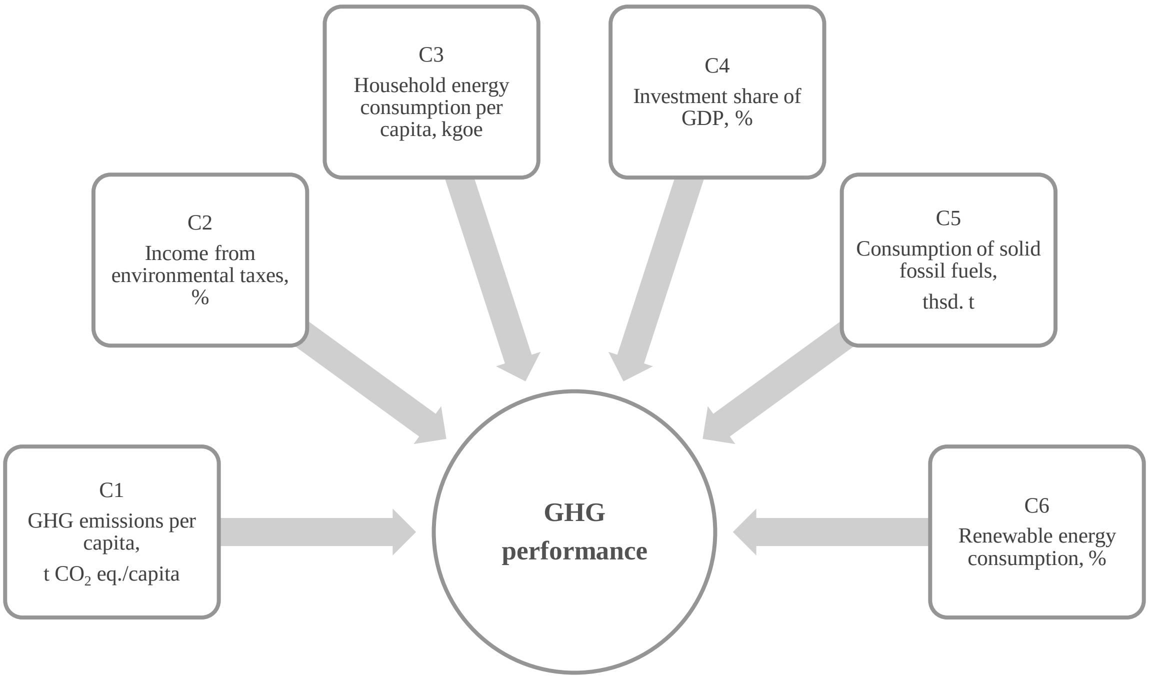
AHP (Analytic hierarchy process) was developed by Thomas L. Saaty and it is one of the most popular methods used for finding criteria weight. With this method all criteria are listed and then compared pair-wise according to their importance (contribution to reaching an objective) [89]. All criteria are 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). 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 (Analytic hierarchy process). Lastly, the ranking of countries' GHG performance was made with TOPSIS method.



2.1. Fig. MCDA methodology algorithm.

Based on the information provided in literature as well as considering the available data, six criteria were chosen for the evaluation of GHG performance (Fig. 3). 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. 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. Household energy consumption per capita is expressed as kg of oil equivalent, and it allows easily compare the energy needs of population. Investment share of GDP is an indicator used to monitor progress towards EU Sustainable Development Goals and represents the level of economic productivity. 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. Lastly, 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. Fig. GHG performance criteria.

After defining criteria, their importance is evaluated. All criteria are compared in pairs and attributed with values on a scale from 1 to 9, where 1 means that the criteria are equally important and 9 means that one criterion is absolutely more important than the other comparable criterion. Criteria weights were determined with expert judgement method. Two experts in environmental science participated in the evaluation process. The mean values from expert judgements are given in table below (tab. 2.1.). Criteria with the highest attributed importance is GHG emissions per capita (32 %), while all other criteria are significantly less important. In addition, table below also indicates the desired direction for criteria values. Minimal values are desired for GHG emissions, energy consumption, investment from GDP and solid fuel consumption criteria, while the maximal values are desired for income from environmental taxes and renewable energy consumption. AHP analysis gives a consistency index (CI) of 0.118 and consistency ratio (CR) of 0.095 indicating that the pair-wise comparisons are consistent.

2.1.table

Criteria weights

Criteria		Weight	Best values
C1	Greenhouse gas (GHG) emissions per capita	32 %	MIN
C2	Income from environmental taxes	19 %	MAX
C3	Household energy consumption per capita	15 %	MIN
C4	Investment from GDP	13 %	MIN
C5	Solid fuel consumption	13%	MIN
C6	Renewable energy consumption	8%	MAX

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 centers, and national foundations [90]. Some of them include internationally recognized organizations such as the European Commission [91], the International Energy Agency [92], the European Commission's Joint Research Centre, the United Nations Industrial Development Organization [93], the Agency’s for Ecological Transition project Odysee-Mure, and many others [94].

Index decomposition analysis (IDA) is based on the fundamental principle that changes in aggregate indicator is determined by a list of carefully predefined factors. Theoretical foundation of IDA approaches in energy studies was summarized and described in a study by [95] 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 [95]. The advantageous properties of LMDI I method is further demonstrated in numerous energy analysis and climate change assessment studies, including in-depth energy efficiency progress evaluation in manufacturing industry [96]–[99].

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 [100]–[102]. 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 [95], 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 [103]. Energy consumption in industry is decomposed according to Equation (Eq. 2.1.).

$$E = \sum_i E_i = \sum_i Q \frac{Q_i}{Q} \frac{E_i}{Q_i} = \sum_i Q S_i I_i \quad (2.1.)$$

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 (Eq. 2.2. and 2.3., 2.4. and 2.5.).

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

$$\Delta E_{act} = \sum_i \frac{E^T - E^0}{lnE^T - lnE^0} ln \frac{Act_1^T}{Act_1^0} \quad (2.3.)$$

$$\Delta E_{str} = \sum_i \frac{E^T - E^0}{lnE^T - lnE^0} ln \frac{Str_1^T}{Str_1^0} \quad (2.4.)$$

$$\Delta E_{int} = \sum_i \frac{E^T - E^0}{lnE^T - lnE^0} ln \frac{Int_1^T}{Int_1^0} \quad (2.5.)$$

where ΔE – change in total energy consumption, TJ;

E^T – energy consumption in the following year, TJ;

E^0 – energy consumption at the initial year, TJ;

ΔE_{act} – industrial activity indicator, TJ;

ΔE_{str} – structural change indicator, TJ;

ΔE_{int} – 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 before (Eq. 2.3., 2.4. and 2.5.), as well as described below (tab. 2.1.).

2.2.table

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.

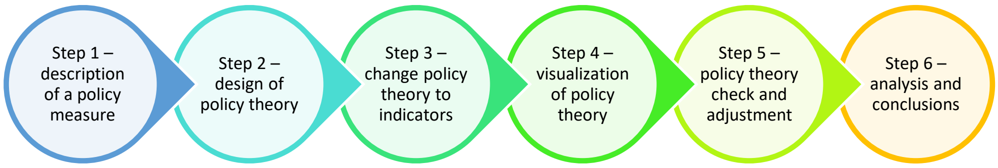
Data utilized in this study was collected from Eurostat and Central Statistical Bureau of Latvia (CSB) databases [104], [105]. To account for possible industry production output data fluctuations due to price changes, all data on sub-sectoral value added were adjusted according to data on producer price changes in industry sector [106]. Therefore, value added data represent chain-linked volumes of base year 2010. Moreover, change index was constructed to compare the obtained adjusted value-added data with volume indices of industrial production [107]. 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 the 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. [108], [109] with the criteria from the Better Regulation Agenda (BRA) guidelines [110]. 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. System dynamics modeling is used to reach the second goal of the study.

Combined Ex-post Evaluation Method

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. Figure below (Fig. 2.3.) illustrates the different steps of this method. 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 draw it up. The theory-based policy evaluation is presented as a flow chart.



2.3. Fig. Theory-based analysis dissertation methodology.

In this study, the policy theory is transformed into indicators for each causal relation by applying "The Better Regulation Agenda" evaluation criteria:

- Effectiveness - determines progress towards achieving the goal. It should be based on evidence on why, whether, and how these changes are related to a policy measure.
- Efficiency - assesses both the costs and the benefits of the measure, as they arise to different stakeholders, by determining what these costs/benefits are and how these factors are related to the policy measure.
- Relevance - assesses how well objectives of the policy measure meet needs and challenges.
- Coherence - determines how well the policy measure works internally and with other policy measures.
- Value-added - consider arguments on the value of a policy measure, which is in addition to the value that could be created by policy measures initiated at regional or national level by both public authorities and the private sector.
- Validity - assesses to what extent the policy measure does or does not satisfy the needs of stakeholders and what is the difference between the satisfaction of the various stakeholders.
- Equality - assesses how fairly are the effects shared between different groups of society.
- Sustainability - assesses the likelihood that the effect of the policy measure continues after the end of the measure.
- Acceptability - assesses to what extent a change in the perception of a policy measure in the target audience and in general in society is reached.

In addition to the criteria mentioned above, institutional capacity was studied, and three indicators reflect it:

- Clear objectives and powers of the policy implementing body.

- Ability to balance and consolidate both flexibility (the ability to adapt to changing conditions and reducing potential failure factors in the implementation process) and continuity (stable and predictable conditions).
- Degree of involvement of stakeholders in the design and implementation of the policy measure.

Data Collection for the Evaluation

The verification of the policy theory was carried out with mixed methods, in which quantitative and qualitative methods are 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.

The quantitative method included data collection from different data sources:

- Regulations No.226 annotation [78] was used to build policy theory.
- Data obtained during interviews with obliged parties.
- Information available on the Ministry of Economics website [111].
- Information available on web pages of obliged parties subjected to this policy measure, e.g. [112].
- Other publicly available information related to this policy measure.

As qualitative research focuses on in-depth exploration, a small but diverse sample is recommended, e.g., [113] suggests that eight long interviews are a sufficient basis for qualitative research. In 2019, 15 companies were eligible as EEOS parties. From the 15 companies, nine had to fulfill EEOS obligations. In total, seven in-depth interviews with EEOS responsible parties were conducted from September to December 2019. Their particular knowledge and understanding were valuable sources of information to gain insight into the nature of problems and give recommendations for solutions. Semi-structured interviews were conducted face-to-face with each participant at a time and place chosen by the interviewee. The interviews focused on extracting specific energy efficiency-related information from stakeholders and understanding the knowledge held by those stakeholders. Interviews lasted on average 95 minutes and were digitally recorded for transcription purposes.

An interview guide with eight questions was used:

1. Let’s start by having you describe what you do here.

2. What happened in your company after the government issued the Law on Energy Efficiency with defined obligations for EEOS parties? Can you walk me through the process?
3. What happened in your company after it became an EEOS obliged party? Can you walk me through the process?
4. Has the process always worked this way? If it has changed, can you tell me about when that happened and how it went?
5. What challenges have you experienced during the process?
6. What role do technology suppliers, energy consultants, and researchers play?
7. Do you see any added value of the EEOS?
8. Would you continue the energy efficiency program in your company if the government withdraws the obligations? Can you elaborate on this? A deductive coding approach with a pre-selected coding pattern was applied.

Pre-selected coding was developed based on the literature review ([68], [75], [114]). Following each interview, the recording was transcribed verbatim, and analysis was conducted. The credibility of the results was increased by both the pilot interviews and the triangulation method.

2.4. Systemdynamic Modelling

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

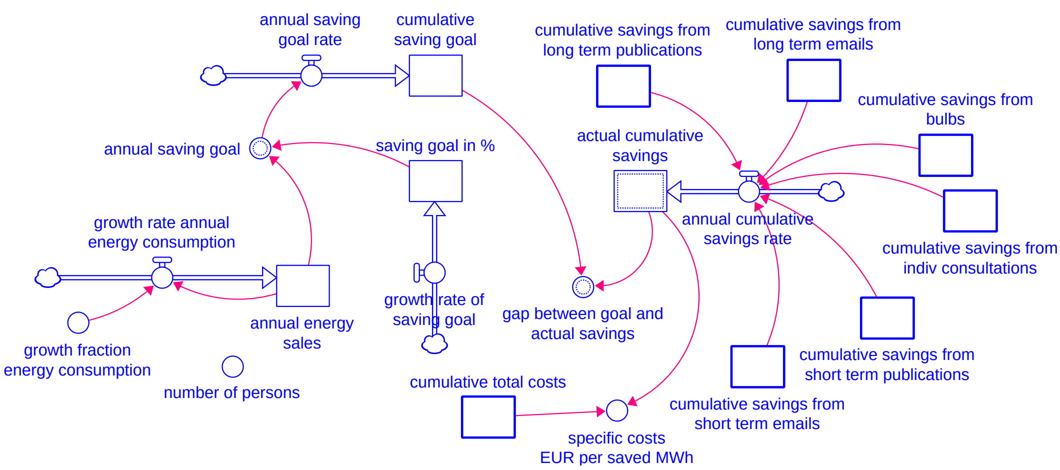
Systemdynamics and the EEOS Model

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 for 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 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.

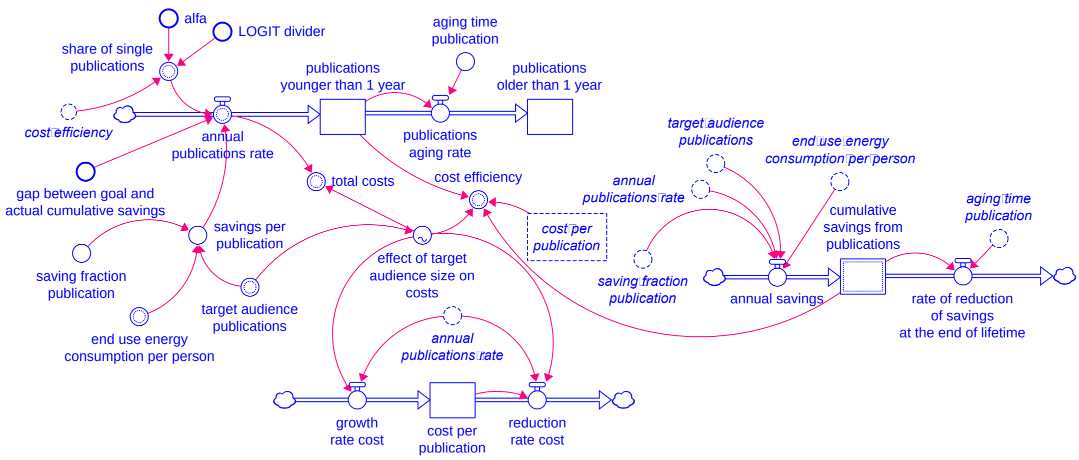
The structure of the model is built as goal-seeking: the model searches for the most cost-effective solution to close the gap between the savings target set by the legislation for EEOS participants and the actual savings generated by the model. The target function for the optimization is defined as the 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, taking into account limitations set for different activities.

Figure below (fig. 2.4.) shows the stock and flow structure of the savings module, which includes the cumulative savings goal that depends on the amount of energy sold and the savings goal set by the government. The actual cumulative savings are accumulating over the years as the sum of savings delivered by individual measures. The model then calculates the gap between cumulative saving goal and actual cumulative savings. The savings goal can be increased or decreased by changing the growth rate. Annual energy sales can also be increased or decreased by adjusting the growth rate fraction.



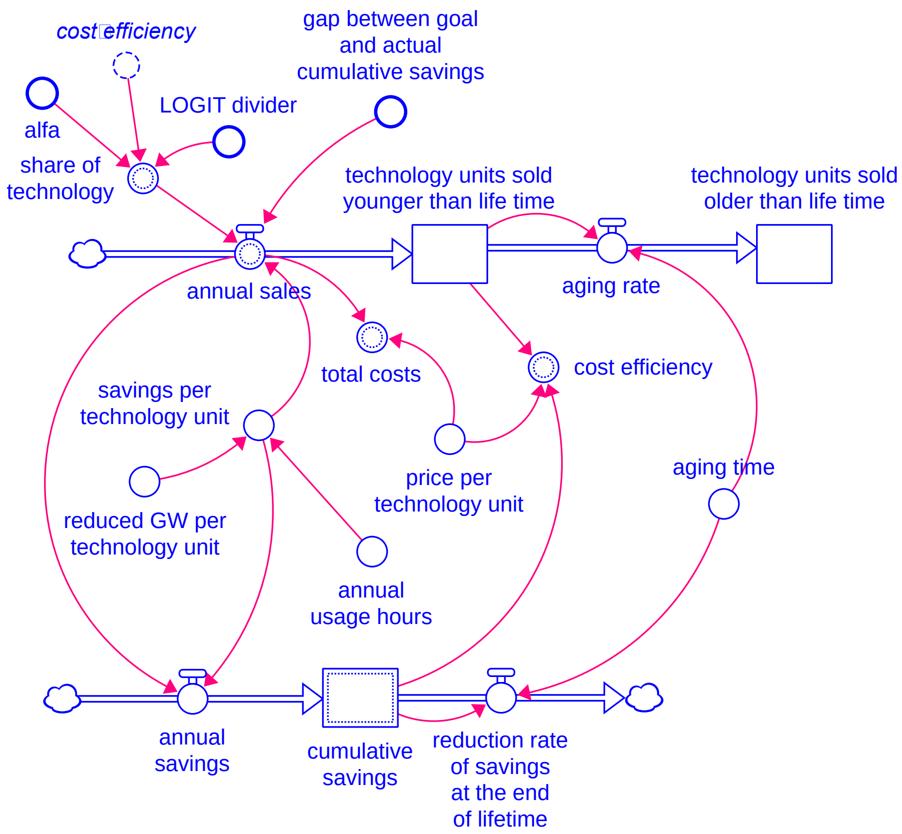
2.4. Fig. Stock and flow structure of the EEOS savings sub-model.

Next figure (fig. 2.5.) shows the stock and flow structure of the one-time publication in the mass media module. It includes the savings of a single publication, costs, the size of the target audience, its impact on costs, the impact of the measure on the savings target. The values of these parameters can be changed during the application of the model. Logit function is used to calculate the share of a particular measure in the overall target. The Alfa value used for the logit function can be adjusted. The same stock and flow structure is used for other types of information activities. For example, both single e-mails, and e-mail campaigns sub-model are supplemented with additional parameters required by the Ministry of Economics that define the opening rate of e-mails.



2.5. Fig. One-time publications in mass media module.

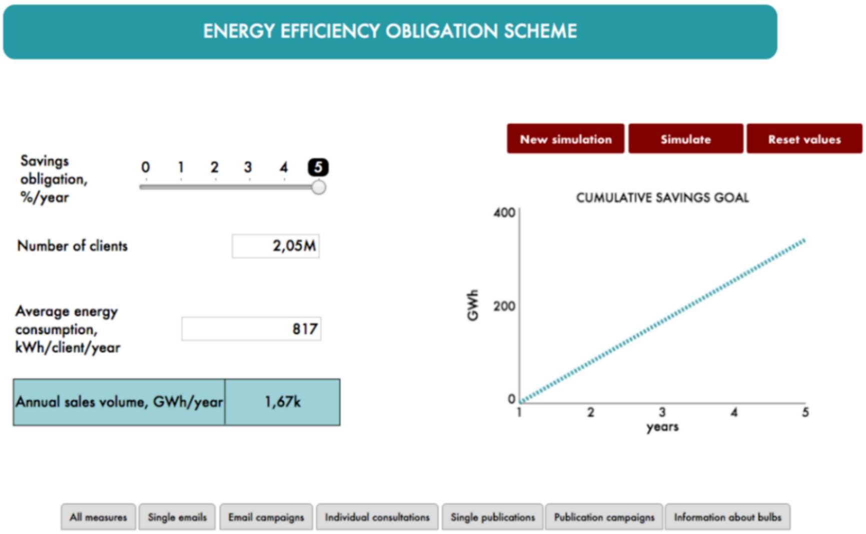
The stock and flow structure of the energy efficiency technological measures sub-module is presented in the following figure (fig. 2.6.). It can be applied to any technology that is replaced by more energy efficient technology, including efficiency, planned savings, costs, a lifetime of measure, share allocated to the measure from the overall target, which is calculated as logit function.



2.6. Fig. Stock and flow structure of energy efficiency technological measures sub-module.

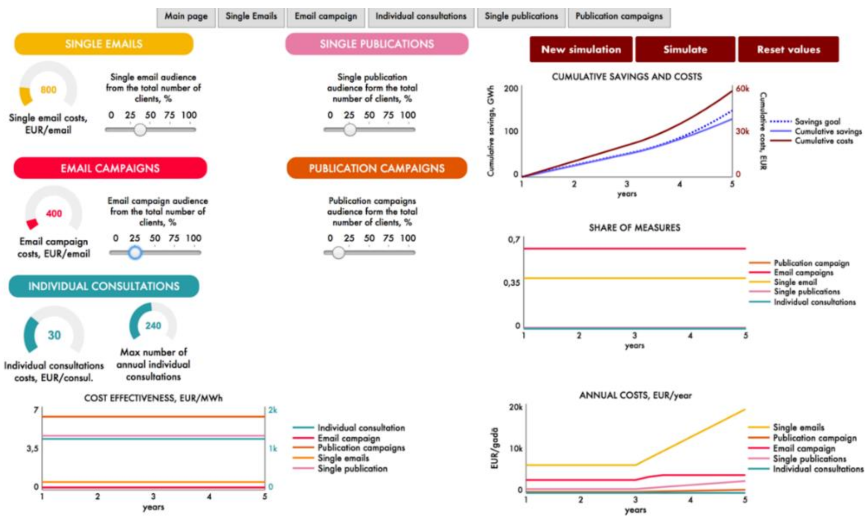
Validation of the model was carried out for both structure and behaviour [115]. Structure validity tests included direct structure tests, structure-oriented behaviour tests. Behaviour tests were carried out after structure tests were finished.

Figure below (fig. 2.7.) illustrates the main page of the free access Internet-based interface tool (https://exchange.iseesystems.com/public/andra/eps/index.html#page1) where users can manually insert input parameters (savings obligation per year, number of clients, average annual energy consumption per client) and calculate annual energy sales volume. The illustration presents a graphical presentation of EEOS obligations.



2.7. Fig. The main page of the free access Internet-based interface tool (for illustrative purposes).

The second page of the interface (fig. 2.8.) is dedicated to all measures defined by the legislation. In the first phase of the EEOS in Latvia, only information activities are applied by EEOS parties. Therefore, the interface can be easily supplemented with energy efficiency technological measures. The user can either manually find the set of measures to reach the savings goal or run the optimization model. Users can change the costs of a single unit and the size of the audience from the total number of clients per measure. The graphs show the dynamics of the impact of choice on cumulative savings, cumulative costs, the share of measures, cost-effectiveness, and annual costs in the live mode. Other pages of the tool provide more internal details of each of the measures.



2.8. Fig. The second page of the interface of all measures defined by legislation (for illustrative purposes).

Systemdynamics and the Evaluation of the Role of Bioeconomy

Particular investigation was carried out by implementing a theoretical experiment, while using system dynamics modelling. As mentioned before, system dynamics as a research discipline allows focusing attention particularly to causalities rather than correlations [116]; hence, explaining complex phenomenon with endogenous factors contributing to the overall behaviour of systems.

On general note, construction of a model combining various biotechonomic forest industry parameters in separate variables (and in the context of macroeconomic development) is possible due to former investigations carried out by Riga Technical University on micro-level biotechonomic forestry segment modelling, namely found in Blumberga et al (2016). While former investigations clearly elaborate on the environmental engineering aspects of this research, the investigation will attempt 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.

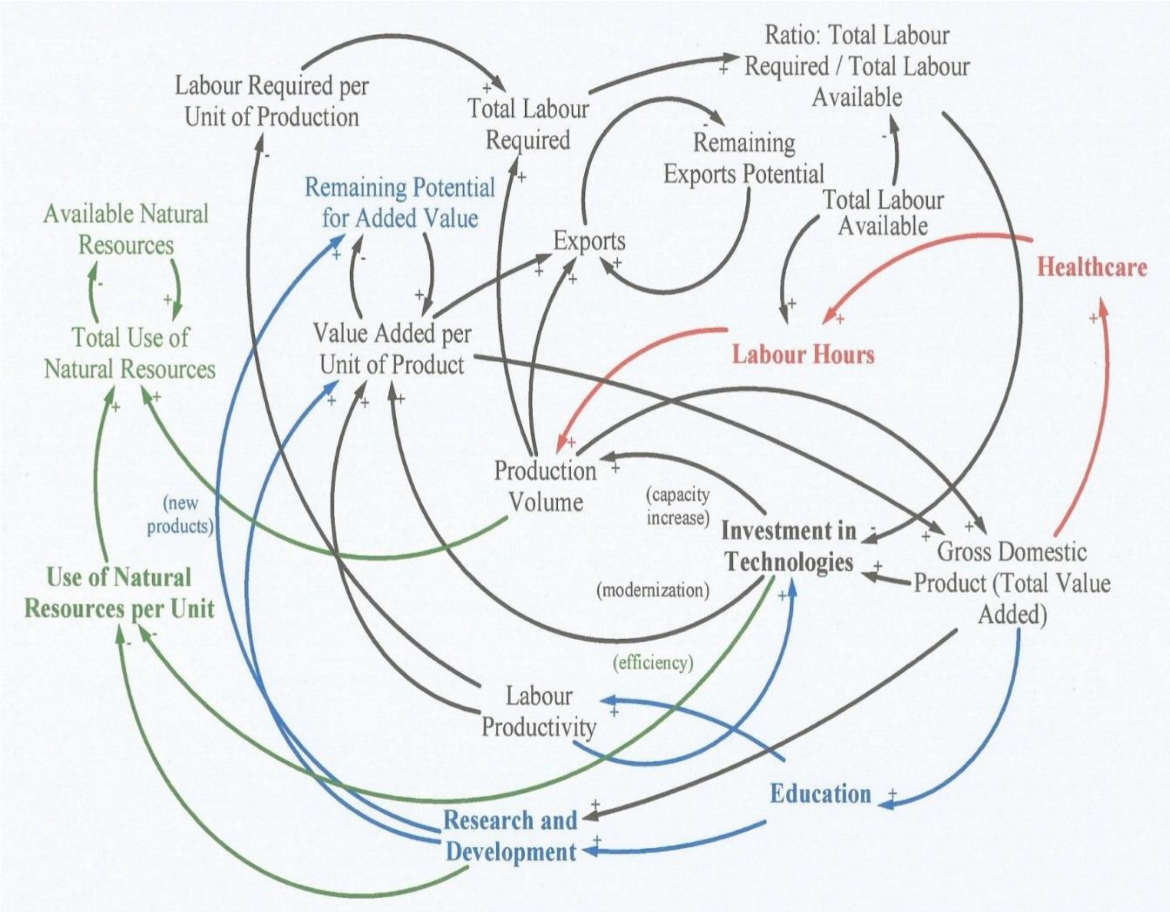
The dynamic problem of the research should be considered overall stumbling Latvian economic growth – 1.5% to 2.5% average – and deriving pressures on various macro-level segments as discussed before. Furthermore, to some extent, slowing down of the national economy has recently been attempted to be balanced out by diversifying export markets (Ministry of Economics, 2016). 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. 2.1). 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 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 widespread, 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.

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

Dynamic Hypothesis and Causal Loop Diagrams

Below, please find conceptual causal loop diagram, explaining the total causalities in the modelled macroeconomic environment and referring to the dynamic problem expresses before.



2.9. Fig. Conceptual causal loop diagram of macroeconomic development and crucial environmental aspects.

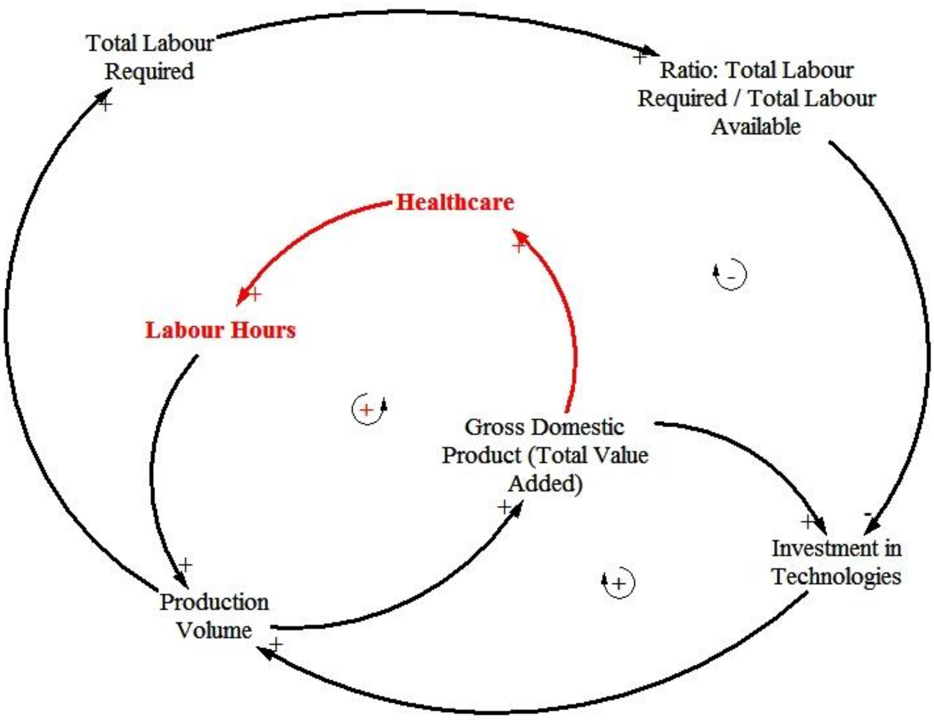
While the conceptual causal loop diagram is a theoretical portrayal of macroeconomic dynamics, it can be also assessed in order to pragmatically evaluate what aspects should be incorporated within the actual mathematical model. What clearly stands out in the conceptual model is that there are five negative loops, limiting the expansion of systems. These are: (I) the limited use of resources related to resource efficiency, (II) the limited use of resources *per se*,

(III) the limited capacity for added value expansion, (IV) the limited capacity for expanding marketing channels and (V) the total availability of labour force.

While, to some extent, most of these limitations are conceptually complex and beyond the scope of this investigation, the aspect of limited use of resources or usage of resources as such stands out as the most crucial limitation aspect to be included in the macroeconomic development model. To similar extent, another crucial limiting concept to be included is population (and deriving labour pool availability), while financial flow will be assumed as self-regulating with substantial annual growth rate (1.5%) is taken as an exogenous factor.

Conceptual causal loop diagram analysis also highlights some potential avenues for further research and two factors should be mentioned separately. Both availability of labour force and availability of financial wealth – investment – are not assessed in greater detail due to limited scope of this research. However, it is clear that labour and investment mobility would also be a dynamic function, which would depend, arguably, on profitability analysis of both traditional and biotechonomic segments on both investor and employee levels. While, indeed, such mechanism could be incorporated within the model, the main aim of this research is to assess the macroeconomic benefits of social and environmental realms brought by forest biotechonomy; hence, this aspect is left for further investigations.

In order to have a greater understanding of the dynamic causalities, most prominent causal loops should be considered separately.

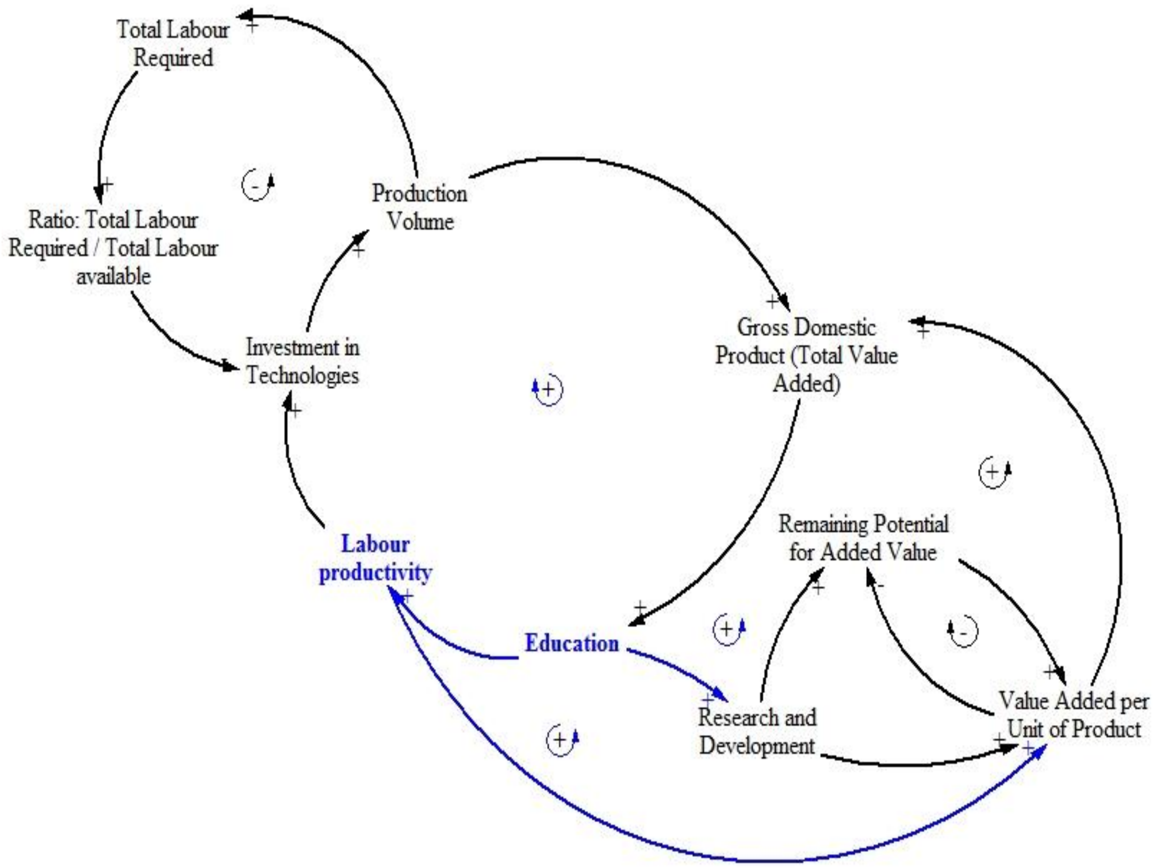


2.10. Fig. Healthcare segment causal loop diagram of the model.

In figure above (fig. 2.10.) the healthcare related causal loop diagram can be observed. In the particular construction of the model, a dynamic improvement factor from proportionally developing healthcare segment was created, based on increasing number of labour hours. Such conceptual tool has been used in reference to the previously mentioned *production function*, whereby it would be possible to mathematically define and translate additional improvements from healthcare to macroeconomic level production.

What is important to understand is the definition of labour hours in this particular context. The particular investigation does not assume absolute increase in working hours, but rather relative to every employee operating in the sector. For example, an increasing factor of *1.5* would not mean that an additional employee is taken into consideration as a part-time production worker in the model equations. Instead, the health-related productivity is increased – meaning that during the same 8 normal working hours the same employee, while experiencing the healthcare improvement factor, can manage a work that before would require 12 normal working hours.

Furthermore, as it can be observed in the figure above, while positive causal loops are developing in respect to GDP and investment cycles, the absolute labour availability is the limiting factor on broader scale, causing a negative causal loop creation in the system. An essential semi-conclusion is the fact that while indeed a theoretical growing importance of health via labour hours is developing, it is relatively difficult to assess the particular intensity of it. Hence, it is clear that even in traditional economy such improvement factor phenomenon may be observed, but the extent, in turn, is dependent on the monetary and financial value generated endogenously by the system. To continue with, an education improvement factor (via labour productivity) causal loop diagram (fig. 2.11.) must be assessed.



2.11. Fig. Education segment causal loop diagram of the model.

It has to be stated that three prominent positive loops can be observed; hence, leading to the improvement of total manufacturing output via education segment improvement. First, education improvements resulting in increased labour productivity theoretically foster economic growth via technological investment and related production output increase.

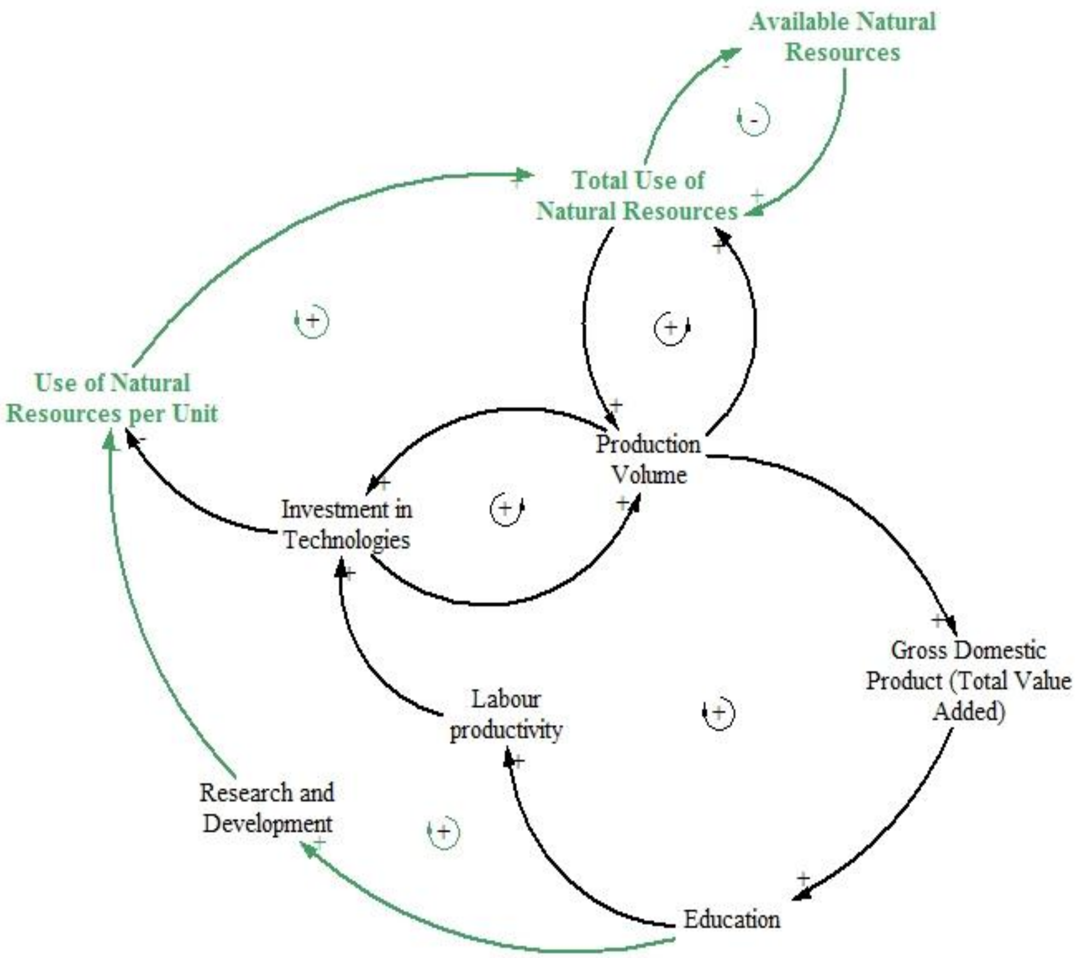
Second, education via research and development can contribute to the overall standard of academia thereby increasing the overall limits of remaining potential for added value generation, which, in turn, can lead to particular added-value improvements on macroeconomic scale.

Third, education segment improvement resulting in increased labour productivity and increase of the skillsets of labour pool can lead to introduction of new products in particular manufacturing processes precisely due to the new professional skills obtained by the workers. Furthermore, if we consider forest biotechonomy segment as such, the role of relatively more academically educated work force – i.e., engineers – is even more prominent than on general macroeconomic scale.

As it can be observed in the figure above, there are also two prominent negative causal loops limiting the overall theoretical development of the system. First, is the labour availability variable (similarly to health segment). Nevertheless, it is to some extent a general argument meaning that available population as such is limiting the particular economic growth. In turn, such aspects would be also relevant to R&D related limit increasing, while academia being explained as potentially diminishing variable resource related to general population decline.

Second, the negative causal loop of R&D limiting ceiling is the other balancing out negative loop. Even though theoretically it can be assessed that additional educational improvements can lead to positive-sum type of overall potential increase in research and development, in absolute terms even such development has limits either again in population terms or available educational infrastructure.

Again, similarly to the health segment improvement factor, it is possible to conclude that this theoretical speculation could be applicable to any macroeconomic development modelling, and plainly forest biotechonomy could be a convenient case study for exploration of such dynamics.



2.12. Fig. Environmental segment causal loop diagram of the model.

In reference to the environmental segment of the model (fig. 2.12.), it is vital to initially point out that any economic activity based in processing of any natural resources by definition cannot lead to positive causal development; hence, the upper-right causality between total use of resources and overall availability should be considered central.

Nevertheless, it can be argued that further investments and economic development trends, notably via education and research and development, as well as via labour productivity can significantly expand the capacity for biological resource processing without leaving significant impact on environment and climate. While the latter trend explains the innovation of products via developing labour force skill sets resulting in less resource intensive product manufacturing capacity, the former trend (via R&D) would lead to entirely new approaches to manufacturing as such – i.e. forest biotechonomy – where traditional extent of natural resource exploitation would be conceptually changed.

Furthermore, even though there are two particular negative loops linking R&D and investment in technologies with per capita consumption of natural resources, these do not indicate that to some extent amount of natural resources could be increased. Rather that the velocity of resource consumption is causing innovation to slow down or vice versa. In any case, understanding the forestry industry today as such, it is possible to argue that some type of causal links should be incorporated in order to reflect the possibility to replant or simply expand the existing capacity of biological products. Nevertheless, this research does not tackle this issue as it to some extent is outside the scope of investigation, as well as this scenario would arguably have a continuous lasting impact on climate and environment.

Dynamic Hypothesis

Bearing in mind the fact that investigation focused on two main realms: (I) the role of forest biotechonomy in fostering macroeconomic development via education and healthcare economy improving factors and (II) the role of forest biotechonomy in limiting resource intensity throughout development of national economic development, the hypothesis put forward was twofold.

With the inclusion of biotechonomic forest industry in the macroeconomic development framework of the national economy of Latvia via forest biotechonomy improvement factors (BIFs) in education and healthcare, annual budget revenues for both segments will be significantly[1] increased and the annual contributions of forest biotechonomy industry to the

[1] For forest biotechonomy's contribution, a benchmark for a *significant* level contribution 50 million Euros and a *notable* level 10 million Euros were used and chosen based on the regulation No. 800/2008, Appendix No. 1.

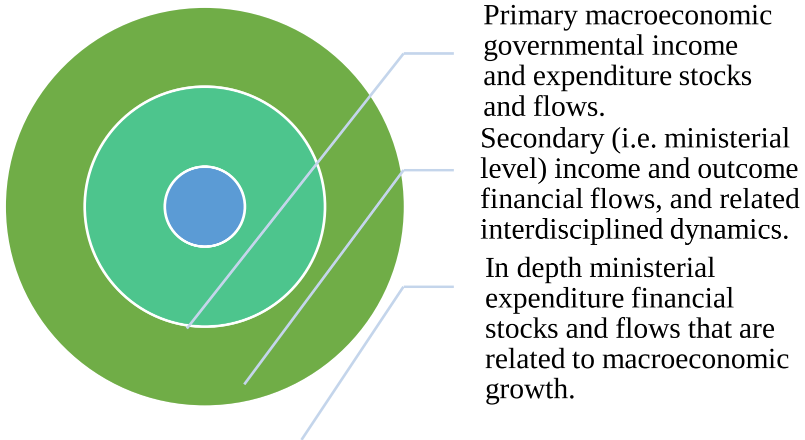
national economy of Latvia will be significantly reinforced via increase in manufacturing output, generated by additional impact of education and healthcare variables.

With the inclusion of biotechonomic forest industry in the macroeconomic development framework of the national economy of Latvia via forest biotechonomy improvement factors (BIFs) in education and healthcare, the electricity consumption intensity per 1 Euro generated in sales turnover (EBITDA) is at least 50% lower than in traditional processing industry of the national economy of Latvia.

Model formulation and simulation

Throughout this research general system and related boundaries should be considered the annual governmental budget allocation mechanism of Latvia. Below (fig.2.13.) find a graphic visualisation of the scope of the system dynamics model, where primary and secondary macroeconomic budget flow should be considered as a central scope of this investigation, in order to trace the dynamics of governmental fund flow.

In addition, particular budgetary programmes of ministries, namely related to healthcare and education in relation to manufacturing, will be incorporated in the model that could affect the macroeconomic development of the national economy. *All* other expenditure positions of the annual budget shall be summarized and incorporated in order to allow the model to function properly.



2.13. Fig. Graphic visualisation of the scope of the investigation.

Furthermore, the basic structure was built on two equally essential sections of revenues and expenditure, following the biotechonomy improvement factors (BIFs) for both education and healthcare.

The most crucial flows include budget revenues (both for special and basic budget of the national economy of Latvia), as well as expenditure flows related to education and healthcare segments that may influence production output as discussed previously. In this context, the most central stock is the annual governmental total budget (with incorporated 1% deficit of GDP), followed by sub-budget stocks of both expenditure and revenue structure.

The coloured stocks and flows relevant values are introduced in the particular model in order to assess the particular role of forest biotechonomy when excluding biotechonomy improvement factors – BIF(e) – from the feedback loop mechanisms.

To continue with, some of the most crucial stocks of the model include various annual budgets of macroeconomic annual budget revenues. For example, annual profit tax budget revenues (flow, leading to a stock) can be explored as the following equation (eq. 2.6.) below.

$$R_{tax} = R_{CIT} + R_{PIT} + R_{Sol} \qquad (2.6.)$$

where

R_{TAX} – total annual profit tax revenues, EUR/year;

R_{CIT} – total annual corporate income tax revenues, EUR/year;

R_{PIT} – total annual personal income tax revenues, EUR/year;

R_{Sol} – total annual solidarity tax revenues, EUR/year.

In addition, once the role of biotechonomy should be assessed for particular variable, previously modelled factor of various biotechonomy income tax values was introduced in the equation (eq. 2.7.).

$$R_{tax} = R_{CIT} + R_{PIT} + R_{Sol} + B_{CIT} + B_{PIT} \qquad (2.7.)$$

where

R_{TAX} – total annual profit tax revenues, EUR/year;

R_{CIT} – total annual corporate income tax revenues, EUR/year;

R_{PIT} – total annual personal income tax revenues, EUR/year;

R_{Sol} – total annual solidarity tax revenues, EUR/year;

B_{CIT} – total annual biotechonomy segment corporate income tax revenues, EUR/year;

B_{PIT} – total annual biotechonomy segment personal income tax revenues, EUR/year.

While the example equation was chosen rather simplistic to conceptually reflect the construction of macroeconomic budget layers, other stocks and flows included also general accounting and tax principles, in order to reflect the fiscal policy and environment of the national economy [117].

As mentioned before, some of the factors controlling particular extent of variable values, for example, in reference to share of sub-budget realm in context of total sub-budget of a segment (i.e. education), were analytically deducted after exploring the national planning documents [117]. Nevertheless, revenues of particular variables from special or basic budget were also linearly modelled in order to reflect a scheduled growth average of 1.5% per year and were reflected as graphical functions in the system dynamics model.

Some other analytical and model construction principles required fewer ordinary measures. When considering the central part of the investigation – biotechonomy improvement factors (BIFs) – a following formula was developed (eq. 2.8.).

$$BIF_{edu} = \frac{BIF_n}{BIF_0} \tag{2.8}$$

where

BIF_{edu} – biotechonomy education improvement factor;

BIF_n – biotechonomy education improvement factor value at the year of modelling;

BIF_0 – biotechonomy education improvement factor value at the initial year of modelling.

The main idea behind the improvement factor modelling was for its value to dynamically reflect the improvements of total macroeconomic development model and to translate them to particular improvement factor of a segment of economy (i.e., education). By exploiting the initial function of the system dynamic modelling, it was possible to dynamically compare the improvements and to incorporate the results in the model dynamically.

Furthermore, it was noted that improvement factor would generate additional positive effect even without the inclusion of forest biotechonomic segment in the model; therefore, a comparison throughout the research was made, evaluating the improvement impact both with and without biotechonomy inclusion – BIF (i) standing for inclusive forest biotechonomy improvement factor and BIF (e) improvement factor excluding the additional improvement of forest biotechonomy industry.

Last, but not least, modelled values of BIFs were qualitatively validated depending on the formerly explored education and healthcare improvement factors in the academic debate (explored in previous sections). Once approximate range of values was confirmed, the investigation was carried out accordingly. Below please find the table with related dynamic modelling scenarios.

2.3. table

Modelling scenarios' goals and descriptions regarding bioeconomy

Modelling scenario	Modelling scenario description	Modelling scenario goal and related considerations
Traditional economic development	Construction of macroeconomic development model of the national economy of Latvia (with 1.5% growth) and related system dynamic modelling.	The goal of the modelling scenario is to set a base-line to which both remaining forest biotechonomy scenarios and related macroeconomic inputs will be evaluated.
BIF(e)	Construction of macroeconomic development model of the national economy of Latvia and incorporation, and modelling of dynamic in time benefits that annually would be brought by the inclusion of forest biotechonomy industry in the national macroeconomic framework.	The goal of the modelling scenario is to evaluate the macroeconomic role of forest biotechonomy industry and its inputs in total annual governmental budget revenues. Nine clusters of forest biotechonomy products evaluated.
BIF(i)	Construction of macroeconomic development model of the national economy of Latvia and incorporation of forest biotechonomy industry in the national economy of Latvia. Furthermore, construction and modelling of so called biotechonomy improvement factors (BIFs) in education and healthcare in order to foster the manufacturing of forest biotechonomic products.	The goal of the modelling scenario is not only to evaluate the role of forest biotechonomy and related benefits in reference to national economy of Latvia, but also to assess the role of BIFs in forest biotechonomy production industry and related additional marginal benefits.

In turn, biotechonomy improvement factor was incorporated and used to model both the significant stocks and flows. An example of stock mathematical calculations should be observed next. Below please feel free to explore the equation (eq. 2.9.) for total accumulated tax income from forest biotechonomy segments per year.

$$TATI_{BIF(i)} = \int_{t=0}^{t=1} \left[VAT_{BIF(i)}(t) + CIT_{BIF(i)}(t) + PIT_{BIF(i)}(t) + ESC_{BIF(i)}(t) + WSC_{BIF(i)}(t)\right] \times dt + TATI_{BIF(i)0} \quad (2.9.)$$

where

$TATI_{BIF(i)}$ – the total annual accumulated forest biotechonomy tax income, in the modelling scenario BIF(i), EUR/year;

$VAT_{BIF(i)}$ – VAT annual forest biotechonomy income, in the modelling scenario BIF(i), EUR/year;

$CIT_{BIF(i)}$ – CIT annual forest biotechonomy income, in the modelling scenario BIF(i), EUR/year;

$PIT_{BIF(i)}$ – personal income tax annual forest biotechonomy income, in the modelling scenario BIF(i), EUR/year;

$ESC_{BIF(i)}$ – employers' annual social contributions from forest biotechonomy, in the modelling scenario BIF(i), EUR/year;

$WSC_{BIF(i)}$ – employees' annual social contributions from forest biotechonomy, in the modelling scenario BIF(i), EUR/year;

$TATI_{BIF(i)0}$ – the initial annual forest biotechonomy tax income, in the modelling scenario BIF(i), EUR/year.

As another example, an equation (eq. 2.10.) for exploring the electricity intensity per Euro generated in sales turnover should be observed, in reference to the energy intensity evaluation throughout the investigation.

$$Intensity_{bio}^{el} = \frac{\sum electricity\ consumption\ biotechonomy}{\sum EBITDA_{bio}} \tag{2.10.}$$

where

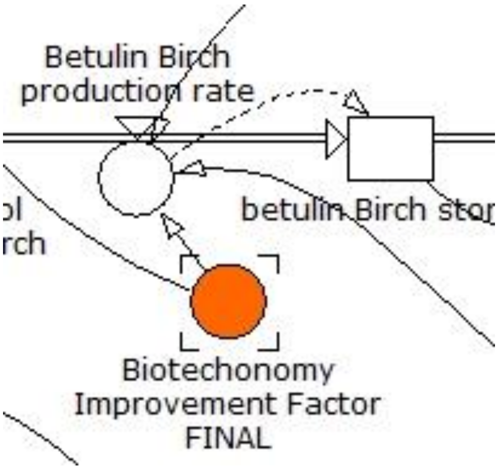
$Intensity^{el}_{bio}$ – electricity intensity per 1 Euro generated in forest biotechonomy, kWh/EUR;

Electricity consumption biotechonomy – total electricity consumption of forest biotechonomy manufacturing segments per year, kWh/year;

$EBITDA_{bio}$ – total annual revenues before taxes of forest biotechonomy segment, EUR/year.

While exploring particular equation, it is vital to point out that while the novelty of such comparison on its own would be relatively marginal, i.e., plainly evaluating the additional devotion of forest biotechonomy to the decarbonisation of the national economy, it becomes more essential once modelled in system dynamics; therefore allowing to explore this value and compare it to traditional processing industry over time.

Once the general macroeconomic structure is briefly observed, in addition to already existing industries and services that lead to generate income flow of the Latvian governmental budget today, BIFs values were incorporated within the formerly developed model [84]. The linkages (fig.2.14.) between additional biotechonomic manufacturing capacities and Latvian industries and services as known today, arguably, form the core part of this research.



2.14. Fig. A capture of stock-and-flow diagram of incorporation of biotechonomy improvement factor in the forestry biotechonomy manufacturing segment – birch betulin production.

For example, the *betulin birch production rate* annual improvement via biotechonomy improvement factor – BIF(i) can be mathematically explored in the following equation (eq. 2.11).

$$PR_{BB} = IF(CO_{BB} < PPR_{BB}), CO_{BB}, PPR_{BB} \times BIF(i) \quad (2.11.)$$

where

PR_{BB} – betulin birch production rate, tons/year;

IF – mathematical conditional function;

CO_{BB} – betulin birch production capacity in operation, tons/year;

PPR_{BB} – betulin potential production rate, tons/year;

BIF(i) – biotechonomy improvement factor.

In turn, the accumulated stock of produced amount of birch betulin can be explored with the following equation (2.12.).

$$P_{BB} = \int_{t=0}^{t=1} PR_{BB}(t) \times dt + PS_{BB\,0} \quad (2.12)$$

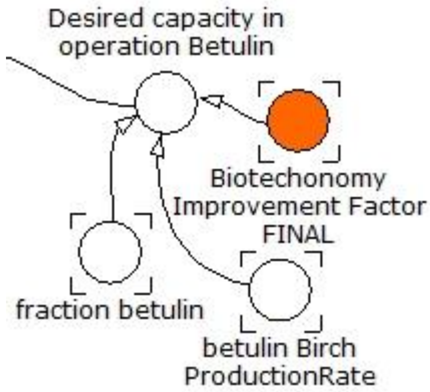
where

P_{BB} – produced stock of birch betulin, tons;

PR_{BB} – betulin birch production rate, tons/year;

$PS_{BB\,0}$ – initial betulin birch production stock, tons.

While in the above-mentioned calculations and modelling principles the impact of education biotechonomic improvement was explored, in reference to labour productivity, below (fig.2.15.) the impact of healthcare biotechonomic improvement via relative working hours will be observed next.



2.15. Fig. A capture of stock-and-flow diagram of incorporation of biotechonomy improvement factor in the forestry biotechonomy manufacturing segment – desired capacity in operation for birch betulin manufacturing.

Desired capacity in operation for birch betulin can be expressed with the following equation (eq. 2.13).

$$DC_{BB} = PR_{BB} \times MF_{BB} \times BIF(i) \tag{2.13.}$$

where

DC_{BB} – desired capacity in operation for birch betulin, tons/year;

PR_{BB} – betulin birch production rate, tons/year;

MF_{BB} – modelling factor for betulin birch;

$BIF(i)$ – forest biotechonomy improvement factor.

In contrast to evaluation of education biotechonomic improvement discussed earlier, the healthcare improvement factor and the modelled DC_{BB} values are not directly linked with any stock. In turn, via several notable variable inclusion and related calculations – *desired order rate for birch betulin manufacturing*, *desired manufacturing capacity under construction*, *capacity order rate* and *commissioning order rate of birch betulin manufacturing* – it is possible to arrive at the defining flow (*initially installed manufacturing capacity fraction* for birch betulin) and stock for the healthcare benefit transmission – betulin birch production capacity in operation explore the following equation (eq. 2.14.).

$$CO_{BB} = \int_{t=0}^{t=1} IICF_{BB}(t) \times PPR_{BB}(t) \times dt + CR_{BB} \tag{2.14.}$$

where

CO_{BB} – betulin birch production capacity in operation, tons;

$IICF_{BB}$ – initially installed manufacturing factor for birch betulin;

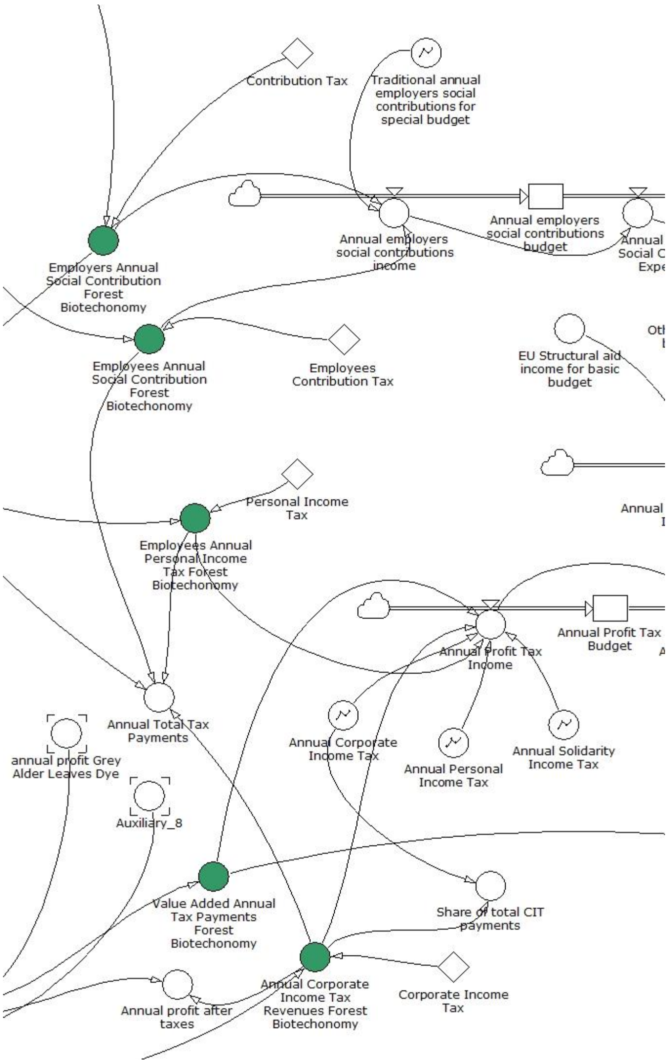
PPR_{BB} – betulin potential production rate, tons/year;

CR_{BB} – commissioning rate for birch betulin manufacturing; tons/year/year.

Again, as it can be observed in figures above, particular BIFs were introduced in already formerly developed micro forest biotechonomy structure developed by Blumberga et al (2016). By introduction of such variable as a multiplier it is possible to assess the role of both BIF(i) and BIF(e) over time, once forest biotechonomy industry becomes fully operational.

Particular modelling locations of the former model where chosen for the introduction of the BIFs by both closely consulting with the authors of the former model, as well as depending on independent assessment of the model. Main aspects in favour of inclusion in these variable were (I) the fact that both *desired capacity rate* and *production rate* variables were previously constructed in order to dynamically incorporate required resources (natural, energy, human capital, etc.) in order to produce the most precise final data; (II) while the latter could reflect on labour skill-set improvement and deriving technological investment (according to dynamic causal-loop diagram), the former could reflect on relative *labour hour* increase via *desired capacity* volumes; (III) as there are two BIFs – related to education and healthcare – it was vital so that the inclusion variables would not be directly linked in single output equation, in order not to double the impact of BIFs and exercise mathematical errors.

In turn, the total output of model with incorporated BIFs was tested throughout the general macroeconomic structure, solely developed in this research.



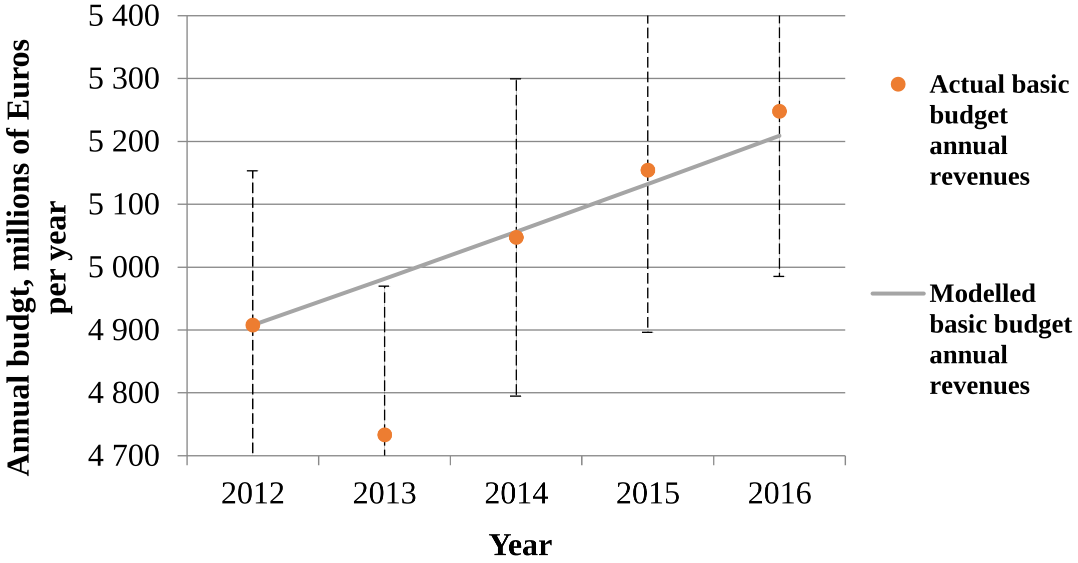
2.16. Fig. A capture of stock-and-flow diagram of incorporation of forest biotechonomy variables in the macroeconomic structure of the national development model of Latvia.

Via structure as represented above (fig.2.16.), the overall added wealth to the annual budget was deducted; hence, in the outflow block incorporating proportional expenditure levels based on former governmental spending, it was possible to assess the role of biotechonomic forestry sector in various other macroeconomic fields. In turn, dynamic hypothesis was formed, based on the assumptions of how the macroeconomic model would react either with or without biotechonomic segment added.

Model validation

Model validation was carried out with the biotechonomic structure excluded from the equation because of two prominent issues: (I) in order for the validation of the macroeconomic model so it would be compatible with former macroeconomic data (with no forest biotechonomy industry) and (II) the biotechonomic model formerly developed has been already validated beforehand [84].

Even though compatible macroeconomic data for the Latvian economy are available starting from year 2004 [117], for the purposes of particular research, annual data for five years, starting from 2012 – 2016 were used. The main reason for this was the global financial recession that arguably had extraordinary impacts on domestic budget cuts and on the budget structure as such.



2.17. Fig. Actual and modelled basic budget annual revenues 2012 – 2016 (for model validation purposes).

As it can be observed in figure above (fig. 2.17.), the modelled and actual data regarding the chosen variable match relatively well and can be considered within the range of 5% error margin. Nevertheless, it is vital to point out that future data prognosis should be dependent on the overall capability of the national economy of Latvia to incorporate conceptual reforms in education, labour, and healthcare sectors, as without those the future growth tendencies could remain in the above illustrated development range.

However, as discussed later in the results section, potential increase of growth figures would arguably result in increasing tendencies for both BIFs and potential positive impact of biotechonomy forest sector in future. Therefore, the data processed and related considerations if not accurate in future, should at least highlight the baseline for minimum positive impact or factorial impact that forest biotechonomy introduction could bring to the national economy development model of Latvia.

3. RESULTS

3.1. Evaluation of the GHG Emission Indicator and Comparison

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 below (tab. 3.1.).

3.1.table

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

Results of the TOPSIS analysis indicate that the best GHG performance is convincingly reached by Sweden, which achieved a coefficient of 0.64 (tab 3.2.). Sweden was expected to rank first, as it has showed high performance in other studies evaluating sustainability and environmental performance (e.g. [52] 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 for this indicator might be explained by the size of its population and industry or other factors related to consumption of resources.

3.2.table

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**

Despite the highest GHG emissions per capita, Ireland takes the second-best place in GHG performance evaluation (tab. 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.

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 with significantly high importance. Still, Lithuania performs the worst for the share of income from environmental taxes and renewable energy consumption, which could be responsible for its low overall GHG performance.

3.2. The role of various sub-sectors of the economy in shaping the energy efficiency debate of the Green Deal

In order 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 have 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 [118]. Manufacturing industry was one of the fastest growing sectors in Latvia over the past ten years, according to CSB data on volume indices of industrial production [107]. Growing demand in the largest export markets stimulated a rapid increase in manufacturing production volumes [119]. 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, beverages and tobacco manufacturing (3271 TJ) consumed large majority or 89% of the overall manufacturing industry energy end-use [105].

The results of decomposition analysis are summarized for long-term (tab. 3.3) and short-term (tab. 3.4.) 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.

3.3.table

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

Long-term decomposition in TJ, 2010-2019

Manufacturing sub-sector	Δ Activity effect	Δ Structure effect	Δ Energy intensity effect	Δ Energy consumption
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**

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 over 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 [120].

Long-term structural effect was driven by two main factors. First, the bankruptcy and market exit of the largest metal manufacturer in Latvia [121] 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 are used in thermal processes that is a CO_2 neutral fuel.

Sub-sectoral differences in energy intensity changes are illustrated in figure below (fig. 3.1.). All sectors, except for wood processing and metal manufacturing sectors indicated energy intensity decrease in first and second half of the decade. Energy intensity reduction in wood processing sector was observed only in the second half of the decade when larger efforts were made to improve energy efficiency in the sector.

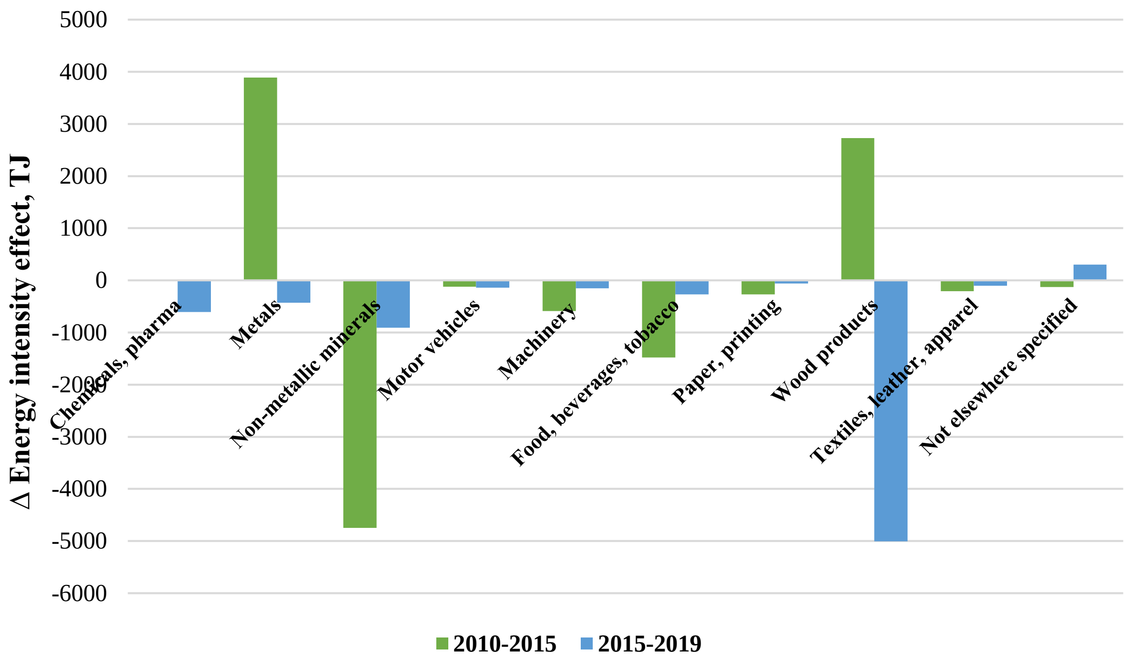


Fig. 3.1. Energy intensity effect in the manufacturing industry subsectors.

In total, in time period from 2015 to 2019 larger decrease in energy intensity in manufacturing industry was observed compared with the first half of the decade. Part of the explanation in energy efficiency activity in past five years can be explained by autonomous developments in the companies where in order to increase company competitiveness there is a constant need to look for ways to decrease energy costs. However, other part of the explanation lies in the effect from policies that might have stimulated larger energy savings and achievement of more ambitious energy efficiency targets [122].

3.4.table

Shot-term decomposition in TJ, 2015-2019

Manufacturing sub-sector	∆ Activity effect	∆ Structure effect	∆ Energy intensity effect	∆ Energy consumption
Chemicals, pharmaceuticals	290	228	-607	-89
Metals	38	-164	-431	-557
Non-metallic minerals	1727	346	-908	1166
Motor vehicles, transportation	84	35	-142	-24
Machinery	199	-53	-156	-9
Food, beverages, tobacco	935	-601	-268	66
Paper, printing	61	13	-62	13
Wood products	5529	1093	-5007	1614

Shot-term decomposition in TJ, 2015-2019

Manufacturing sub-sector	Δ Activity effect	Δ Structure effect	Δ Energy intensity effect	Δ Energy consumption
Textiles, leather, apparel	91	-14	-101	-24
Not elsewhere specified	321	131	302	753
Total	**9275**	**1015**	**-7379**	**2911**

In 2016, when Energy efficiency Law entered into force a number of conditions were imposed on manufacturing companies [123]. 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 [124]. According to estimated results from the national energy efficiency monitoring system and energy audit program in Latvia [125], [126] manufacturing industry companies have reported achieved and planned energy savings from different energy efficiency measures such as lighting replacement, improvements in energy management, heating system, ventilation, renovation of buildings and investments in equipment. However, a study by [126] concludes that initial achieved energy savings from Latvian manufacturing industry within the framework of the program were modest. It was estimated that untapped energy 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.

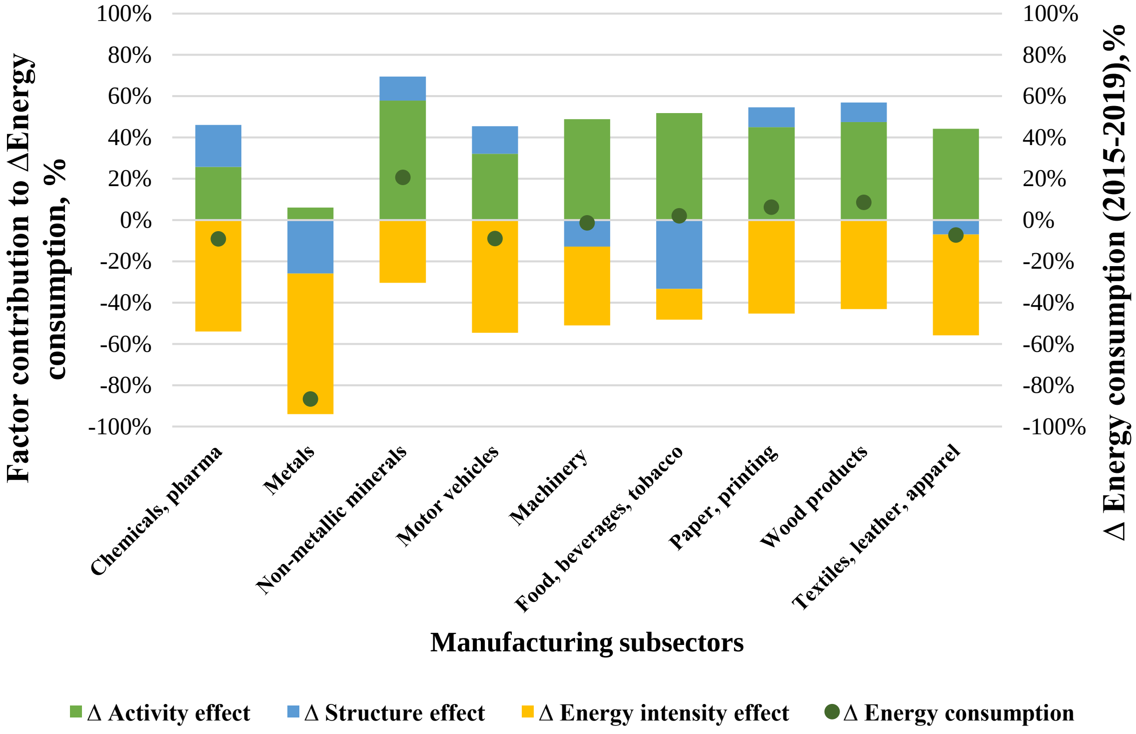


Fig. 3.2. Energy consumption decomposition for period from 2015 to 2019.

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 above (fig. 3.2.) 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.

Year-to-year changes were examined in more detail for all the manufacturing industry sub-sectors. This paper presents decomposition analysis for annual changes in energy consumption for three largest Latvian manufacturing industry sub-sectors – wood (fig. 3.3.), non-metallic mineral (fig.3.4.), and food processing (fig. 3.5.) sectors.

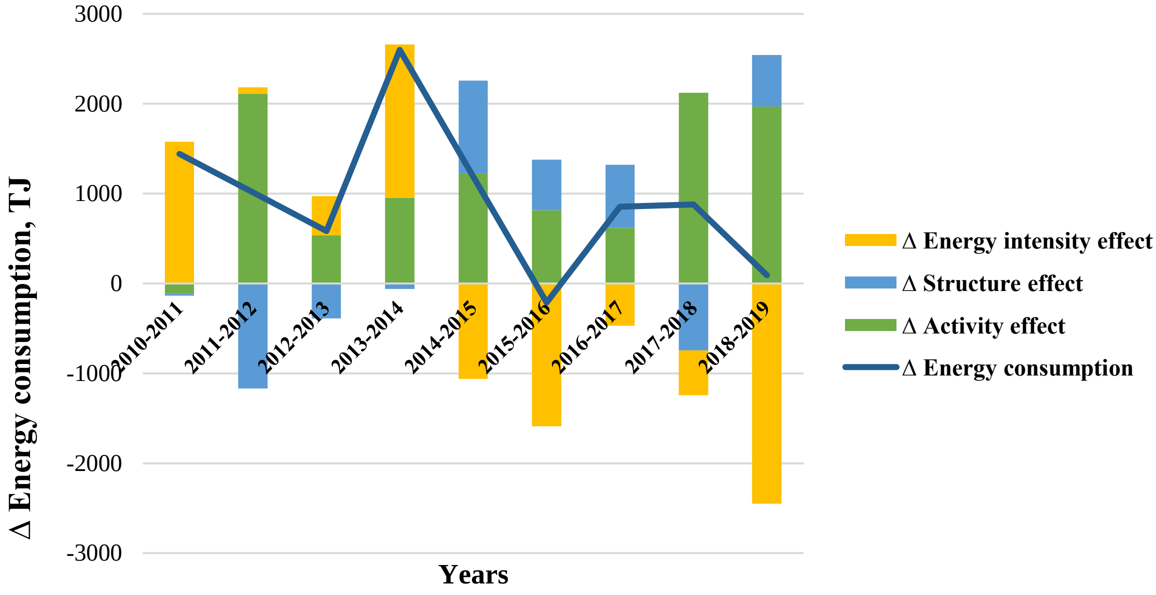


Fig. 3.3. Energy consumption decomposition for wood processing sector (C16).

Industrial production activity effect was the most pronounced in wood processing industry that was also the main determinant of energy consumption increase in the sector. Wood products manufacturing stands out apart from other sub-sectors with the highest growth in production volumes and turnover that was influenced by rapidly growing demand for wood pellets and chips in global export markets. From annual changes it can be observed that in the period from 2010 to 2014 wood processing energy intensity had upward trend, signaling for negative energy efficiency trend. However, since 2014 sector has put larger efforts towards increasing its production efficiency, as a result sector managed to decrease energy intensity on yearly basis.

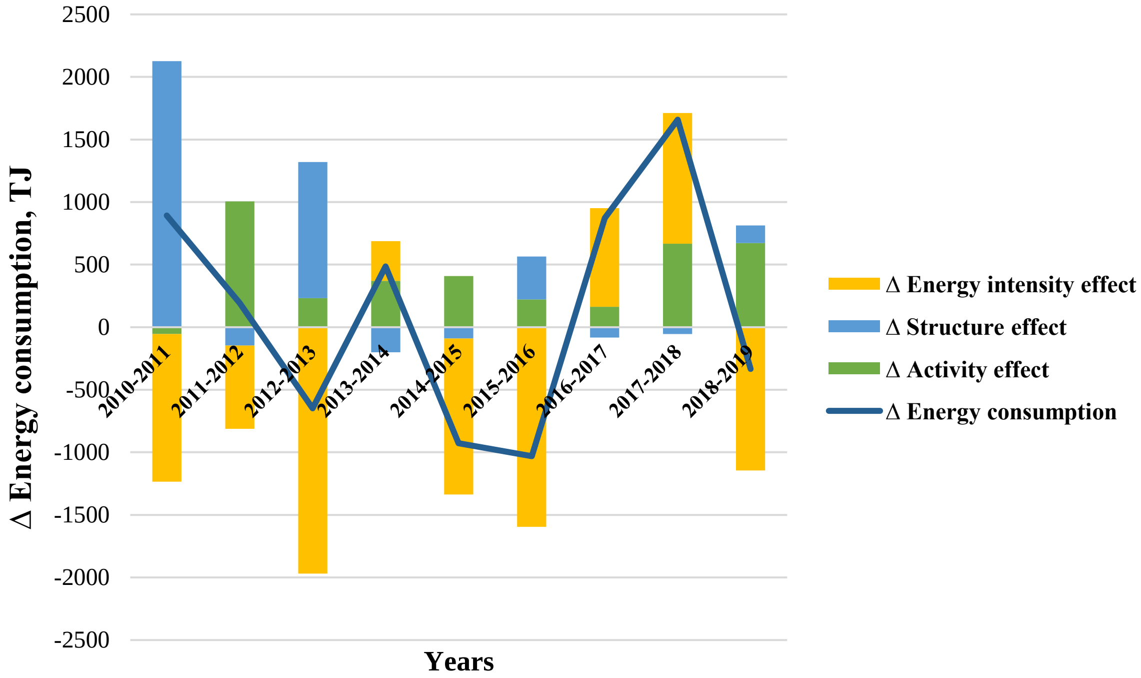


Fig. 3.4. Energy consumption decomposition for non-metallic mineral production sector (C23).

Non-metallic mineral production and food processing sector shows different trend compared with observations in wood products manufacturing sector. For both sectors greater energy efficiency improvements were achieved in the first half of the decade. Rise in energy intensity in period from 2016 to 2018 in non-metallic mineral production sector could be partly explained by increase in specific energy costs (energy costs per generated turnover) and increased share of energy costs in overall production costs in the largest glass manufacturing company in the sector [127], [128].

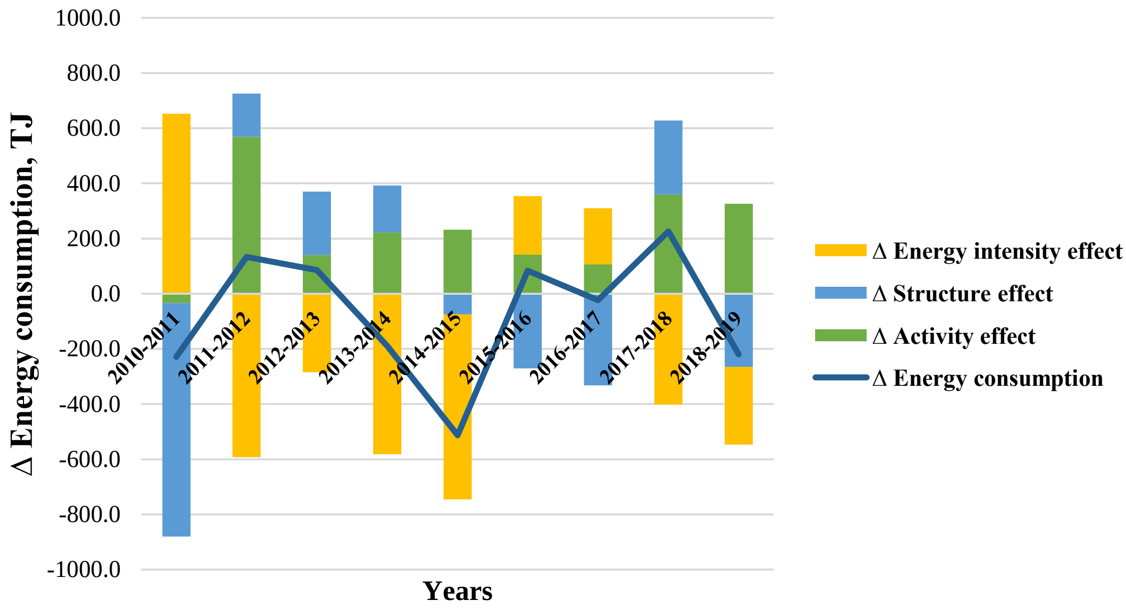


Fig. 3.5. Energy consumption decomposition for food processing sector (C10-C12).

Food processing sector was the only one from these three sectors that managed to decrease its overall energy consumption despite the growth in overall industrial production output. Historically food processing sector had much larger EU fund investment financing opportunities compared with other sectors [129], [130]. Over the period of past ten years numerous food processing companies have made large investments in factory modernization activities and purchase of innovative processing equipment lines. Financial support from EU funding programs played a significant role in the overall increase in manufacturing and operational efficiency in food processing sector. the results are in line with the findings from a study by [131] that performed sustainability analysis of different Latvian manufacturing industry sub-sectors and found out that food processing sector stood out with greater sustainability performance ratios compared with other sub-sectors.

3.3. Evaluation of Latvian Energy-efficiency Policy and Factors for its Successful

Theory-based Analysis Results

Description of the policy measure

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 [132].

EEOS in Latvia entered into force in 2017. The EEOS was introduced in accordance with the Energy Efficiency Law [124] and under the Cabinet of Ministers Regulation No.226 Rules for the Energy Efficiency Obligation Scheme [78]. The legislation stipulates that during the initial (2014-2017) and first (2018-2021) commitment periods of EEOS, the responsible parties of EEOS are electricity retailers. The criterion for the inclusion of responsible parties is the amount of electricity sold per year, and it should be over 10 GWh. 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.

To assess the costs included in the energy tariff and ensure their transparency and reliability, the EEOS responsible party should draw up an energy efficiency action plan for each commitment period. It should include information on the costs of the measures and the contribution to the Energy efficiency Fund if applicable. The plan should be submitted to the Ministry of Economics for comment and adjusted based on comments and feedback. EEOS parties can adjust their plans every year.

Deemed savings have to be calculated and reported every year based on the Energy Savings Catalogue. Implementation of energy efficiency measures has to be demonstrated by supporting documents, e.g., contracts concluded by the EEOS party to introduce energy efficiency measures to final energy consumers. If the savings goal is overachieved, the savings goal is reduced for the following year. If the party has achieved at least 80% of the committed goal, the gap is added to the following year's goal. If it is less than 80%, a penalty of 125 EUR per MWh should be paid to the Energy Efficiency Fund. If a party has fulfilled more than 100% of the amount of the obligation, the excess part is removed from the amount of the obligation for the following year. Ministry of Economics has an obligation to publish savings on its webpage.

Annual electricity sales of 9 electricity retailers exceeded 10 GWh in 2015 and 15 in 2019 [133]. Total sales of these retailers amount to 99.2% of the total national final electricity consumption. The objective set by the Cabinet of Ministers in the annotation of Regulations for this policy measure [78] is to achieve total energy savings of 234 GWh by 2020 as a result of the introduction of the EEOS. This amount equals 2.4% of Latvia's binding energy efficiency goal by 2020 [132]. EEOS energy savings targets initially were set low to reduce potential uncertainties and risks related to the impact of the EEOS on administrative resources and energy costs for different energy users. Initial assumptions forecasted that half of all EEOS savings would come from information and education activities carried out by EEOS parties, and the other half from the contribution to the Energy Efficiency Fund or the implementation of the most cost-effective energy efficiency measures, the cost of which is equivalent to the contribution to the Fund. The ex-ante evaluation estimated indicative total annual costs for EEOS administration and regulation by the Ministry of Economics in the amount of 17.135 EUR, which includes audit costs, review of energy efficiency plans and their amendment, review, and calculation of required data processing of annual reports, etc. Planned indicative costs of EEOS parties (average costs per party) are around 4700 EUR per year, covering the planning costs and costs for collecting and reporting information on energy savings achieved.

Combined ex-post valuation method

The annotation of Regulation No.226 [78] was used to build the policy theory for this case study, and it was detailed enough to build explicit political theory. A theory-based policy analysis chart for the EEOS is presented in Figure 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. 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 the plans in accordance with regulations and, if necessary, informs the participants regarding the non-compliance of the plan with the requirements. Parties have to resubmit the modified plan of measures and/or the amount 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 insert information regarding annual savings into 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 the policy measure is that which 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 is. 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 [134].

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. [68].

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 [111], the estimated new and cumulative savings achieved by the EEOS during the starting period (2014-2017) are presented (see tab). Estimated cumulative savings obtained during starting phase are 68% higher (329.2 GWh) than the cumulative savings planned for 2020 (234 GWh).

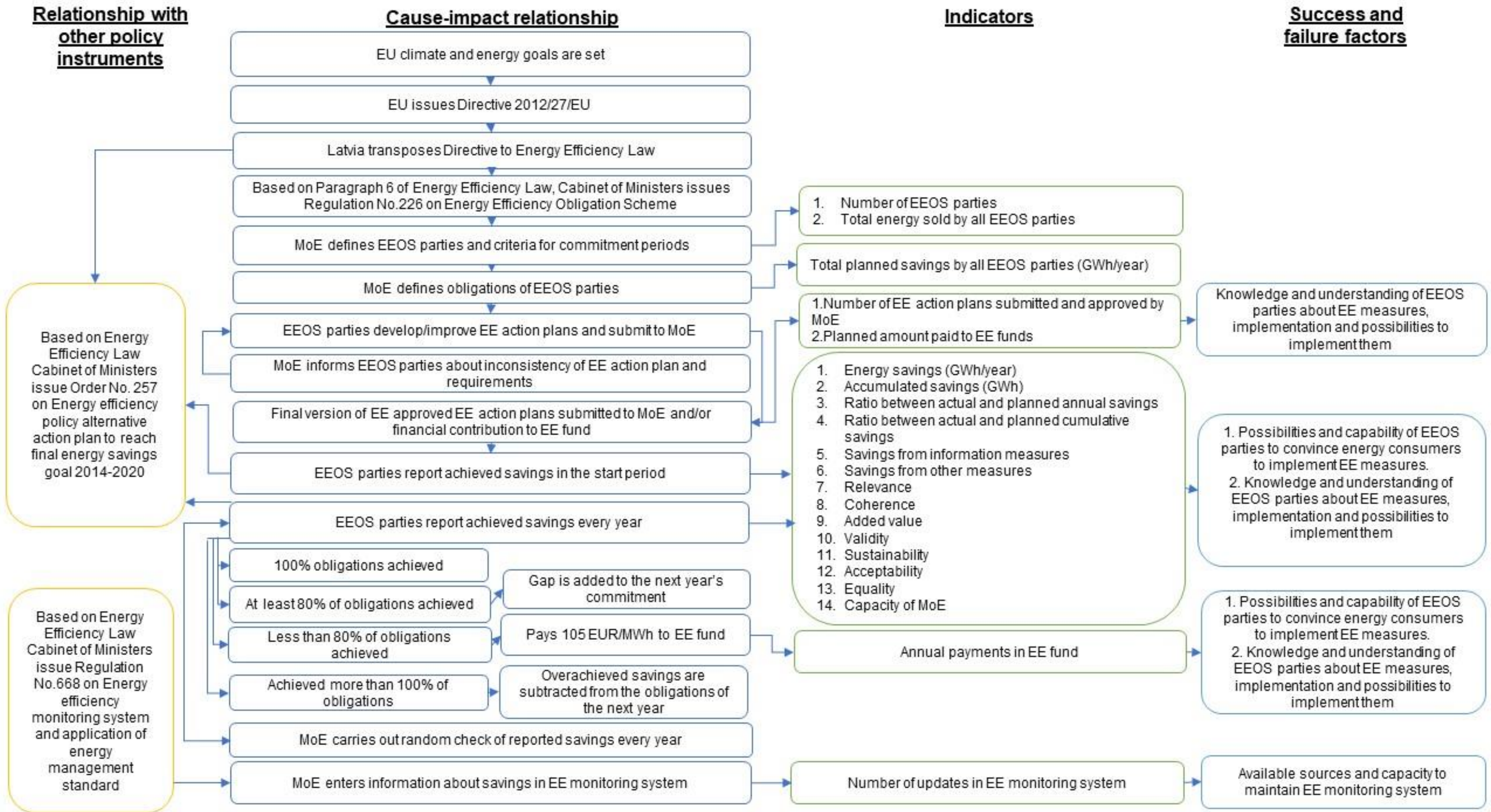


Fig. 3.5. Theory-based policy analysis flow-chart for the implementation of EEOS (MoE – Ministry of Economics, EE - energy efficiency, EEOS -energy efficiency obligation scheme).

3.5.table

Energy savings achieved by the EEOS parties during the starting period [111].

Activity	New savings in 2014, GWh	New savings in 2015, GWh	New savings in 2016, GWh	New savings in 2017	Cumulative savings in 2020, GWh
Information activities	3.4	23.5	21.8	106	154.7
Setting up smart meters	5.0	5.5	13.7	10	68.4
Other measures	0	0	0	26.7	106.1
Total	8.4	29	35.5	142.7	329.2

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

- 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.

In assessing the possibilities and capabilities of EEOS parties to convince energy end-users of the implementation of energy efficiency measures, the EEOS parties provided the following information:

- Perform surveys of the target audience on the main reasons for selecting an energy efficiency measure and then take targeted actions based on the results of the surveys. Surveys show that major barriers are related to costs and a lack of information;
- General marketing techniques are used to promote energy efficiency measures;
- Energy-efficient products are offered for a distributed payment on the home page or directly to customers.

The expertise, understanding, and feasibility of energy efficiency measures and their implementation significantly impact developing and implementing a 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.

In 2019, the Ministry of Economics reported that the functions of administration of the EEOS are not fully achieved because of the lack of capacity [111]. All reports received from EEOS parties are being compiled as far as possible, but no qualitative and detailed evaluation and analysis of these reports has been carried out. Furthermore, no reports on the success or failure of the EEOS have been prepared and published. It also revealed a lack of feedback from the Ministry on the reports and revisions, if needed. The report concludes that the capacity of the Ministry has to be increased. In December 2019, the monitoring function of EEOS was transferred to the Latvian State Construction Control Bureau.

Efficiency

The cost of saved energy is a typical metric used to assess energy efficiency costs across different EEOS [135].

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 the energy utility *Latvenergo* shows that in 2018:

- Costs of information and educational measures to improve energy efficiency implemented 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 4043 EUR;
- Average cost of savings reported is 4.78 EUR/MWh [112].

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 on the administration of the scheme have not been obtained.

Relevance

Interviews show that EEOS parties analyse target audience needs based on surveys, interviews, and individual communication. The household sector surveys reveal that it is essential to provide information and measures that are economically viable. On the other hand, the most valuable information for companies is the increase of capacity, economically viable measures, and available funding. The EEOS ensures that both these needs are met. They also ensure that the policy measure is adapted to technological, scientific, environmental, and social changes. This is done by following the latest technological solutions in cooperation with technology producers and analysing changes in target audience interests.

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.

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.

Added value

EEOS parties see the added value of this policy measure as a trigger in changing other habits of energy end-users such as green thinking, reducing waste, etc. They also noted that boosting energy efficiency increases customer loyalty to the EEOS's parties, which is a critical aspect of the market competition.

Complementarity

The introduction of the EEOS was significantly hampered by poor communication from the Ministry of Economics side. Many important aspects were not described sufficiently. As a result, the legislative documents were widely interpreted by EEOS parties. For example, the methodology for evaluating information campaigns was published only at the end of 2018. The lack of feedback from the Ministry of Economics after the approval of the initial plans confused the EEOS parties. There was no information available on the overall progress and data of the implementation of the EEOS. The Ministry also did not provide information on whether the parties' performance complies with the requirements for energy efficiency measures to achieve Latvia's overall objective. The legislation does not provide the procedure for revising a savings report, i.e., whether the report has been approved or corrections are needed. This led to the situation when the EEOS parties were not provided with information on whether the activities carried out were in line with the overall objectives and if any adjustment has to be made for further activities.

Equality

EEOS parties indicate that they focus on all households under the EEOS scheme. No special attention is paid to fuel poverty. Costs for information measures are included in the operating costs of EEOS parties, thus impacting overall tariffs. However, due to the low values of cost efficiency of measures, the impact is marginal. If the large consumers request information on energy efficiency measures, the EEOS parties provide this information. The EEOS parties ensure that information is provided in Latvian, Russian, and English languages.

Sustainability

The sustainability of this policy measure depends on the capacity of each EEOS party to continue this measure. For example, the energy utility *Latvenergo* has been operating an Energy Efficiency Centre for the last two decades and would continue to deal with energy efficiency issues without the EEOS. Other EEOS parties also confirm that the resources invested in human resources during the first phase of EEOS and accumulated knowledge would be applied further. However, smaller retailers with insufficient resources would suspend further energy efficiency measures if the EEOS were to be discontinued.

Compliance

EEOS parties mentioned that the policy measure is being seen more and more positively as energy efficiency becomes an integral part of life. The change of perception about energy efficiency is experienced within the EEOS obliged parties as increased interest and awareness among employees. If the EEOS party has fulfilled its obligation before the deadline, it continues energy efficiency activities. The EEOS parties have observed that the interest in energy efficiency is increasing when energy price increases.

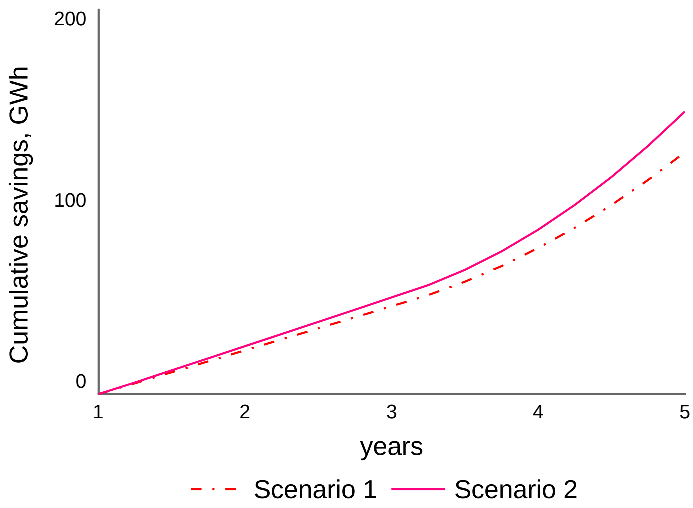
Systemdynamics Tool for Energy Efficiency Policy Validation and Results

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 and are 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 from 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.

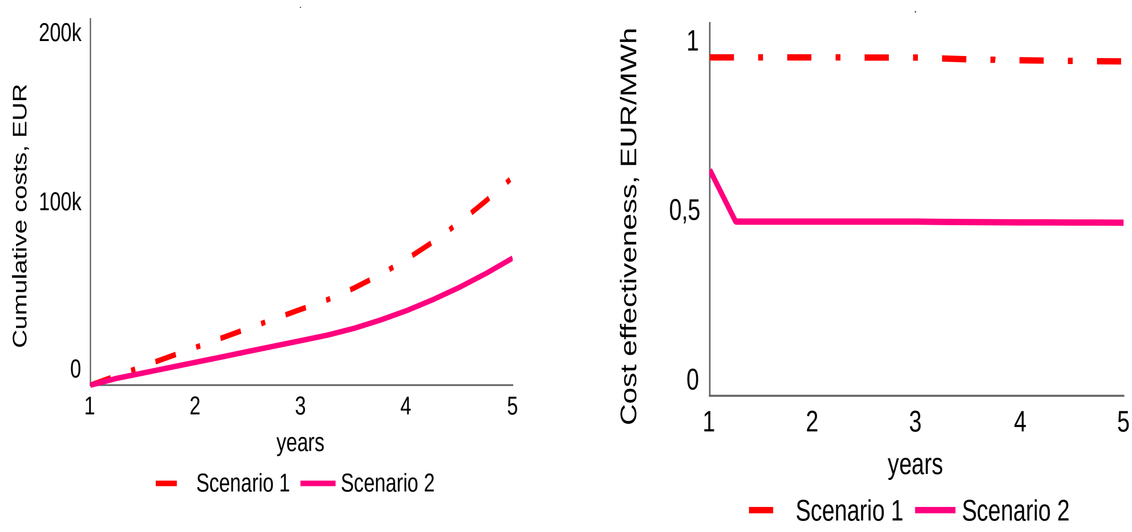
Two scenarios were developed. Scenario 1 is based on manually set input variables: share of audience from the total number of clients is 0.5 for both e-mails and publications. Scenario 2 is an optimization scenario to minimize cumulative costs for every saved energy unit (EUR/MWh) by closing the gap between savings goal and actual savings.

Figure below (fig. 3.6.) illustrates cumulative savings for both scenarios. Scenario 1 does not reach the saving 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.



3.6. Fig. Cumulative savings for both modelled scenarios.

Additional simulation results for both scenarios are represented further (fig.3.7.). In Scenario 1, cumulative costs in year 5 reach 114 000 euros, while in Scenario 2, only 70 000 EUROS. The cost-efficiency for Scenario 1 is 0.9 EUR/MWh, while for Scenario 2 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 a 65% share from 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.



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

Discussion

This study adds to the existing research on the EEOS. It is one of the policy tools to enhance the diffusion of energy savings. Applied mixed research method allowed in-depth analysis of causal relationships and developed an understanding of how the goal set by the government was reached.

At first glance, the goal set by the Latvian government for the starting and first phase of EEOS has been reached and even over fulfilled. It might lead to the conclusion that the concerns about the implementation success of EEOS in Latvia (high risk of savings shortfalls) described by [68] has not been met. However, arguments for failure are used by [68], namely that the Latvian scheme originally was neither built on the existing experience of a voluntary scheme for obligated parties nor adopted (and adapted) based on a successful EEOS design from another country, are still valid. There are several reasons for that.

Types of energy efficiency measures

First, the Latvian EEOS legislation defines that costs for information and education activities can be included in the energy tariff, whereas energy efficiency measures have to 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 actually implement energy efficiency measures, on the other hand, means the individual consumer would need to bear the total investment costs, which contradict 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, e.g. [136], [137].

Moreover, no incentives are provided to Latvian EEOS parties to diffuse energy efficiency technologies that would bring actual energy savings. Behavioral 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 [77], [138].

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

Limitation of the study

Although different approaches were used to enhance the rigor of findings, this study has several limitations.

The problems related to the caveat that the data used are self-reported utility data are mentioned in the literature [77]. However, this risk is eliminated by the reporting requirements set by the legislation, which require providing documented evidence for each measure.

Parameters for the model were obtained from EEOS obliged parties, leading to a bias in the parameter estimates. This bias was reduced by comparing obtained data with publicly available information on costs of information activities in other domains in Latvia.

Social desirability bias comes from the respondents' tendency to give answers to portray themselves in a socially desirable manner. In this study, the authors tried to reduce this bias by asking probing questions to spot inconsistent answers during interviews. Recall bias was reduced by anchoring the respondent's memory in specific events rather than asking them to recall their perceptions and motivations from memory.

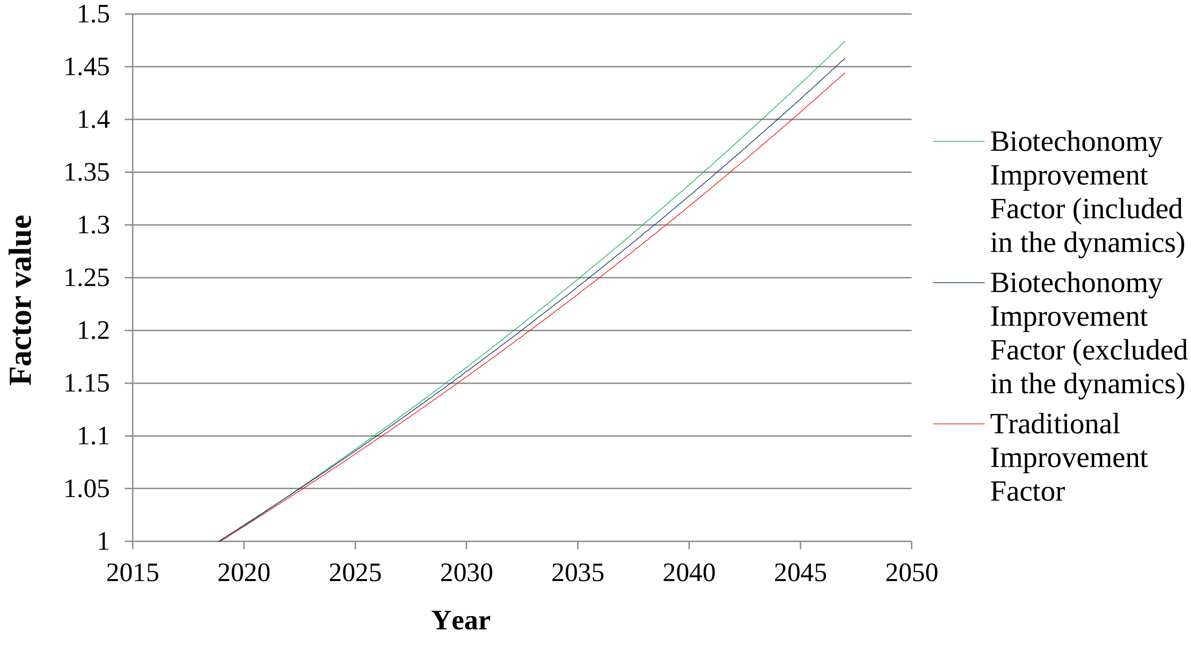
The study does not include interviews with the policymakers from the Ministry of Economics due to a lack of response from the Ministry. There could be several reasons for this: lack of capacity, the high turnover rate of Ministry employees, or pluralism anxiety. An extensive study of publicly available documents from and about Ministry activities was used to substitute for the lack of interviews. Also, interviews with EEOS parties provided helpful information about governance issues. Still, some bias may exist.

3.4. The Role of Bioeconomy towards Climate Neutrality (Energy Efficiency and Economy)

Below please find expanded sub-sections on the role of bioeconomy in economic transformation towards climate neutrality and positive externalities it brings regarding other sectors.

Biotechonomy improvement factor values

To begin with, initial results and considerations have to be made regarding the biotechonomy improvement factor (BIF) as such, construction of which is explained in the previous section, in reference to education and healthcare subsectors. Graphical visualisation of factor values over time is available in figure below (fig. 3.8.) and sample of numerical data in table (tab. 3.6.) below.



3.8. Fig. Graphical results of biotechonomy and traditional economy improvement factors.

3.6.table

Numerical results of biotechonomy and traditional economy improvement factor modelling for years 2030 – 2047

Year	Traditional Improvement Factor	Biotechonomy Improvement Factor (excluded in the simulation dynamics)	Biotechonomy Improvement Factor (included in the simulation dynamics)
2030	1.154	1.161	1.165
2031	1.170	1.177	1.182
2032	1.185	1.193	1.198
2033	1.201	1.209	1.215
2034	1.217	1.225	1.231
2035	1.233	1.241	1.248
2036	1.250	1.258	1.265
2037	1.266	1.275	1.283
2038	1.283	1.293	1.301
2039	1.300	1.310	1.319
2040	1.318	1.328	1.338
2041	1.335	1.346	1.357
2042	1.353	1.364	1.376
2043	1.372	1.382	1.395
2044	1.390	1.401	1.415
2045	1.409	1.420	1.435
2046	1.428	1.439	1.456
2047	1.447	1.459	1.477

First, even though it can be observed that there is a difference of the particular factor values, and biotechonomy improvement factor values included in the simulation model are with the highest values, the difference is relatively marginal. Hence, macroeconomic level improvement could be expected relatively more modest than previously anticipated.

Second, on general note, introduction of improvement factor as such in the model seems to be of relevant importance, as values by year 2047 exceed *1.45* which can be considered a significant multiplier throughout 30 years modelling time, whether derived from biotechonomic considerations or from general macroeconomic growth.

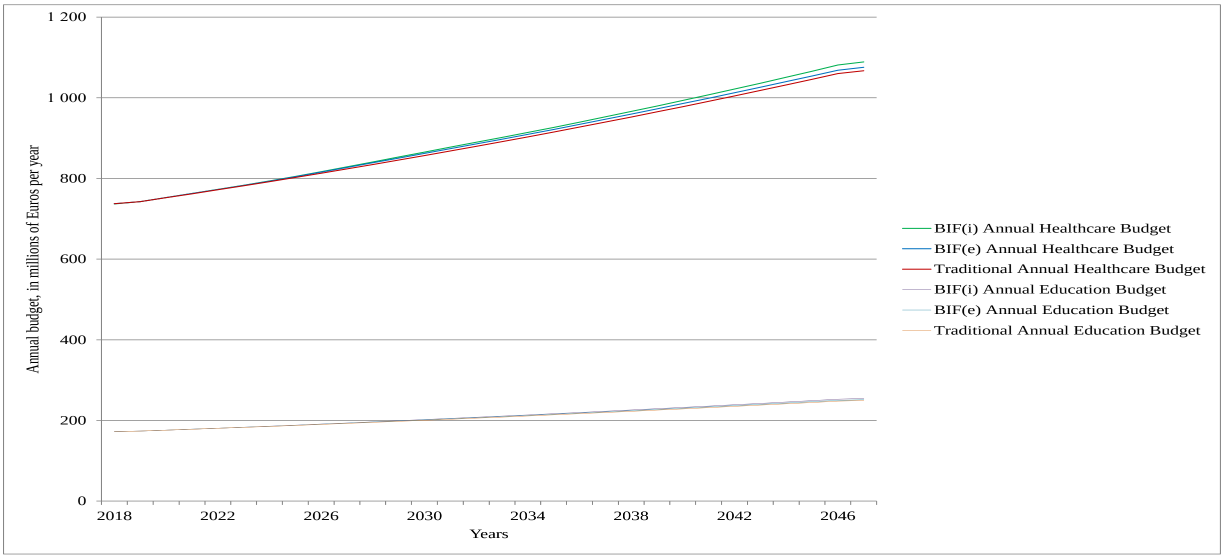
As expected, the factor growth tendency is the same for all three cases and only the proportionality differs. This can clearly be explained by all of these values modelled within the same structure and only with differing proportional input and output values, depending on overall macroeconomic income in particular structure.

Nevertheless, by year 2030 - 2047 the role of biotechonomic forest industry (and related improvement factor included) becomes more prominent and related developments more beneficial to the overall national macroeconomic development model.

Data to be shown starting from year 2030 were chosen as arguably by then improvement factor values begin to take commanding role in shaping the output of experimental modelling. Nevertheless, not to the crucial extent as expected before the exercise of mathematical experiment, but still retaining notable impact on the results, as shown in continuation of data discussion.

Annual education and healthcare budget values

In order to assess the role of forest biotechonomy industry on the development of related education and healthcare governmental budget incomes refer to figure (fig. 3.9.) below.

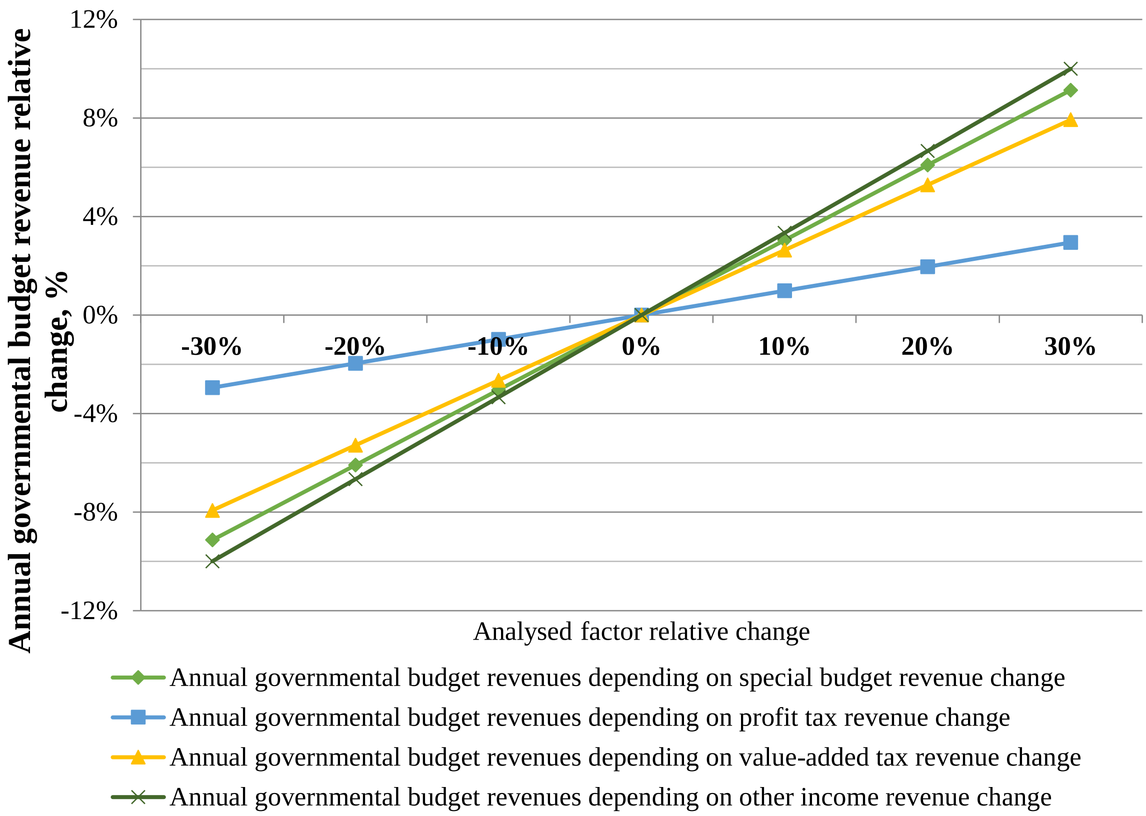


3.9. Fig. Education and healthcare annual budget revenues with and without the impact of forest biotechonomy industry.

Similar to what was expected after evaluation of BIFs, the macro-level impact of forest biotechonomy on education and healthcare budgets while should be considered below the level of expectations, indicates notable improvement tendencies. For instance, graphical improvement on healthcare budget can be observed starting from approximate year of 2030 and leads to notable improvement – approximately 20 million Euros per year by 2047. Nevertheless, education budget additions of 5 million Euros annually closer to year 2047 in best-case scenario – BIF(i) – graphically should be considered relatively insignificant, bearing in mind the overall scale of comparison.

If numerical values are evaluated, it can be mentioned that by year 2047 forest biotechonomy addition to the national economy would bring 1088.96 million Euros for healthcare sector and 254.64 million Euros for education sector per year. Introduction of biotechonomy forest industries without the improvement factor would lead to annual budgets of 1075.69 million and 251.54 million Euros accordingly, but annual budgets without forest biotechonomy production industry whatsoever would be approximately 1067.13 and 249.54 million Euros. Even though the improvement in final year of modelling for both sectors is 20 and 5 million Euros accordingly, on macro-level scale, where annual governmental budget expenditure will be considered to reach almost 12 billion in 2047 such improvement should be considered at least notable for healthcare sector, but fairly adequate for education budget segment.

Due to the fact that BIFs structure is fixed, while incoming values are changed throughout the modelling, it can be also assessed that the improvement value of particular subsectors increases if the total turnover of the industry increases. Such general macroeconomic correlation again leads to the fact that the most crucial driver for particular sub sector annual budgetary improvement is the economic growth per se rather than particular BIFs. In order to evaluate particular components and their devotion to the data, sensitivity analysis was carried, see figure (fig. 3.10.) below.



3.10. Fig. Sensitivity analysis of annual governmental budget revenues.

As expected, sensitivity analysis show that the greatest impact on annual governmental budget revenues is generated by revenues of special budget, value-added tax and other remaining budget revenues. While the role of profit tax revenues (corporate and personal income tax and solidarity tax) is considerably lower. This, in turn, leads to several assumptions.

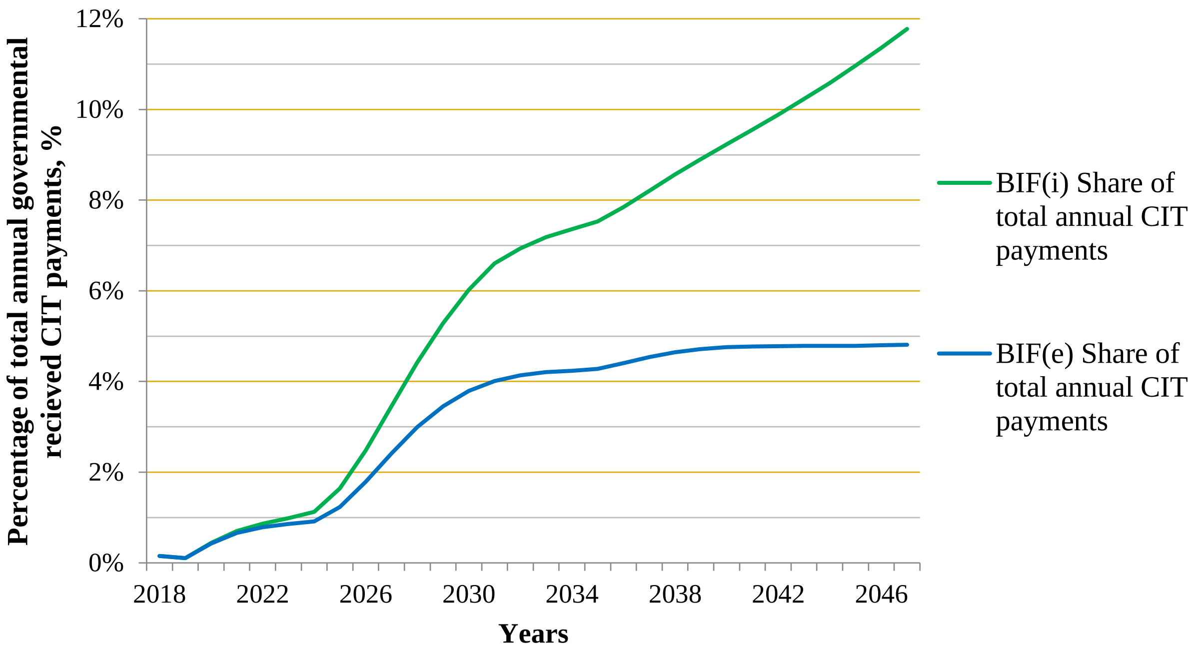
First, the role or impact of forest biotechonomy sector introduction is mainly dependant on value-added tax and profit tax revenues (via corporate income tax). While in the former case the impact can be considerably translated to macroeconomic budget (forest biotechonomy generating about 4% of total VAT revenues by 2047 in scenario BIF(i)), due to the rather marginal macroeconomic role of CIT (forest biotechonomy generates 12% of total CIT by 2047 in scenario BIF(i)) additional macro-level improvement is rather notable than significant.

Second, the fact that special budget revenues provide significant input to the annual governmental budget limits the additional role of forest biotechonomy segment. Special budget revenues are mainly generated by social contribution payments for labour force. In case of forest biotechonomy with little labour force intensity such payments are relatively low – by 2047 barely reaching 2 million Euros annually, in sharp contrast to total special budget revenues of 3.4 billion Euros by 2047.

Nevertheless, in other considerations, the low labour force intensity indicates the prospect for dynamic, sustainable and high-added value development of the forest biotechonomy industry which, paradoxically, contradicts with basic funding principles of the annual governmental budget formations in Latvia.

Annual share of forest biotechonomy corporate income tax (CIT) payments in total CIT revenues

Graphical representation of the share of forest biotechonomy CIT payments in reference to the total annual CIT payments please find in figure below (fig.3.11.).



3.11. Fig. The share of forest biotechonomy CIT payments in reference to the total annual CIT revenues in Latvia.

Once particular focus is shifted from paramount macro-level analysis to in-depth look at forest biotechonomy and its deriving role, a different role of both BIFs and sector as such appears. As it can be observed in Fig. 3.4, already in the case of forest biotechonomy sector inclusion in the macroeconomic model, the sector plays important role in separate annual governmental revenues – reaching nearly 5% (4.81%) of total corporate income tax revenues paid. Furthermore, by year 2024 both forest biotechonomy inclusion scenarios (with or without dynamic inclusion) generate similar results of the proportion of CIT paid in reference to total CIT revenues – approximately 1%.

Beyond doubt, these results reveal the essential role of BIF played in the case of the inclusion of this factor in the feed-back loop within the macroeconomic development model. The share of CIT paid reaches almost 12% (11.78%) in 2047, indicating the significant role that forest biotechonomy can take in reference to total Latvian corporate activities.

From the graph shown above four particular graphical tendencies start to take shape:

- Essentially linear growth starting from year 2025;
- Settling down or more gradual growth in case of BIF(i) starting from year 2030 onwards;
- Another common growth surge in years 2035 – 2036 and;
- The levelling of BIF(e) scenario from 2035 onwards.

In reference to the former trend, first it has to be mentioned that the initial three paradigmatic forest biotechonomy segments with profitable indicators are (I) furfural production from grey alder; (II) oil extract production from pine needles and (III) betulin and lupeol production from birch. While two of the former sub-sectors initiate operation almost immediately from the modelled year 2018, for birch product manufacturing there is a necessity for accumulation of particular amount of veneer log annual supply and deriving birch bark accessibility (approximately 5 thousand tons annually), once these indicators are reached, in addition to capital investments the growth of the crucial betulin and lupeol manufacturing begins, starting from year 2023.

Regarding the settling down tendency after year 2030 in case of BIF(e) and slower pace or gradual growth in case of BIF(i), again birch betulin production is of crucial importance. If independent growth rates of forest biotechonomy product EBITDAs (profits before taxes) are explored, it can be seen that throughout 2025 – 2030 betulin by far exceeds all other products in reaching almost 80 million Euros per year in scenario BIF(e). For frame of reference, second most profitable product – birch flavonoid – reaches 15 million Euros per year, and gradually declines. Key to the gradual growth or stagnation in this stage is the fact that for betulin production after 2030 manufacturing capacity meets potential capacity as the limiting loop; hence, the production in place meets its optimum in relation to limits of available raw materials[2]. Therefore, while containing more or less stable annual growth, after this stage in time other products start playing more central role in growth and decline tendencies.

The growth or the gradual leap from 2035 can be best explained by the dynamic growth surge of furfural. When operational capacity meets the potential capacity of particular production around year 2035, the capital costs experience a sharp decline by roughly 10 million Euros per year which is the most crucial push factor for the exponential growth tendency.

In case of scenario BIF(i), furfural and other products' manufacturing, experiencing continuing improvement factor of education (via production rates) and labour hours (via desired capacity) ensure gradual, but stable and consistent growth. In case of scenario BIF(e),

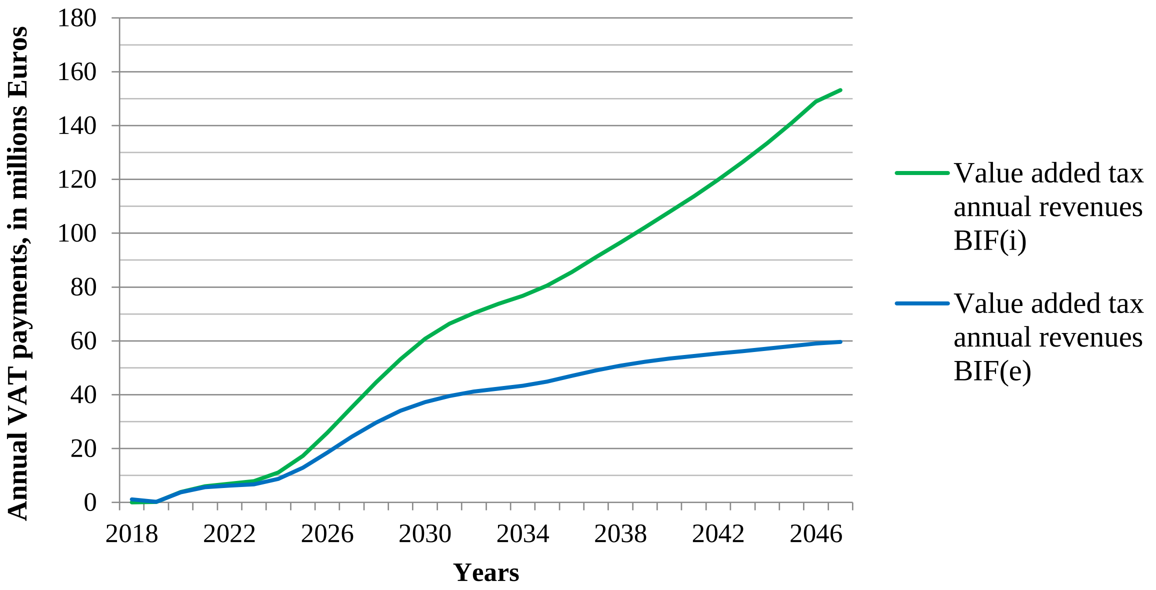
[2] Former model constructed by Blumberga et al. (2016) considers raw material availability that would not interfere with the consumption of raw materials of already existing traditional Latvian forest sector.

where improvement factors are absent, the limitation is met relatively faster and the growth of particular furfural sub-section is levelled out by either gradually declining or consistent tendencies of other products.

Hence, by closer analysis of the data it can be stated that indeed the biotechonomy improvement factor can provide a significant influence in segments development trend by pushing the limiting out borders at least for additional 10 years, from 2035 to roughly mid-2040s.

Annual forest biotechonomy value-added tax (VAT) payments

As shown by the sensitivity analysis above, value-added tax revenues – structuring approximately two thirds of total other tax income revenues – should be considered among crucial source of income for the total annual governmental budget of Latvia, alongside corporate income tax revenues previously discussed. Therefore, the impact of forest biotechonomy inclusion on VAT generated revenues will be explored next (fig. 3.12.).



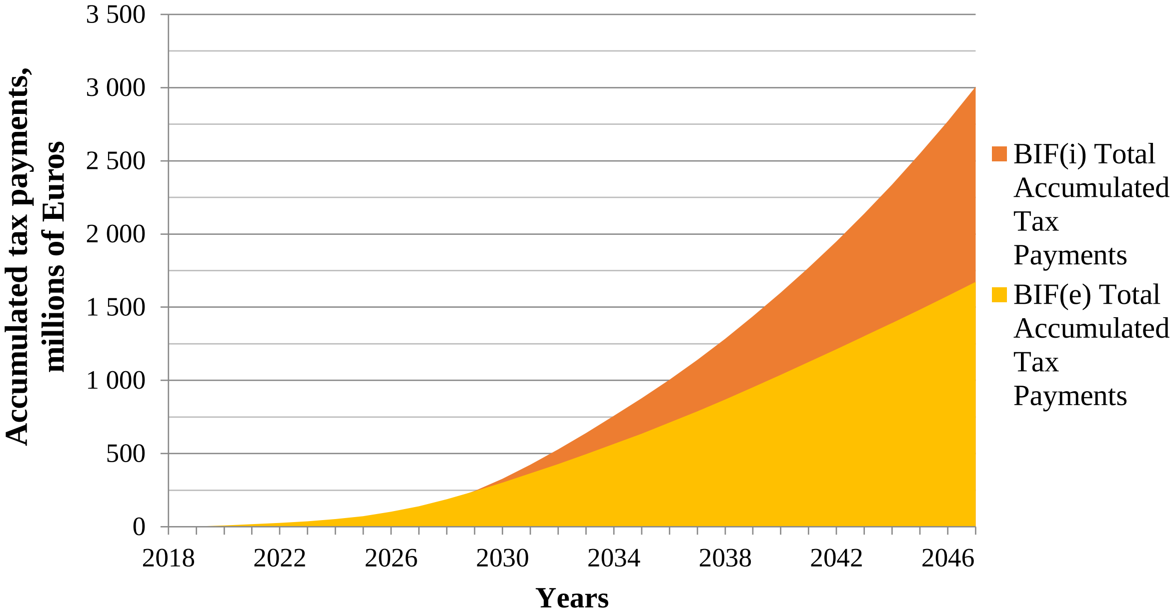
3.12. Fig. Total annual income generated by the forest biotechonomy industry in reference to the value-added budget tax.

As it can be observed in the figure above, the growth tendencies also of forest biotechonomy VAT tax revenues is similar to the former and it can be explained as almost *all* relevant taxes are calculated on the basis of total revenues of forest biotechonomy industry.

Nevertheless, it can be speculated that the role of VAT is the most prominent, generating more than 153 million Euro revenues in 2047 in case of scenario BIF(i) and 59.6 million Euros in case of scenario BIF(e). While on their own these values should be considered of significant addition to the annual governmental budget revenues, if compared to total economy incomes of the governmental budget of Latvia in 2047, the former scenario comprises slightly more than 4% and the latter around 2% of total annual value-added tax revenues. Therefore, again, it can be argued that the impact generated by the forest biotechonomy industry on macro-level scale can be considered notable, but not crucially significant.

Accumulated tax income from forest biotechonomy sector

For graphical data of accumulated tax income from forest biotechonomy segment please refer to figure below (fig. 3.13.).



3.13. Total graphical representation of accumulated tax income from forest biotechonomy in Latvia.

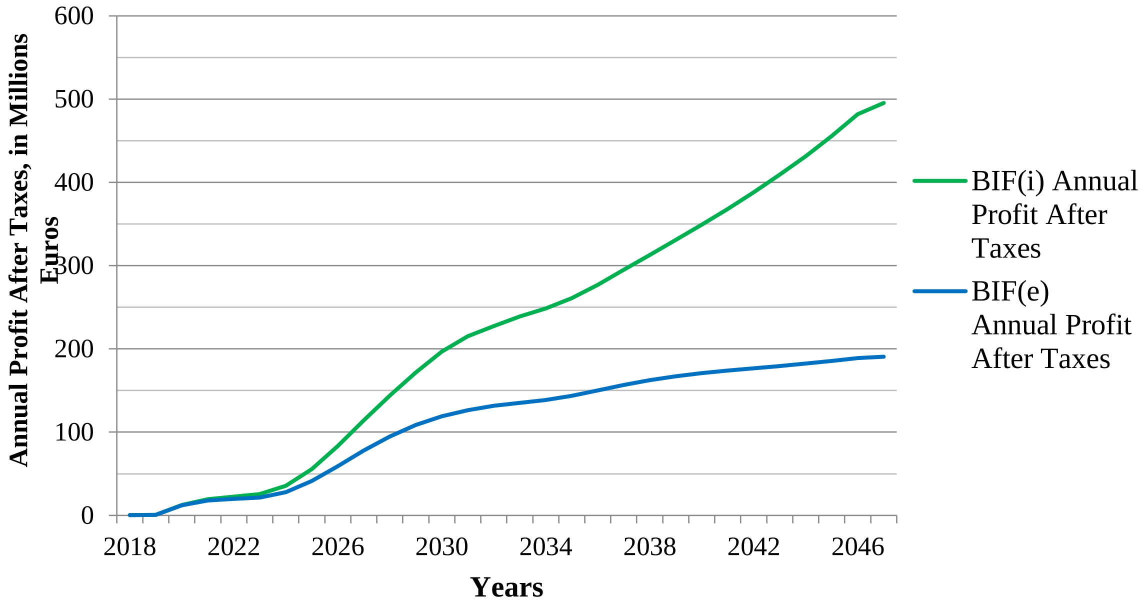
Corresponding CIT and VAT revenue tendencies in Figures 3.11. and 3.12., it can be noticed that accumulated total tax payments (CIT, VAT, as well as social contributions by both employees and employers) form a significant role of industry's input into the national economy of Latvia.

In the case of scenario with inclusive biotechonomy improvement factor, the total accumulated tax revenues exceed 3 billion Euros (3006 millions) by year 2047, while with the inclusion of the biotechonomic segment; however excluding the additional reinforcing role of education and healthcare segments, total additional tax revenues would reach 1672 million Euros, which is almost 40% less. Even though total accumulated revenues in both cases are fairly significant, a central limitation should be considered the absence of investment modelling data available already in the previously established model (reference). This would allow comparing the input extent on both returns, placing these data even more into particular financial and monetary policy context.

Nevertheless, a crucial aspect is the fact that these revenues are modelled to be generated by forest biotechonomic industry exploiting resources that are currently not contested by any other traditional forest industry; hence, arriving at the result that in 30 years' time there is a potential of additional 37% of the national budget of Latvia in 2017 flowing into the national budget should be considered relatively significant.

Annual profit of forest biotechonomy industry after taxes

Even though the tendency is similar to the behaviour of the share of CIT of total annual income tax payments and related VAT income considerations that could be formed by forest biotechonomy industry, the magnitude of the result deserve a separate, brief overview. Graphical results of annual profit after taxes of forest biotechonomy industry please see in figure (fig.3.14.) below.



3.14. The annual profit of forest biotechonomy industry after taxes.

First, both scenarios with the inclusion of forest biotechonomy in the national economic development model indicate significant profit numbers after taxes for related segment. While in the case of scenario BIF(i) the annual profit in 2047 can reach almost 0.5 billion Euros (495 million Euros), in the case of scenario BIF(e) – almost 191 million Euros per year.

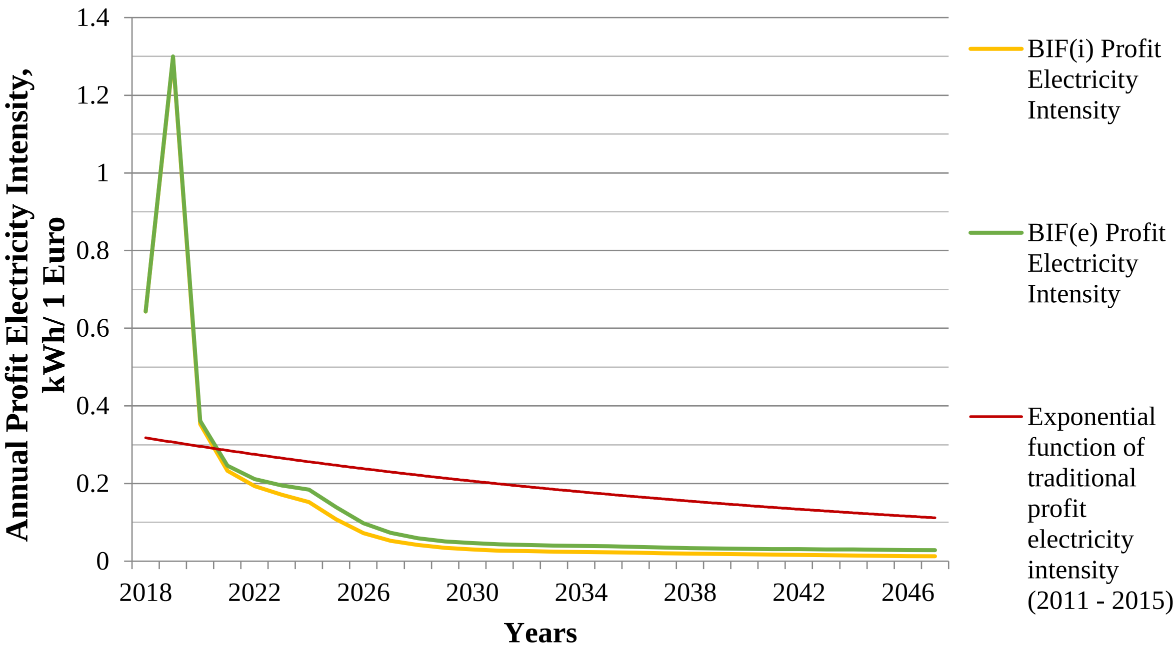
If related tendencies are to be discussed, the key-points in function progression are fairly similar to the fig. 3.11. discussed before. Nevertheless, similarly to what was discussed regarding education and healthcare macroeconomic impacts, the larger the particular volumes of monetary resources, the steeper the increase of economic growth per unit. This can be explored also in this particular section of results, where the time frame between 2030s and 2040s for scenario without biotechonomy improvement factor included in the simulation indicate relatively healthy economic growth, whilst in the proportionate division graph of percentage of CIT (fig. 3.11.) it was rather a time frame of stumbling growth or inertia stagnation.

Last, but not least, initial stages of functions in figures 3.13. and 3.11. require additional explanation. To certain extent the relative slow incline towards growth could be explained by the process of capital investment, in addition to requiring related raw material stocks and other resources (for instance, labour).

However, it can be argued that when modelling in shorter time frames or even in the case of annual representation of data, the growth could have been initiated sooner by the particular model if not for cluster of products which installation of manufacturing capacities, in addition to ensuring raw material capacity, lead to significant initial losses. A notable example is the furfural manufacturing from grey alder, for example, at the scenario BIF(e) acquiring losses of almost 7.7 million Euros in 2019. In any case, it should be considered that some of the forest biotechonomy products could and should be grouped in manufacturing clusters, as they do not compete for the same type of raw materials. Hence, the capital costs, as well as variable costs should experience a decline, resulting in a more profitable operation of particular sub-industries.

Electricity intensity in forest biotechonomy per 1 Euro generated

In figure below (fig. 3.15.) please find graphical representation of electricity intensity per Euro generated (EBITDA) in forest biotechonomy industries and traditional processing industry in Latvia.



3.15. Electricity intensity per Euro generated (sales) in forest biotechonomy and traditional processing industry in Latvia.

To begin with, it is vital to set out this section while recognizing that modelled traditional processing industry electricity intensity was based on academic and analytical assumptions, in sharp contrast to both biotechonomy scenarios, encapsulating nearly *all* production stages and related electricity capacities and requirements.

Nevertheless, in reference to traditional processing industry's electricity intensity, an exponential function was drawn, while using historical industry's electricity consumption data from 2011 – 2015. Furthermore, exponential decrease function of electricity intensity was chosen based on literature analysis, suggesting that exponential decrease in electricity consumption in the 21st century is by far the best-case scenario and with relatively high probability it is possible to conclude that electricity consumption will remain significantly higher than modelled while using exponential equations [139]. The function deducted describing electricity intensity of traditional processing industry in Latvia is expressed in the following equation (eq. 3.1.).

$$y = 0.3295 \times e^{-0.036x} \tag{3.1}$$

In general, it can be observed that in long term forest biotechonomic industry provide significantly higher electricity consumption efficiency in comparison to best case scenario of traditional processing industry. Even though traditional industry is also closing on the 0.1 kWh/per 1 Euro benchmark by 2047, both biotechonomy scenarios reach equivalent level already in mid 2020s, and reaching their optimal consumption of approximately 0.02 – 0.04 kWh/per 1 Euro by the beginning of 2030s.

Furthermore, it is clear that sharp increase at the very beginning of operational cycle is related to capacity instalment and initial production sales turnover. Nevertheless, similarly as before, while this graph provide information on potential future decarbonisation of economy in relation to fossil, centralised energy generation units in Latvia, a certain limitation remains CAPEX investment considerations, which would make corrections in reference to time frame of significant kWh/per 1 Euro generated drop by the time of investment full return.

3.5. Summary of obtained results

First, regarding GHG emission performance indicator and inter-country comparison, find the table below.

In overall, the highest overall evaluation has Sweden, with it ranking among the top indicators of each sub-category, except solid fossil fuel consumption. In comparison, Latvia ranks with the lower score potentially indicating the fact that an accurate GHG emission performance of a country goes beyond high ranking of the share of renewables in energy consumption.

In parallel, Lithuania has scored second lowest value of 0.457, closely linked to the limited amount of income from environmental taxation and share of renewables in the final consumption, despite ranking the highest in GHG emissions pr capita. Estonia, in turn, is in upper quartile with 0.497, where its second lowest household energy consumption per capita stands out.

Second, the research part focussing on the role of Latvian manufacturing industry in-depth elaborates that the main factors behind increase in industrial energy consumption were higher manufacturing activity and economic growth, during the period from 2010 – 2019.

In particular, energy consumption of the manufacturing industry increased by 12%, capping at 34133 TJ in 2019. It was observed that significant increase was within the wood products manufacturing sector (+70%), non-metallic mineral product manufacturing (+21%) and other manufacturing, including rubber, plastics, furniture and other (+217%). It can be argued that further increase of energy demand was not observed even higher due to historical off-sets in the Latvian metalworking industry.

It is vital to outline that the energy intensity effect was the main driver behind energy consumption reduction in the Latvian manufacturing industry. Furthermore, results indicate that despite significant energy efficiency improvements in three largest sub-categories of the manufacturing industry, the total increase of industry activity counterbalanced the energy intensity effect. Meaning that the current energy efficiency solutions did not compensate the industrial activity effect. This, in turn, increased the relative speed of energy consumption by the manufacturing industry versus the pace of energy efficiency measures implemented.

Third, regarding the energy-efficiency policy evaluation and the theoretical modelling of the scenarios, it can be deducted that even though that the goals set by the Latvian government for the initial and first phase of the EEOS have been met, a critical factor is that the study outlines that the Latvian scheme originally was neither built on the existing experience of a voluntarily scheme for obliged parties, nor it was adopted by other successfully working examples globally.

Furthermore, the local EEOS legislation defines that costs for information and education activities can be included in the energy tariff, while regarding energy-efficiency measures customer must be charged. In turn, a structural failure has been created where energy retailers have no incentive to exercise any other energy-efficiency measures apart from the informative ones, based on local developed energy-efficiency catalogue methodology. This is championed by the fact that 95% of all EEOS measures were informal.

This arguably can be considered a systemic failure as energy-efficiency incentives and measures are least cost-effective yet have considerably higher energy savings potential. Moreover, not solely EEOS dedicated financial incentives have been made available to the EEOS parties; hence, there has not been a diffusion of energy-efficient technologies which should be one of the core goals of any EEOS initiative.

Fourth, regarding the role of biotechonomy in the macroeconomic model of the Latvian economy, the biotechonomy improvement factor (coefficient by which bioeconomy financially adds to the realms of healthcare and education) 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.

The difference between the traditional scenario values and the BIF(i) scenario values in healthcare and education budgets reached 21.83 million Euros and 5.10 million Euros per year, while the difference between traditional and BIF(e) scenario values reached 13.27 million Euros and 2.00 million Euros per year accordingly. In reference to annual VAT payments, the BIF(i) scenario reached the value of approximately 153 million Euros per year in 2047, while

BIF(e) scenario reached the value of 59.6 million Euros. 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 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 3 006 million Euros accumulated by year 2047, while scenario BIF(e) – approximately 1 672 million Euros in accumulation. Furthermore, regarding the annual profit after taxes of forest biotechonomy industry in Latvia, by year 2047 in the case of scenario BIF(i) the annual profit accounted for almost 0.5 billion Euros (495 million Euros), but in the case of scenario BIF(e) for approximately 191 million Euros per year. Last, but not least, in reference to electricity intensity per 1 Euro generated, by year 2047 traditional Latvian manufacturing segment value reached the approximate value of 0.11 kWh/1 Euro, while in the scenario BIF(i) it reached approximately 0.02 kWh/1 Euro, but in the case of scenario BIF(e) – 0.04 kWh/1 Euro.

4. DISCUSSION, LIMITATIONS AND RECOMMENDATIONS

It is vital to discuss the impact of the assessed climate neutrality factors during the ongoing both academic and business debate regarding the Green Deal, as well as post-pandemic recovery. Among the first notable takeaways is that for both climate neutrality transition and post-pandemic recovery a more extensive emphasis should be placed on formulation of new skills and know-hows to overcome both challenges, instead of plain protection of energy system and economic status quo in favour of state aid and conservation of conventional jobs. Such approach, in principle, also allows countries to better respond to disruptive shocks [141] which both climate neutrality implementation change, and pandemics are.

Furthermore, current economic situation may even serve as catalyst for the larger energy system shift. If decarbonization is facilitated, in combination with refraining from new investment in fossil, fissile industries, this may not only assist policymakers to distinguishing between Covid-19 and sustainability factors regarding business sector performance, but also have a long-term impact of creating a stronger, more private markets oriented sustainable investment thread.

Another aspect that should be discussed separately is the deep fragmentation of the local level climate neutrality enforcers and the related lack of coordination towards goal-oriented actions. While this has been a characteristic of both energy and research and development local landscape [142], it can be argued that such system and corresponding actions within the energy realm may lead to even deeper divisions and partisan policy centricity regarding energy transition. Meaning, that the conventional energy sector will continue not being checked and balanced; hence, leading to continuous path dependency and missing the "shifting effect" to achieve transition towards climate neutral energy system. Nevertheless, also other path dependency factors regarding the energy system should be considered. For example, the overwhelming emphasis on the building sector in the energy efficiency debate, as well as others more knowledge creation created – say, catching-up mentality of EU energy acquis implementation and specific country size related factors.

The research clearly illustrates potential governmental monetary benefits that would follow the change traditional trajectory of energy system towards climate neutrality. Furthermore, research also builds on the role of the biotechonomy in extensively limiting the impact on climate and environment that traditionally has been one of the most pressing issues of rapidly developing processing sector. Several governmental political steps would contribute to facilitating the development of energy system and related climate neutrality improvements and bringing associated macro-level and personal-level benefits:

- Introduction of more dynamic natural resource tax system, incentivising entrepreneurs to drive for higher-added value per capita of energy or biological resource consumption;
- Long-term economic feasibility decision-making introduction in reference to the governmental resource management companies; therefore, making additional forest

resources more available in the free market and decoupling governmental forest sales from wood price in the market.

- Public recognition and analysis of additional funds available for governmental expenditure after incentivizing the transition towards climate neutrality (i.e., in education and healthcare); therefore, stimulating well-thought and high-added value manufacturing.
- Even though not discussed in the research but facilitating foreign direct investment in order to provide sufficient financial capital for high-added value development of climate neutral technologies and forest biotechonomy – i.e., approaching already existing foreign entrepreneurs in biological resource processing in Latvia – Swedish, Dutch, North American and others.
- Stimulating local demand via various financial mechanisms for high-added value products developed and processed locally.
- Highlighting the current development tendencies of the climate change; therefore, rising awareness of the public in relation to sustainable manufacturing and not just free riding on the abundance of natural habitats in reference to climate and environmental macro-level development goals.

CONCLUSION

To conclude, 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, 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 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 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 countries compared, following tot 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. In overall, the energy consumption of the Latvian manufacturing industry increased by 12%, during the time period from 2010 – 2019. In addition, 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" saving 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, proved over to be 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.

As a part 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 dynamic 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 energy-efficiency in the Latvian manufacturing industry. In particular, the modelled increase in education and healthcare sectors has been relatively notable. In case of scenario BIF(i) it has been 5 million and 20 million accordingly, but in case of scenario BIF(e) – 2 million and 8 million Euros.

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 the annual contributions to the macro-level economy. In terms of annual value added tax payments – from roughly 60 million Euros – in scenario BIF(e) – to 153 million Euros in 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 1.61 billion Euros – scenario BIF(e) – to nearly 3 billion Euros in scenario BIF(i). This serves not only as the climate related externality, but 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-efficient within the manufacturing industry. In case of scenario BIF(i) by 2047 the generation of 1 Euro 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 Euro generation. Furthermore, if converted to carbon dioxide equivalent per 1 Euro profit, the results would indicate 2 grams, 4 grams and 18 grams CO_2 equivalent accordingly.

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

- 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 to be 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 signal 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.

BIBLIOGRAPHY

[1] European Commission, “A European Green Deal. Striving to be the first climate-neutral continent.” https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en#highlights.

[2] Ekonomikas ministrija, “Nacionālais Enerģētika un klimata plāns,” 2020. https://www.em.gov.lv/lv/nacionalais-energetikas-un-klimata-plans.

[3] Ekonomikas ministrija, “Industriālā politika,” 2020, [Online]. Available: https://www.em.gov.lv/lv/industriala-politika.

[4] N. et. al. Höhne, “Analysis beyond IPCC AR5: Net Phase Out of Global and Regional Greenhouse Gas Emissions and Reduction Implications for 2030 and 2050.” [Online]. Available: https://www.pbl.nl/sites/default/files/downloads/pbl-215-act-factsheet-net-phase-out-of-global-and-regional-ghg-emissions-and-reduction-implications-for-2030-and-2050.pdf.

[5] Pernille Seljom and Eva Rosenberg, “A Scandinavian Transition Towards a Carbon-Neutral Energy System,” *Limiting Glob. Warm. to Well Below 2 °C Energy Syst. Model. Policy Dev.*, pp. 105–121, 2018, [Online]. Available: https://link.springer.com/chapter/10.1007%2F978-3-319-74424-7_7.

[6] IRENA, *World Energy Transitions Outlook: 1.5°C Pathway*. 2021.

[7] G. H. Rau, H. D. Willauer, and Z. J. Ren, “The global potential for converting renewable electricity to negative-CO2-emissions hydrogen,” *Nat. Clim. Chang.*, vol. 8, no. 7, pp. 621–625, Jul. 2018, doi: 10.1038/s41558-018-0203-0.

[8] H. Blanco and A. Faaij, “A review at the role of storage in energy systems with a focus on Power to Gas and long-term storage,” *Renew. Sustain. Energy Rev.*, vol. 81, pp. 1049–1086, Jan. 2018, doi: 10.1016/j.rser.2017.07.062.

[9] D. C. Malins, “What role is there for electrofuel technologies in European transport’s low carbon future?,” 2017. [Online]. Available: https://www.transportenvironment.org/sites/te/files/publications/2017_11_Cerulogy_study_What_role_electrofuels_final_0.pdf.

[10] “GAS FOR CLIMATE. The optimal role for gas in a net-zero emissions energy system,” 2019. [Online]. Available: https://gasforclimate2050.eu/wp-content/uploads/2020/03/Navigant-Gas-for-Climate-The-optimal-role-for-gas-in-a-net-zero-emissions-energy-system-March-2019.pdf.

[11] C. Brand, M. Tran, and J. Anable, “The UK transport carbon model: An integrated life cycle approach to explore low carbon futures,” *Energy Policy*, vol. 41, pp. 107–124, Feb. 2012, doi: 10.1016/j.enpol.2010.08.019.

[12] H. Wang, W. Chen, and J. Shi, “Low carbon transition of global building sector under 2- and 1.5-degree targets,” *Appl. Energy*, vol. 222, pp. 148–157, Jul. 2018, doi: 10.1016/j.apenergy.2018.03.090.

[13] K. Dahal, S. Juhola, and J. Niemelä, “The role of renewable energy policies for carbon neutrality in Helsinki Metropolitan area,” *Sustain. Cities Soc.*, vol. 40, pp. 222–232, Jul. 2018, doi: 10.1016/j.scs.2018.04.015.

[14] D. F. C. Matthes, R. Blanck, B. Greiner, and D. W. Zimme, “The Vision Scenario for the European Union 2017 Update for the EU-28,” 2018. [Online]. Available: https://www.oeko.de/fileadmin/oekodoc/Vision_Scenario__EU-28-Report_2017.pdf.

[15] “Fully decarbonising Europe’s energy system by 2050,” 2018. [Online]. Available: https://afry.com/sites/default/files/2020-06/poyrypointofview_fullydecarbonisingeuropesenergysystemby2050.pdf.

[16] K. Hainsch *et al.*, “Make the European Green Deal real: Combining climate neutrality

and economic recovery," 2020. [Online]. Available: https://www.econstor.eu/bitstream/10419/222849/1/1701746166.pdf.
[17] European Commission, "2030 Climate Target Plan." https://ec.europa.eu/clima/policies/eu-climate-action/2030_ctp_en.
[18] EIROPAS and KOMISIJA, "Eiropas 2030. gada klimatisko ieceru vēriena kāpināšana: investīcijas klimatneitrālā nākotnē cilvēku labā," 2020. [Online]. Available: https://eur-lex.europa.eu/legal-content/LV/TXT/PDF/?uri=CELEX:52020SC0177&from=EN (I.
[19] European Commission, "Decarbonising our energy system to meet our climate goals," *Fit 55 factsheets*, no. July, 2021.
[20] European Commission, "EU strategy on energy system integration." https://ec.europa.eu/energy/topics/energy-system-integration/eu-strategy-energy-system-integration_en.
[21] European Commission, "Mobility Strategy." https://ec.europa.eu/transport/themes/mobilitystrategy_en.
[22] European Commission, "An industrial strategy for a competitive, green, digital Europe." https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/industry-and-green-deal_en.
[23] European Commission, "The Recovery and Resilience Facility." https://ec.europa.eu/info/business-economy-euro/recovery-coronavirus/recovery-and-resilience-facility_en.
[24] European Commission, "Recovery plan for Europe." https://ec.europa.eu/info/strategy/recovery-plan-europe_en.
[25] European Commission, "Missions in Horizon Europe." https://ec.europa.eu/info/research-and-innovation/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/missions-horizon-europe_en.
[26] European Commission, "Shaping more beautiful, sustainable and inclusive forms of living together." https://europa.eu/new-european-bauhaus/index_en.
[27] E. Campiglio, "Who should pay for climate? The effect of burden-sharing mechanisms on abatement policies and technological transfers," 2012, [Online]. Available: https://www.lse.ac.uk/granthaminstitute/wp-content/uploads/2014/02/WP96-climate-abatement-policies-and-technological-transfers.pdf.
[28] and T. B. Auer, Hans, Pedro Crespo del Granado, Daniel Huppmann, Pao-Yu Oei, Karlo Hainsch, Konstantin Löffler, "Quantitative Scenarios for Low Carbon Futures of the Pan-European Energy System," 2020. [Online]. Available: https://openentrance.eu/wp-content/uploads/openENTRANCE-D3.13.pdf.
[29] J. L. Teigland, H. J. Bax, and M. Lhermitte, "Foreign investors back Europe, but is Europe back?," 2021. https://www.ey.com/en_lv/attractiveness/21/foreign-investors-back-europe-but-is-europe-back.
[30] International Energy Agency, "Net Zero by 2050 A Roadmap for the Global Energy Sector." [Online]. Available: https://iea.blob.core.windows.net/assets/beceb956-0dcf-4d73-89fe-1310e3046d68/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf.
[31] Innovation and Technology, "Gross domestic spending on R&D," *OECD*, 2021, [Online]. Available: https://data.oecd.org/rd/gross-domestic-spending-on-r-d.htm.
[32] Saeima, *Energoefektivitātes likums*. 2016.
[33] "OECD Main Science and Technology Indicators," 2021. [Online]. Available: https://www.oecd.org/sti/msti-highlights-march-2021.pdf.
[34] Dienas bizness, "Darbu uzsāk Latvijas inovāciju un tehnoloģiju pārstāvniecība Briselē," 2021. https://www.db.lv/zinas/darbu-uzsak-latvijas-inovaciju-un-tehnologiju-

parstavnieciba-brisele-501875.
[35] B. Bajcinovci, "Environment Quality: Impact From Traffic, Power Plant and Land Morphology, a Case Study of Prishtina," *Environ. Clim. Technol.*, vol. 19, no. 1, pp. 65–74, May 2017, doi: 10.1515/rtuect-2017-0006.
[36] et al. Danila A. M., *Annual European Union greenhouse gas inventory 1990–2016 and inventory report 2018*. 2018.
[37] T. Luzzati and G. Gucciardi, "A non-simplistic approach to composite indicators and rankings: an illustration by comparing the sustainability of the EU Countries," *Ecol. Econ.*, vol. 113, pp. 25–38, May 2015, doi: 10.1016/j.ecolecon.2015.02.018.
[38] D. Antanasijević, V. Pocajt, M. Ristić, and A. Perić-Grujić, "A differential multi-criteria analysis for the assessment of sustainability performance of European countries: Beyond country ranking," *J. Clean. Prod.*, vol. 165, pp. 213–220, 2017, doi: 10.1016/j.jclepro.2017.07.131.
[39] V. Moutinho, M. Madaleno, and M. Robaina, "The economic and environmental efficiency assessment in EU cross-country: Evidence from DEA and quantile regression approach," *Ecol. Indic.*, vol. 78, pp. 85–97, 2017, doi: 10.1016/j.ecolind.2017.02.042.
[40] M. T. García-Álvarez, B. Moreno, and I. Soares, "Analyzing the sustainable energy development in the EU-15 by an aggregated synthetic index," *Ecol. Indic.*, vol. 60, pp. 996–1007, Jan. 2016, doi: 10.1016/j.ecolind.2015.07.006.
[41] I. Siksnelyte, E. K. Zavadskas, R. Bausys, and D. Streimikiene, "Implementation of EU energy policy priorities in the Baltic Sea Region countries: Sustainability assessment based on neutrosophic MULTIMOORA method," *Energy Policy*, vol. 125, no. October 2018, pp. 90–102, 2019, doi: 10.1016/j.enpol.2018.10.013.
[42] F. Cucchiella, I. D'Adamo, M. Gastaldi, S. L. Koh, and P. Rosa, "A comparison of environmental and energetic performance of European countries: A sustainability index," *Renew. Sustain. Energy Rev.*, vol. 78, pp. 401–413, Oct. 2017, doi: 10.1016/j.rser.2017.04.077.
[43] I. M. De Alegría, A. Basañez, P. D. De Basurto, and A. Fernández-Sainz, "Spains fulfillment of its Kyoto commitments and its fundamental greenhouse gas (GHG) emission reduction drivers," *Renew. Sustain. Energy Rev.*, vol. 59, pp. 858–867, 2016, doi: 10.1016/j.rser.2015.12.208.
[44] L. Cruz and J. Dias, "Energy and CO2 intensity changes in the EU-27: Decomposition into explanatory effects," *Sustain. Cities Soc.*, vol. 26, pp. 486–495, 2016, doi: 10.1016/j.scs.2016.03.007.
[45] D. Štreimikiene and T. Balezentis, "Kaya identity for analysis of the main drivers of GHG emissions and feasibility to implement EU '20-20-20' targets in the Baltic States," *Renew. Sustain. Energy Rev.*, vol. 58, no. 2016, pp. 1108–1113, 2016, doi: 10.1016/j.rser.2015.12.311.
[46] M. Su, S. Pauleit, X. Yin, Y. Zheng, S. Chen, and C. Xu, "Greenhouse gas emission accounting for EU member states from 1991 to 2012," *Appl. Energy*, vol. 184, no. 2016, pp. 759–768, 2016, doi: 10.1016/j.apenergy.2016.02.074.
[47] A. Kijewska and A. Bluszcz, "Research of varying levels of greenhouse gas emissions in European countries using the k-means method," *Atmos. Pollut. Res.*, vol. 7, no. 5, pp. 935–944, 2016, doi: 10.1016/j.apr.2016.05.010.
[48] A. Kijewska and A. Bluszcz, "Analysis of greenhouse gas emissions in the European Union member states with the use of an agglomeration algorithm," *J. Sustain. Min.*, vol. 15, no. 4, pp. 133–142, 2016, doi: 10.1016/j.jsm.2017.02.001.
[49] Teet Randma, "Estonia needs a plan – and support – to get rid of its dirty oil shale," *Energy Post*, 2018, [Online]. Available: .
[50] A. Volkova, E. Latosov, and A. Siirde, "Heat Storage Combined with Biomass CHP

under the National Support Policy. A Case Study of Estonia," *Environ. Clim. Technol.*, vol. 24, no. 1, pp. 171–184, Jan. 2020, doi: 10.2478/rtuect-2020-0011.

[51] K. O'Sullivan, "Ireland has third highest emissions of greenhouse gas in EU," *The Irish Times*, 2019. .

[52] Statistics Finland, "Greenhouse gas emissions increased, emission allocation exceeded," 2019. .

[53] European Commission, "Energy efficiency first: accelerating towards a 2030 objective of 32.5%," 2020. https://ec.europa.eu/info/news/energy-efficiency-first-accelerating-towards-2030-objective-2019-sep-25_en.

[54] European Commission, "REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL 2018 assessment of the progress made by Member States towards the national energy efficiency targets for 2020 and towards the implementation of the Energy Efficiency Directive as requir," 2020. [Online]. Available: https://ec.europa.eu/commission/sites/beta-political/files/report-2018-assessment-progress-energy-efficiency-targets-april2019_en.pdf.

[55] G. Marques and R. Pitarma, "Monitoring Energy Consumption System to Improve Energy Efficiency," 2017, pp. 3–11.

[56] K. Dolge, A. Kubule, S. Rozakis, I. Gulbe, D. Blumberga, and O. Krievs, "Towards Industrial Energy Efficiency Index," *Environ. Clim. Technol.*, vol. 24, no. 1, pp. 419–430, Jan. 2020, doi: 10.2478/rtuect-2020-0025.

[57] K. Dolge, A. Kubule, and D. Blumberga, "Composite index for energy efficiency evaluation of industrial sector: sub-sectoral comparison," *Environ. Sustain. Indic.*, vol. 8, p. 100062, Dec. 2020, doi: 10.1016/j.indic.2020.100062.

[58] EUROPEAN COMMISSION, "REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL," 2020. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1595408944398&uri=CELEX:52020DC0326.

[59] and J. R. S. Nadel, R. Cowart, D. Crossley, "Energy saving obligations across three continents : contrasting approaches and results," *ECEE Summer study Proc.*, pp. 295–308, 2017, [Online]. Available: http://cied.ac.uk/publication/energy-saving-obligations-across-three-continents-contrasting-approaches-results/.

[60] S. Moser, "Overestimation of savings in energy efficiency obligation schemes," *Energy*, vol. 121, pp. 599–605, 2017, doi: https://doi.org/10.1016/j.energy.2017.01.034.

[61] J. Rosenow, "Energy savings obligations in the UK-A history of change," *Energy Policy*, vol. 49, pp. 373–382, 2012, doi: 10.1016/j.enpol.2012.06.052.

[62] J. Rosenow and E. Bayer, "Costs and benefits of Energy Efficiency Obligations: A review of European programmes," *Energy Policy*, vol. 107, pp. 53–62, 2017, doi: https://doi.org/10.1016/j.enpol.2017.04.014.

[63] J. Rosenow, T. Skoczkowski, S. Thomas, A. Węglarz, W. Stańczyk, and M. Jędra, "Evaluating the Polish White Certificate scheme," *Energy Policy*, vol. 144, no. April, 2020, doi: 10.1016/j.enpol.2020.111689.

[64] B. Duzgun and G. Komurgoz, "Turkey's energy efficiency assessment: White certificates systems and their applicability in Turkey," *Energy Policy*, vol. 65, pp. 465–474, 2014, doi: 10.1016/j.enpol.2013.10.036.

[65] P. Bertoldi, S. Rezessy, E. Lees, P. Baudry, A. Jeandel, and N. Labanca, "Energy supplier obligations and white certificate schemes: Comparative analysis of experiences in the European Union," *Energy Policy*, vol. 38, no. 3, pp. 1455–1469, 2010, doi: DOI:101016/jenpol200911027.

[66] ATEE, "Snapshot of Energy Efficiency Obligations schemes in Europe: 2017 update," 2017. [Online]. Available: https://atee.fr/system/files/2021-

04/2017_snapshot_of_eeos_in_europe_0.pdf.
[67] ADEME, "Energy efficiency trends and policies," *ODYSSEE-MURE*, vol. 2000, no. April, 2020.
[68] T. Fawcett, J. Rosenow, and P. Bertoldi, "Energy efficiency obligation schemes: their future in the EU," *Energy Effic.*, vol. 12, no. 1, pp. 57–71, 2019, doi: 10.1007/s12053-018-9657-1.
[69] P. Bertoldi, N. Labanca, S. Rezessy, S. Steuwer, and V. Oikonomou, "Where to place the saving obligation: Energy end-users or suppliers?," *Energy Policy*, vol. 63, pp. 328–337, 2013, doi: 10.1016/j.enpol.2013.07.134.
[70] E. L. Aldrich and C. L. Koerner, "White certificate trading: A dying concept or just making its debut? Part II: Challenges to trading white certificates," *Electr. J.*, vol. 31, no. 4, pp. 41–47, 2018, doi: 10.1016/j.tej.2018.05.006.
[71] M. Reuter, M. K. Patel, W. Eichhammer, B. Lapillonne, and K. Pollier, "A comprehensive indicator set for measuring multiple benefits of energy efficiency," *Energy Policy*, vol. 139, no. May 2019, p. 111284, 2020, doi: 10.1016/j.enpol.2020.111284.
[72] A. Kamal, S. G. Al-Ghamdi, and M. Koc, "Revaluing the costs and benefits of energy efficiency: A systematic review," *Energy Res. Soc. Sci.*, vol. 54, no. September 2018, pp. 68–84, 2019, doi: 10.1016/j.erss.2019.03.012.
[73] D. Font Vivanco, R. Kemp, and E. van der Voet, "How to deal with the rebound effect? A policy-oriented approach," *Energy Policy*, vol. 94, pp. 114–125, 2016, doi: 10.1016/j.enpol.2016.03.054.
[74] D. Azhgaliyeva, Y. Liu, and B. Liddle, "An empirical analysis of energy intensity and the role of policy instruments," *Energy Policy*, vol. 145, no. April, p. 111773, 2020, doi: 10.1016/j.enpol.2020.111773.
[75] S. Moser, "Poor energy poor: Energy saving obligations, distributional effects, and the malfunction of the priority group," *Energy Policy*, vol. 61, pp. 1003–1010, 2013, doi: 10.1016/j.enpol.2013.06.021.
[76] L. Mundaca, "Markets for energy efficiency: Exploring the implications of an EU-wide 'Tradable White Certificate' scheme," *Energy Econ.*, vol. 30, no. 6, pp. 3016–3043, 2008, doi: 10.1016/j.eneco.2008.03.004.
[77] K. Gillingham, A. Keyes, and K. Palmer, "Advances in Evaluating Energy Efficiency Policies and Programs," *Annu. Rev. Resour. Econ.*, vol. 10, no. 1, pp. 511–532, Oct. 2018, doi: 10.1146/annurev-resource-100517-023028.
[78] Cabinet of Ministers, "Regulation No. 226 'Regulations Regarding the Energy Efficiency Obligation Scheme,'" *Latv. Vēstnesis*, no. 97, 2017.
[79] H. A. Simon, "Applying Information Technology to Organization Design," *Public Adm. Rev.*, vol. 33, no. 3, p. 268, May 1973, doi: 10.2307/974804.
[80] J. W. Forrester, "The System Dynamics National Model: Macrobehavior from Microstructure," in *Computer-Based Management of Complex Systems*, Berlin, Heidelberg: Springer Berlin Heidelberg, 1989, pp. 3–12.
[81] J. D. Sterman, "System Dynamics Modeling: Tools for Learning in a Complex World," *Calif. Manage. Rev.*, vol. 43, no. 4, pp. 8–25, Jul. 2001, doi: 10.2307/41166098.
[82] J. W. Forrester, "Policies, decisions and information sources for modeling," *Eur. J. Oper. Res.*, vol. 59, no. 1, pp. 42–63, May 1992, doi: 10.1016/0377-2217(92)90006-U.
[83] I. Dierickx and K. Cool, "Asset Stock Accumulation and Sustainability of Competitive Advantage," *Manage. Sci.*, vol. 35, no. 12, pp. 1504–1511, Dec. 1989, doi: 10.1287/mnsc.35.12.1504.
[84] A. Blumberga, G. Bažbauers, P. Davidsens, D. Blumberga, A. Grāvelsiņš, and T. Prodaņuks, *System dynamic modelling in bioeconomy sector*. RTU PRESS, 2016.

[85] J. W. Forrester, “Economic theory for the new millennium (2003),” *Syst. Dyn. Rev.*, vol. 29, no. 1, pp. 26–41, Jan. 2013, doi: 10.1002/sdr.1490.
[86] J. D. Sterman, *Business Dynamics: Systems Thinking and Modelling for a Complex World*. Boston: McGraw-Hill, 2000.
[87] S. Plous, “Psychological Mechanisms in the Human Use of Animals,” *J. Soc. Issues*, vol. 49, no. 1, pp. 11–52, Apr. 1993, doi: 10.1111/j.1540-4560.1993.tb00907.x.
[88] S. Opricovic and G. H. Tzeng, “Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS,” *Eur. J. Oper. Res.*, vol. 156, no. 2, pp. 445–455, 2004, doi: 10.1016/S0377-2217(03)00020-1.
[89] J. E. Leal, “AHP-express: A simplified version of the analytical hierarchy process method,” *MethodsX*, vol. 7, 2020, doi: 10.1016/j.mex.2019.11.021.
[90] M. ECONOMIDOU and R. ROMAN COLLADO, “Assessing the progress towards the EU energy efficiency targets using index decomposition analysis in 2005-2016,” 2019. doi: 10.2760/61167.
[91] European Commission, “Summary for Policymakers,” in *Climate Change 2013 - The Physical Science Basis*, Intergovernmental Panel on Climate Change, Ed. Cambridge: Cambridge University Press, 2019, pp. 1–30.
[92] B. W. Ang and N. Liu, “Energy decomposition analysis: IEA model versus other methods,” *Energy Policy*, vol. 35, no. 3, pp. 1426–1432, Mar. 2007, doi: 10.1016/j.enpol.2006.04.020.
[93] U. N. I. D. Organization, “STRUCTURAL DECOMPOSITIONS OF ENERGY CONSUMPTION , ENERGY INTENSITY , EMISSIONS AND EMISSION INTENSITY A SECTORAL PERSPECTIVE : EMPIRICAL EVIDENCE FROM WIOD OVER 1995 TO 2009,” Vienna, 2015. [Online]. Available: https://www.unido.org/sites/default/files/2015-12/WP_11_0.pdf.
[94] ODYSEE-MURE, “Understanding variation in energy consumption Methodology,” 2020. [Online]. Available: https://www.indicators.odyssee-mure.eu/php/odyssee-decomposition/documents/interpretation-of-the-energy-consumption-variation-glossary.pdf.
[95] B. W. Ang, “Decomposition analysis for policymaking in energy : which is the preferred method ?,” *Energy Policy*, vol. 32, pp. 1131–1139, 2004, doi: 10.1016/S0301-4215(03)00076-4.
[96] A. Talaei, E. Gemechu, and A. Kumar, “Key factors affecting greenhouse gas emissions in the Canadian industrial sector: A decomposition analysis,” *J. Clean. Prod.*, vol. 246, p. 119026, Feb. 2020, doi: 10.1016/j.jclepro.2019.119026.
[97] B. W. Ang, “The LMDI approach to decomposition analysis: a practical guide,” *Energy Policy*, vol. 33, no. 7, pp. 867–871, May 2005, doi: 10.1016/j.enpol.2003.10.010.
[98] N. Liu and B. W. Ang, “Factors shaping aggregate energy intensity trend for industry: Energy intensity versus product mix,” *Energy Econ.*, vol. 29, no. 4, pp. 609–635, Jul. 2007, doi: 10.1016/j.eneco.2006.12.004.
[99] S. Voigt, E. De Cian, M. Schymura, and E. Verdolini, “Energy intensity developments in 40 major economies: Structural change or technology improvement?,” *Energy Econ.*, vol. 41, pp. 47–62, Jan. 2014, doi: 10.1016/j.eneco.2013.10.015.
[100] B. W. Ang and X. Y. Xu, “Tracking industrial energy efficiency trends using index decomposition analysis,” *Energy Econ.*, vol. 40, pp. 1014–1021, Nov. 2013, doi: 10.1016/j.eneco.2013.05.014.
[101] J. B. Norman, “Measuring improvements in industrial energy efficiency: A decomposition analysis applied to the UK,” *Energy*, vol. 137, pp. 1144–1151, Oct. 2017, doi: 10.1016/j.energy.2017.04.163.
[102] G. Trotta, “Assessing energy efficiency improvements and related energy security and

climate benefits in Finland: An ex post multi-sectoral decomposition analysis," *Energy Econ.*, vol. 86, p. 104640, Feb. 2020, doi: 10.1016/j.eneco.2019.104640.
[103] Eurostat, *Energy balance guide - Methodology guide for the construction of energy balances & Operational guide for the energy balance builder tool,* no. January. 2019, p. 52.
[104] Central Statistics Bureau of Latvia, "Entrepreneurship indicators of enterprises (SBG010)," 2020. https://www.csb.gov.lv/en/statistics/statistics-by-theme/enterprises/structural-business-statistics/tables/sbg010/entrepreneurship-indicators.
[105] Eurostat, "Complete energy balances [nrg_bal_c]," 2019. https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_bal_c&lang=en.
[106] Central Statistics Bureau of Latvia, "Producer price changes in industry sector, as per cent of previous year [RCG030]." https://www.csb.gov.lv/en/statistics/statistics-by-theme/economy/producer-prices/tables/rcg030/producer-price-changes-industry-sector-cent.
[107] Central Statistics Bureau of Latvia, "Volume indices of industrial production [RUG031]." https://www.csb.gov.lv/en/statistics/statistics-by-theme/construction-industry-trade/industry/tables/rug031/volume-indices-industrial-production.
[108] M. Harmelink, L. Nilsson, and R. Harmsen, "Theory-based policy evaluation of 20 energy efficiency instruments. Energy Efficiency," pp. 131–148, 2008, doi: 10.1007/s12053-008-9007-9.
[109] C. G. Blumstein, "A theory-based approach to market transformation," *Energy Policy*, no. 28, pp. 137–144, 2000.
[110] European Commission, "Commission staff working document. Better Regulation Guidelines. SWD (2017) 350," 2017.
[111] Ministry of Economics, "Report on progress towards meeting the national energy efficiency targets for 2020 for 2017. Year in accordance with the requirements of Article 24(1) and Part 1 of Annex XIV to Directive 2012/27/EU," 2019.
[112] Elektrum, "Energy savings achieved through energy efficiency measures," 2019. .
[113] G. McCracken, *The Long Interview*. Sage Publishing, 1988.
[114] S. Nadel, R. Cowart, D. Crossley, and J. Rosenow, "Energy saving obligations across three continents : contrasting approaches and results," *ECEE Summer study Proc.*, pp. 295–308, 2017.
[115] Y. Barlas, "Formal aspects of model validity and validation in system dynamics," *Syst. Dyn. Rev.*, vol. 12, no. 3, pp. 183–210, 1996.
[116] A. Blumberga, A., Blumberga, D., Bažbauers, G., Davidsen, P., Moxnes, E., Dzene, I., Barisa, A., Žogla, G., Dāce, E., Bērziņa, *Sistēmdinamika vides inženierzinātņu studentiem*. Rīga, 2010.
[117] M. of F. of the R. of Latvia, "Valsts budžets," 2017. http://www.fm.gov.lv/lv/sadalas/valsts_budzets/.
[118] Ministry of Economics of the Republic of Latvia, "Macroeconomic Review of Latvia," Riga, 2020. [Online]. Available: https://www.em.gov.lv/en/media/1477/download.
[119] Central Statistics Bureau of Latvia, "Export unit value and import price index weights by sections and divisions of CPA by Index, Market area and Time period [RCE010c]." https://stat.gov.lv/en/statistics-themes/economy/producer-prices/tables/rce010c-export-unit-value-and-import-price-indices.
[120] Central Statistics Bureau of Latvia, "Volume indices and changes in volume of construction production by economic activity [BU010c]." https://www.csb.gov.lv/en/statistics/statistics-by-theme/construction-industry-trade/construction/tables/bu010c/volume-indices-and-changes-volume.

[121] Fastmarkets, "Latvian steelmaker Liepajas Metalurgs applies for bankruptcy," 2013, [Online]. Available: https://www.metalbulletin.com/Article/3275040/Latvian-steelmaker-Liepajas-Metalurgs-applies-for-bankruptcy.html.
[122] M. Reuter, M. K. Patel, and W. Eichhammer, "Applying ex post index decomposition analysis to final energy consumption for evaluating European energy efficiency policies and targets," *Energy Effic.*, vol. 12, no. 5, pp. 1329–1357, Jun. 2019, doi: 10.1007/s12053-018-09772-w.
[123] K. Locmelis, D. Blumberga, and U. Bariss, "Energy efficiency in large industrial plants. Legislative aspects," *Energy Procedia*, vol. 147, pp. 202–206, Aug. 2018, doi: 10.1016/j.egypro.2018.07.058.
[124] Saeima, *Energy Efficiency Law*. Latvia, 2016.
[125] A. Kubule, K. Ločmelis, and D. Blumberga, "Analysis of the results of national energy audit program in Latvia," *Energy*, vol. 202, p. 117679, Jul. 2020, doi: 10.1016/j.energy.2020.117679.
[126] K. Locmelis, D. Blumberga, A. Blumberga, and A. Kubule, "Benchmarking of Industrial Energy Efficiency. Outcomes of an Energy Audit Policy Program," *Energies*, vol. 13, no. 9, p. 2210, May 2020, doi: 10.3390/en13092210.
[127] AS VALMIERAS STIKLA ŠĶIEDRA, "Konsolidētais finanšu pārskats un atsevišķais finanšu pārskats," Rīga, 2017. [Online]. Available: https://www.nasdaqbaltic.com/market/upload/reports/vss/2017_ar_lv_eur_con_ias.pdf.
[128] AS VALMIERAS STIKLA ŠĶIEDRA, "Konsolidētais finanšu pārskats un atsevišķais finanšu pārskats," Rīga, 2018. [Online]. Available: https://www.nasdaqbaltic.com/market/upload/reports/vss/2018_ar_lv_eur_con_ias.pdf.
[129] ODYSSEE-MURE, "Energy efficiency trends and policies. Latvia. Energy profile.," 2020. https://www.odyssee-mure.eu/publications/efficiency-trends-policies-profiles/latvia.html#industry.
[130] Rural Support Service of the Republic of Latvia, "State & EU Support." [Online]. Available: https://www.lad.gov.lv/lv/atbalsta-veidi/projekti-un-investicijas/lap-investiciju-pasakumi.
[131] A. Kubule and D. Blumberga, "Sustainability Analysis of Manufacturing Industry," *Environ. Clim. Technol.*, vol. 23, no. 3, pp. 159–169, Dec. 2019, doi: 10.2478/rtuect-2019-0086.
[132] Cabinet of Ministers, "No. 257. On the Plan of Alternative Measures of the Energy Efficiency Policy for the Energy End-Use Savings Target 2014-2020," . *Latv. Vēstnesis*, no. 104, 2017.
[133] CSB, "Central Statistical Bureau of Latvia, 'Energy balance, TJ, thsd toe (NACE Rev.2).,'" 2020. .
[134] State Audit Office, "Is a targeted energy efficiency policy in place to achieve the planned energy end-use savings?," 2018.
[135] M. A. Billingsley, I. M. Hoffman, E. Stuart, S. R. Schiller, C. A. Goldman, and K. H. LaCommare, "The Program Administrator Cost of Saved Energy for Utility Customer-Funded Energy Efficiency Programs," Mar. 2014.
[136] ENSPOL, "Report on existing and planned EEOs in the EU – Part II: Description of planned schemes," vol. 2015, no. February 2016, pp. 1–187, 2016.
[137] G. T. Gardner and P. C. Stern, *Environmental problems and human behavior*. 2002.
[138] I. M. Hoffman *et al.*, "The Total Cost of Saving Electricity Through Utility Customer-Funded Energy Efficiency Programs: Estimates at the National, State, Sector and Program Level." Apr. 2015.
[139] M. J. Perman R., Ma Y., Common M., Maddison D., *Natural Resource and Environmental Economics. 4th ed. Edinburgh: Person.* 2011.

[140] European Commission, “Commission Recommendation of 6 May 2003 concerning the definition of micro, small and medium-sized enterprises (Text with EEA relevance) (notified under document number C(2003) 1422).,” 2008. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32003H0361 (accessed Apr. 22, 2017).

[141] Ornston, D. (2012a). Creative Corporatism: The Politics of High-Technology Competition in Nordic Europe. *Comparative Political Studies, 46*(6), 702-729. https://doi.org/10.1177/0010414012463881

[142] Muižniece, L.; Cepilovs, A. (2018). Disregarding History and Context: Innovation Policy in Latvia Post 1990. New Challenges of Economic and Business Development – 2018: Productivity and Economic Growth. Proceedings, 474−487. Riga, Latvia: University of Latvia.

GHG PERFORMANCE EVALUATION IN GREEN DEAL CONTEXT

Environmental and Climate Technologies
2020, vol. 24, no. 1, pp. 431–441
https://doi.org/10.2478/rtuect-2020-0026
https://content.sciendo.com

GHG Performance Evaluation in Green Deal Context

Beate ZLAUGOTNE[1]*, Linda IEVINA[2], Reinis AZIS[3], Denis BARANENKO[4], Dagnija BLUMBERGA[5]

[1–3, 5]*Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*
[4]*Institute of Refrigeration and Biotechnologies, ITMO University, Lomonosova street 9, Saint-Petersburg, 191002, Russian Federation*

***Abstract* – Recently introduced European Green Deal has set a target for Europe to become the first climate-neutral continent by 2050. This ambitious commitment will bring a serious challenge for the EU. However, the degree of this challenge will not be the same to all EU member states. In this paper, the multi-criteria decision analysis is applied to rank eight selected EU countries (Denmark, Estonia, Ireland, Latvia, Lithuania, Slovenia, Finland and Sweden) regarding GHG performance, and thus illustrate different starting points of the transition to carbon-neutrality. In parallel to the widely used indicator of GHG emissions per capita, evaluation incorporates various other criteria covering energy consumption, population size, and the use of renewable energy and fossil fuel, as well as investment and tax rates. TOPSIS analysis shows that the best GHG performance is achieved by Sweden, while Latvia ranks the lowest. The presented evaluation method could be a useful tool in planning implementation of policies to reach Green Deal settings on European, as well as on a national level.**

***Keywords* – Country ranking; European Green Deal; greenhouse gas (GHG) emissions; TOPSIS.**

1. INTRODUCTION

The newly introduced European Green Deal has set a particularly ambitious target for Europe to become climate-neutral by 2050. It requires to reduce GHG emissions by 50–55 % by 2030 in comparison to the levels of 1990, and to reach net-zero GHG emissions by 2050 [1]. To clearly illustrate the ambitious extent of this target, it can be mentioned that the EU GHG emissions were reduced by 22 % in 2017, compared to 1990 levels. In order to achieve full reductions up to 100 % by 2050, EU must reduce its GHG emissions by additional 78 % throughout the next 30 years. Although it is determined, that emissions not mitigated by 2050 will be removed, e.g. via natural carbon sinks such as forests and carbon capture and storage technologies [2], there are still uncertainties concerning carbon storage in geological structures related to long-term leakage and safety, as well as storage in oceans due to possible negative impacts on ecology [3]. In addition, carbon storage technologies can be expensive [4]. Meanwhile, the possibilities for increasing natural carbon sequestration are ambiguous, taking into consideration the growing demand for bio resources. This confirms that the primary focus must be on reducing emissions to the maximum already at the production stage. Considering the past progress in emission reduction, introduction of the Green Deal will demand a completely new approach to the economy and quite drastic

* Corresponding author.
E-mail address: beate.zlaugotne@rtu.lv

measures in all sectors of economy. It is clear it will possess serious challenge for all EU countries. However, it is also obvious that the starting point differs widely, bringing variations in the degree of challenge.

In this paper multi-criteria decision analysis (MCDA) is applied to determine the present position of eight selected EU countries (Denmark, Estonia, Ireland, Latvia, Lithuania, Slovenia, Finland and Sweden) in terms of GHG performance. Various indicators are applied, along with GHG emissions considering economic, political, and social and energy consumption factors. This comparison allows determining what the starting points for various countries are and which could take the lead in reaching carbon neutrality. Moreover, taking into account that countries influence each other's energy, environment and economic conditions [5], such comparison can be useful in researching the links between countries. Regarding Latvia, it gives the opportunity to detect its position compared to other EU countries and to judge on the required intensity of the necessary measures. For countries at worse GHG positions, this comparison shows the roadmap for the implementation of successful policies.

2. EVALUATION OF GHG PERFORMANCE

Greenhouse gas inventory, prepared by the European Environment Agency (EEA), ranks the EU countries according to the total amount of their GHG emissions. On the EU level, progress in GHG emission reduction is mainly measured by the annual changes of the total GHG amount, changes since 1990 and (or) regarding the achievement of national targets [6]. Although, the criterion regarding carbon-neutrality achievement is net GHG emissions, implementation of various indicators allows determining how advantageous countries are in terms of GHG emission reduction.

GHG performance is often evaluated as a part of a broader environmental performance and sustainability assessments [7]–[9]. Along with direct GHG indicators, such as the total GHG emissions per country or GHG emissions per capita, such evaluations often include factors, which do not directly express the GHG emissions while still being closely related. Such factors include: the share of renewable energy [7]–[12], energy consumption [7], [8], [10], [11], environmental or energy taxes [7], [9], [10], [12], environmental protection expenditure [12] and others.

There are few studies investigating environmental indicators with the aim to evaluate GHG performance. Some are discussed below. Also, many studies have focused on the drivers of GHG emission reduction. Arguably, the most important are the increase of energy efficiency [13]–[15] and renewable energy [9], [13]. Although, [15] reported that the impact of the share of renewable energy was insignificant in GHG emission reduction, while policies to increase energy efficiency were assessed to have a greater impact.

Lately countries are often grouped into categories according to their GHG performance as an attempt to give a general demonstration of similarities and differences and search for correlations. For example, [16] established a method of four quadrants to compare the countries' performance in emission intensity, carbon removal rate, and net reduction rate of GHG emissions from 1991 to 2012. Such division is based on absolute emission quantity, as well as relative emission quantity (the ratio of GHG emissions and GDP) and trends in GHG emissions (the annual net reduction of GHG emissions). According to [16] related calculations, Latvia was the only country in the EU28 to report net GHG removal in 2012. Latvia along with other countries, including Lithuania and Estonia, was grouped in Quadrant I, representing countries with high emission intensities and high carbon removal rates. On the contrary, Germany stood out with significantly high net GHG emissions. However, due to Germany's low emission intensity it was located in Quadrant III representing countries with low emission intensities and low carbon removal rates. Quadrant II grouped countries representing low emission intensities and low carbon removal rates (for instance, Sweden), while Quadrant IV grouped countries with high emission intensities and low carbon removal rates (e.g. Poland).

Meanwhile, [17] grouped the EU countries into clusters according to their similarities in emissions of four types of GHG to examine the diversity of European countries in terms of GHG emissions. Four clusters regarding the application of k-means algorithm and Euclidian distance have been developed. The clusters were classified according to the amount of emissions. In this evaluation, two approaches were used – the total GHG emissions per country and the GHG emissions per capita. Grouping of the total emissions and grouping of the emissions per capita resulted in different sizes of clusters, which highlighted the question of whether countries should be evaluated by their total emissions or emissions per capita. A similar study [18] grouped countries into clusters by applying agglomeration algorithm. In other investigations [15], [16], [18] countries were evaluated by a narrow set of indicators, and the purpose of such evaluations was to group countries rather than to compare to each other in order to assess the best and the worst performances. The aim of this paper is to rank the selected EU countries according to their GHG performance by offering a set of economic, political, and social indicators.

3. GHG Emission Profile of the Selected EU Countries

For the comparison of GHG performance, eight EU countries have been selected, ensuring that different national environmental, economic and political backgrounds are covered. The main point of reference for selecting countries for comparison was the GHG intensity of energy consumption. Latvia was chosen as the main focus of analysis, alongside Ireland and Slovenia, classified as medium GHG intense. Estonia and Lithuania were selected as the countries with high GHG intensity, whereas Finland, Denmark and Sweden were chosen to represent countries with relatively low GHG intensity.

Eurostat data analysis from 2005 to 2015 indicates that Estonia had the highest average GHG emissions per capita (15.2 t CO_2 eq./capita) (Fig. 1), followed by Ireland (14.4 t CO_2 eq./capita), while the lowest GHG emissions were achieved by Latvia (5.7 t CO_2 eq./capita), Sweden (6.7 t CO_2 eq./capita) and Lithuania (7.1 t CO_2 eq./capita).

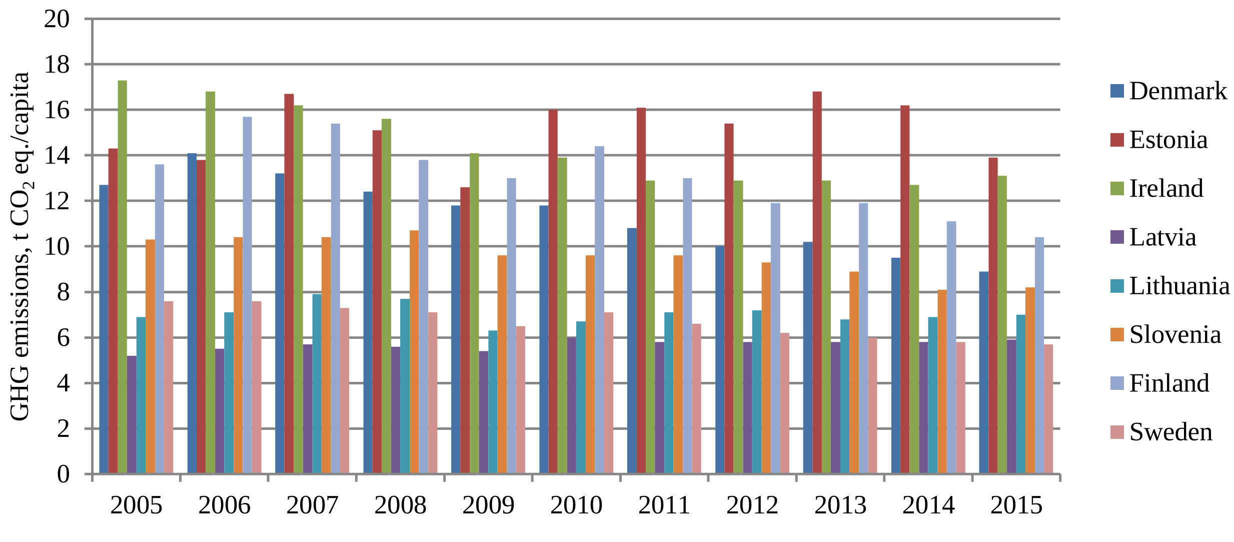


Fig. 1. GHG emissions per capita.

During the studied period, Sweden had the best performance regarding renewable energy consumption. All countries have made improvements in the share of renewable energy. Some countries such as Sweden, Finland, and Denmark have made improvements by more than 10 % in a 10-year-period.

In terms of environmental taxes, Denmark had the highest performance. Denmark has the second highest tax rate in the EU energy sector. Slovenia has been approaching Denmark's environmental tax revenues since 2012, as Slovenia has higher tax rate on transport fuels than on fuels used for energy production – heating or electricity.

From all selected countries, Estonia has the highest CO_2 emissions, which is the second highest value in the EU after Luxembourg. The main reason for the high emissions in Estonia is electricity production from oil shale, which accounts for about 90 % of the total CO_2 pollution, and recently oil shale has also been used for liquid fuel (diesel) production [19]. However, Estonia has set ambitious goals to increase electricity production from biomass [20]. Ireland is also a significant source of CO_2 emissions with most of the emissions coming from industry and agriculture [21], and Finland, where emissions from energy sector are mainly generated by utilization of natural gas and peat [22]. Overall, in a 10-year-period, emissions are decreasing periodically, except for Estonia where the trend is uneven.

The total consumption of solid fossil fuel is low in Estonia, Latvia and Lithuania in comparison to other selected countries. Generally, the consumption of solid fossil fuels is decreasing. Finland stands out with significantly high values for this indicator because over half of its heat is generated from solid fossil fuels.

Households hold an important position in the total energy consumption and represent the overall energy consumption image of a population. Household energy consumption per capita is the lowest in Lithuania, while Finland scores the highest. All the selected countries have reduced their household energy consumption over recent years.

Eurostat data indicates that the investment share of GDP was high during a period from 2005 to 2008 for all selected countries, and in 2009 it decreased by 10 % on average, which can be related to the global financial crisis. However, the investment share for all countries started to increase afterwards. The highest average investment share was in Estonia (28.5 %).

4. METHODOLOGY

4.1. Methodology Algorithm

The evaluation process consisted of four main steps (Fig. 2). First, eight EU countries for the comparison have been selected. Next, criteria for GHG performance evaluation have been chosen, followed by the determination of their importance with the application of AHP (Analytic hierarchy process). Lastly, the ranking of countries' GHG performance was made using the TOPSIS method.

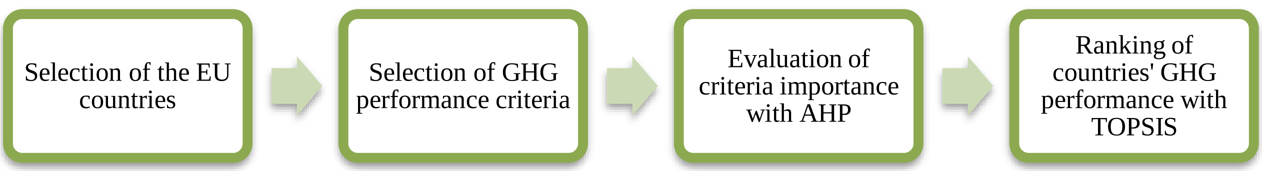


Fig. 2. Methodology algorithm.

MCDA (Multi-criteria decision analysis) is a set of processes by which problems are solved, when problems, alternatives and criteria are defined. There are dozens of methods for calculating the best alternatives, 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 [23]. As far as the TOPSIS method is concerned, 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. 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) [24]. All criteria are compared to each other assigning values from 1 to 9. After calculations, each criterion has a weight and is further used in ranking alternatives.

4.2. Selection of Criteria

Based on the information provided in literature, as well as considering the available data, six criteria were chosen for the evaluation of GHG performance (Fig. 3). GHG emissions per capita were chosen as a widely used indicator in many studies and EU reports, as well as a basic representative factor of countries' emissions level. Income from environmental taxes was selected as an indicator representing the overall role of environmental protection in the national tax system, expressed as a percentage of the total income from taxes. Household energy consumption per capita was expressed as kg of oil equivalent, and it allowed to easily compare the energy needs of population.

Investment share of GDP is an indicator used to monitor progress towards EU Sustainable Development Goals and represents the level of economic productivity. Consumption of solid fossil fuels was chosen as a basic representative of the amount of the main GHG generating fuels, and was expressed in absolute values of thousand tonnes. Last, renewable energy consumption represents the achievements towards clean energy, and was expressed as a share of consumed renewable energy in gross final energy consumption.

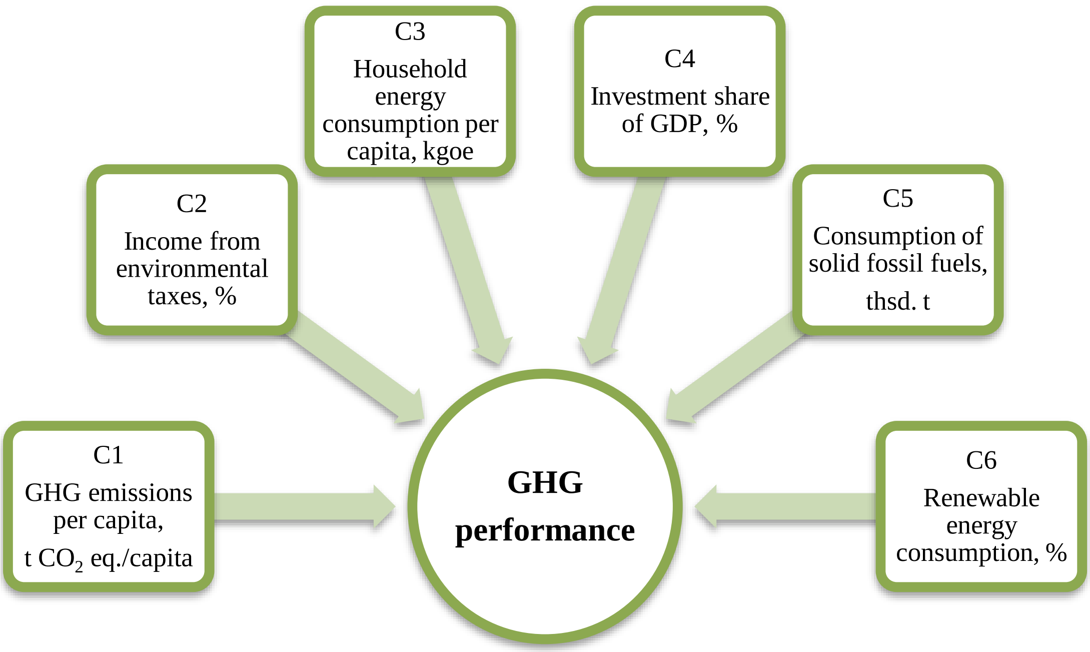


Fig. 3. GHG performance criteria.

4.3. Evaluation of Criteria Weight

After defining criteria, their weight was evaluated. All criteria were compared in pairs and attributed with values on a scale from 1 to 9, where 1 means that the criteria are equally important and 9 means that one criterion is absolutely more important than the other comparable criterion. Criteria weights were determined with expert judgement method. Two experts of the environmental science participated in the evaluation process. The mean values from expert judgements can be seen in Table 1.

Criterion with the highest attributed importance was GHG emissions per capita (32 %), while all other criteria were significantly less important. In addition, Table 1 indicates the desired direction for criteria values. Minimal values are desired for GHG emissions, energy consumption, investment from GDP and solid fuel consumption criteria, while the maximal values are desired for income from environmental taxes and renewable energy consumption. AHP analysis gave a consistency index (CI) of 0.118 and consistency ratio (CR) of 0.095 indicating that the pair-wise comparisons are consistent.

TABLE 1. CRITERIA WEIGHTS

Criteria		Weight	Best values
C1	Greenhouse gas (GHG) emissions per capita	32 %	MIN
C2	Income from environmental taxes	19 %	MAX
C3	Household energy consumption per capita	15 %	MIN
C4	Investment share of GDP	13 %	MIN
C5	Solid fuel consumption	13 %	MIN
C6	Renewable energy consumption	8 %	MAX

The statistical 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 2.

TABLE 2. TOPSIS INPUT DATA

		A1	A2	A3	A4	A5	A6	A7	A8
		Denmark	Estonia	Ireland	Latvia	Lithuania	Slovenia	Finland	Sweden
C1	Greenhouse gas (GHG) emissions per capita	0.481	0.613	0.760	0.602	0.472	0.559	0.741	0.517
C2	Income from environmental taxes	0.282	0.500	0.797	0.494	0.273	0.527	0.614	0.565
C3	Household energy consumption per capita	0.552	0.432	0.575	0.632	0.615	0.558	0.411	0.573
C4	Investment share of GDP	0.420	0.470	0.442	0.419	0.355	0.412	0.466	0.319
C5	Solid fossil fuel consumption	0.475	0.469	0.382	0.615	0.484	0.696	0.435	0.612
C6	Renewable energy consumption	0.434	0.530	0.465	0.445	0.388	0.549	0.421	0.539

5. RESULTS

Results of the TOPSIS analysis indicate that the best GHG performance is reached by Sweden, which achieved a coefficient of 0.64 (Table 3). Sweden was expected to rank first, as it has showed high performance in other studies evaluating sustainability and environmental performance (e.g. [9] and [11]). Also, it has one of the lowest GHG emissions per capita and the share of renewable energy is one of the highest as well. Regarding other indicators, Sweden reached 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 for this indicator may be explained by the size of its population and industry or other factors related to consumption of resources.

TABLE 3. RESULTING COUNTRY COEFFICIENTS

Denmark	Estonia	Ireland	Latvia	Lithuania	Slovenia	Finland	Sweden
A1	A2	A3	A4	A5	A6	A7	A8
0.463	0.497	0.538	0.424	0.457	0.499	0.481	0.644
6	4	2	8	7	3	5	1

Despite the highest GHG emissions per capita, Ireland ranks second in GHG performance evaluation (Fig. 4). 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 were considered rather average.

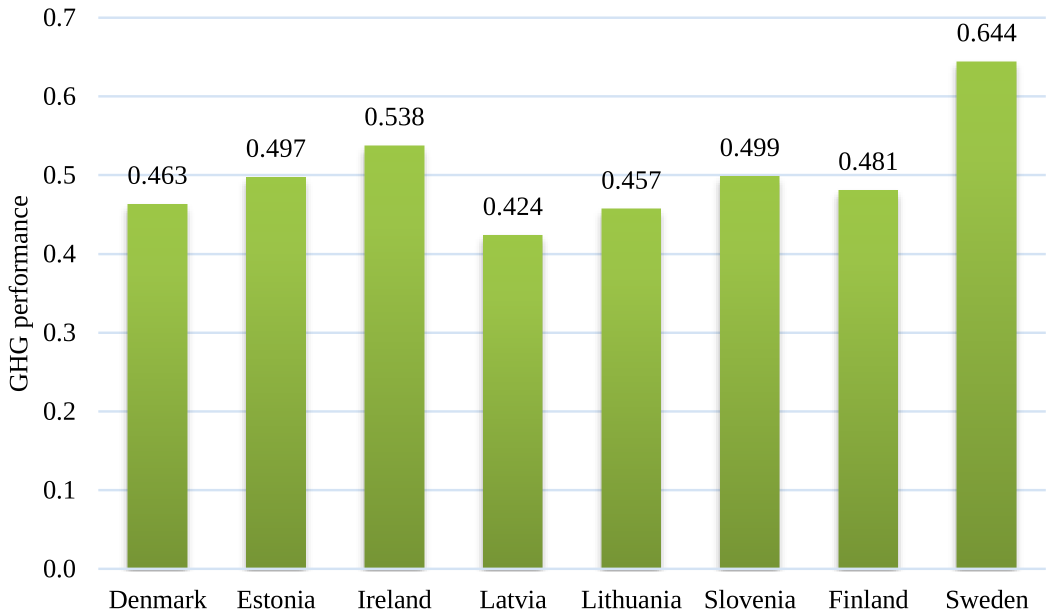


Fig. 4. Ranking of countries' GHG performance.

However, it is important to consider that evaluations were made from the average values for a period from 2005 to 2015, therefore, development trends of indicator values were not considered.

For example, the share of income from environmental taxes in 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.

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

The results indicate that Estonia and Slovenia perform almost equally in terms of GHG performance. Both countries have similar values for most 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 for the share of income from environmental taxes and renewable energy consumption which arguably results in the low overall GHG performance.

6. CONCLUSION

The aim of the paper was to rank selected EU countries according to their GHG performance. Several indicators were implemented, covering aspects of energy consumption, as well as considering political (environmental taxes), economic (investment) and social (population size) factors. The ranking was performed with TOPSIS method, which allowed a simple comparison of the criteria.

Results indicate that from all the compared countries Sweden is at the most desired position in terms of GHG performance and has the most promising starting point to achieve carbon-neutrality by 2050. Sweden had relatively good values for the most of the selected criteria, and therefore its implemented policies could work as an example for other countries.

Despite the fact that Latvia performs rather well in many environmental and sustainability assessments of the EU countries (e.g. [10] and [15]), results show that it holds the lowest position in terms of GHG performance in comparison to the other selected EU countries. This indicates that achievement of carbon neutrality by 2050 will be a particular challenge to Latvia. Results suggest that one of the focus points for Latvia should be reducing its energy consumption, which, arguably, can be achieved by increasing energy efficiency.

Although some countries perform better than others in terms of GHG performance, it has been highlighted that the current policies will only reduce EU's GHG emissions by 60 % by 2050 [1], therefore, all countries need to take drastic measures in reorganizing their policies to achieve clean energy and sustainable economy.

Further studies should arguably focus on:

- Implementation of additional indicators to arrive at a more precise countries' ranking;
- Application of quantitative data for the determination of criteria weights;
- Application of methods that allow to investigate connections between indicators, thus revealing the necessary focuses for policy development;
- Consideration of the past progress of indicator values, which would make the evaluation more future-oriented.

With the above-mentioned and other slight improvements, the presented GHG performance evaluation could be a useful tool in planning the implementation of policies to reach the Green Deal settings on European, as well as on a national level.

ACKNOWLEDGEMENT

The research is funded by the Ministry of Economics of the Republic of Latvia, project "Assessment of Latvia's renewable energy supply-demand economic potential and policy recommendations", Project No. VPP-EM-2018/AER-1-0001.

REFERENCES

[1] European Commission. The European Green Deal. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. Brussels, 2019.
[2] European Commission. Clean energy. The European Green Deal. 2019.
[3] Lee H. *Climate Change Biology*, 1st ed. Academic Press, 2010.
[4] Lal R. Carbon sequestration. *Philosophical Transactions of the Royal Society B* 2008:363(1492):815–830. https://doi.org/10.1098/rstb.2007.2185
[5] Bajcinovci B. Environment quality: Impact from traffic, power plant and land morphology, a case study of Prishtina. *Environmental and Climate Technologies* 2017:19(1):65–74. https://doi.org/10.1515/rtuect-2017-0006
[6] Danila A. M., et al. Annual European Union greenhouse gas inventory 1990 – 2016 and inventory report 2018. Copenhagen: EEA, 2018.
[7] Luzzati T., Gucciardi G. A non-simplistic approach to composite indicators and rankings: An illustration by comparing the sustainability of the EU Countries. *Ecological Economics* 2015:113:25–38. https://doi.org/10.1016/j.ecolecon.2015.02.018
[8] Antanasijević D., et al. A differential multi-criteria analysis for the assessment of sustainability performance of European countries: Beyond country ranking. *Journal of Cleaner Production* 2017:165:213–220. https://doi.org/10.1016/j.jclepro.2017.07.131
[9] Moutinho V., Madaleno M., Robaina M. The economic and environmental efficiency assessment in EU cross-country: Evidence from DEA and quantile regression approach. *Ecological Indicators* 2017:78:85–97. https://doi.org/10.1016/j.ecolind.2017.02.042
[10] García-Álvarez M. T., Moreno B., Soares I. Analyzing the sustainable energy development in the EU-15 by an aggregated synthetic index. *Ecological Indicators* 2016:60:96–1007. https://doi.org/10.1016/j.ecolind.2015.07.006
[11] Siksnelyte I., Zavadskas E. K., Bausys R., Streimikiene D. Implementation of EU energy policy priorities in the Baltic Sea Region countries: Sustainability assessment based on neutrosophic MULTIMOORA method. *Energy Policy* 2018:125:90–102. https://doi.org/10.1016/j.enpol.2018.10.013
[12] Cucchiella F., et al. A comparison of environmental and energetic performance of European countries: A sustainability index. *Renewable and Sustainable Energy Reviews* 2017:78:401–413. https://doi.org/10.1016/j.rser.2017.04.077
[13] De Alegría I. M., et al. Spain's fulfillment of its Kyoto commitments and its fundamental greenhouse gas (GHG) emission reduction drivers. *Renewable and Sustainable Energy Reviews*, 2016:59:858–867. https://doi.org/10.1016/j.rser.2015.12.208
[14] Cruz L., Dias J. Energy and CO_2 intensity changes in the EU-27: Decomposition into explanatory effects. *Sustainable Cities and Society* 2016:26:486–495. https://doi.org/10.1016/j.scs.2016.03.007
[15] Štreimikiene D., Balezentis T. Kaya identity for analysis of the main drivers of GHG emissions and feasibility to implement EU '20-20-20' targets in the Baltic States. *Renewable and Sustainable Energy Reviews* 2016:58:1108–1113. https://doi.org/10.1016/j.rser.2015.12.311
[16] Su M., et al. Greenhouse gas emission accounting for EU member states from 1991 to 2012. *Applied Energy* 2016:184:759–768. https://doi.org/10.1016/j.apenergy.2016.02.074
[17] Kijewska A., Bluszcz A. Research of varying levels of greenhouse gas emissions in European countries using the k-means method. *Atmospheric Pollution Research*. 2016:7(5):935–944. https://doi.org/10.1016/j.apr.2016.05.010
[18] Kijewska A., Bluszcz A. Analysis of greenhouse gas emissions in the European Union member states with the use of an agglomeration algorithm. *Journal of Sustainable Mining* 2016:15(4):133–142. https://doi.org/10.1016/j.jsm.2017.02.001
[19] Randma T. Estonia needs a plan and support to get rid of its dirty oil shale. Energy Post, 2018.
[20] Volkova A., Latosov E., Siirde A. Heat Storage Combined with Biomass CHP under the National Support Policy. A Case Study of Estonia. *Environmental and Climate Technologies* 2020:24(1):171–184. https://doi.org/10.2478/rtuect-2020-0011
[21] O'Sullivan K. Ireland has third highest emissions of greenhouse gas in EU. The Irish Times, 2019.
[22] Statistics Finland. Greenhouse gas emissions increased, emission allocation exceeded. Environmental and natural Resources 2019. Helsinki, 2019.
[23] Opricovic S., Tzeng G. H. Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. *European Journal of Operational Research* 2004:156(2):445–455. https://doi.org/10.1016/S0377-2217(03)00020-1

[24] Leal J. E. AHP-express: A simplified version of the analytical hierarchy process method. *MethodsX* 2020:7:100748. https://doi.org/10.1016/j.mex.2019.11.021

Beate Zlaugotne, M. sc. ing. student, research assistant at RTU Institute of Energy Systems and Environment (IESE). The main areas of research are the analysis of multi-criteria decisions and the use of renewable energy sources and their alternatives.
E-mail: Beate.Zlaugotne@rtu.lv

Linda Ievina, M. Sc. env. works as a researcher at Institute of Energy Systems and Environment, Riga Technical University. Her research interests are related to renewable energy and sustainable use of resources, as well as the application of geographic information systems in energy development planning. Currently she is working on her PhD thesis on the spatial distribution of renewable energy sources in Latvia.
E-mail: Linda.Ievina@rtu.lv

Denis Baranenko graduated with honours from the Saint-Petersburg State University of Refrigeration and Food Engineering (later – Institute of Refrigeration and Biotechnologies, ITMO University) in 2003. He received the PhD degree from the same university in 2006. Since 2006 works there as an associate professor, from 2011 directed the work of a research laboratory, from 2014 heads the International research centre “Biotechnologies of the Third Millennium”.
Research interests: resource and energy saving food biotechnologies, biologically active compounds, functional food products.
E-mail: denis.baranenko@niuitmo.ru

Reinis Azis, M. sc. He has received his Bachelor’s degree in the field of international politics, Master’s degree in the field of environmental science in Riga Technical University, Latvia (2017) and since 2017 is a PhD student of environmental science in Riga Technical University, Faculty of Electrical and Environmental Engineering. Reinis Azis works in Investment and Development Agency of Latvia - since 2018 as a Representative Office Head in the United Kingdom, now as a Deputy Director in Latvia. Research interests: energy politics, innovative technologies, financial instruments and technology development.
E-mail: reinis.azis@gmail.com

Dagnija Blumberga, Dr. habil. sc. ing., professor, director of the Institute of Energy Systems and Environment, Riga Technical University. Her two-step doctoral degree “Condensing Unit” was defended in Lithuanian Energy Institute, Kaunas (1988). Doctor Habilitus Thesis “Analysis of Energy Efficiency from Environmental, Economical and Management Aspects” was prepared in Royal Institute of Technology (KTH) Stockholm (1995) and was defended in Riga Technical University (1996).
Dagnija Blumberga has been part of academic staff of Riga Technical University since 1976 and director of Institute of Environmental Protection and Energy Systems since 1999.
The main research area is renewable energy resources. She has participated in different local and international projects related to energy and environment as well as an author of more than 200 publications and 14 books.
E-mail: dagnija.blumberga@rtu.lv
ORCID iD: https://orcid.org/0000-0002-9712-0804

IMPORTANCE OF ENERGY EFFICIENCY IN MANUFACTURING INDUSTRIES FOR CLIMATE AND COMPETITIVENESS

Environmental and Climate Technologies
2021, vol. 25, no. 1, pp. 306–317
https://doi.org/10.2478/rtuect-2021-0022
https://content.sciendo.com

Importance of Energy Efficiency in Manufacturing Industries for Climate and Competitiveness

Kristiāna DOLGE[1*], Reinis ĀZIS[2], Peter D. LUND[3], Dagnija BLUMBERGA[4]

[1, 2, 4] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV–1048, Latvia*

[3] *Aalto University School of Science, PO Box 15100, FI-00076, Aalto, Espoo, Finland*

***Abstract* – The manufacturing industry in Europe is currently enfacing one of its greatest challenges due to the emission reductions needed to reach carbon neutrality by the middle of this century. The European Union's Energy Efficiency Directive and Green Deal will force manufacturing industries to significantly reduce their present energy consumption, but at the same time sustain their competitiveness globally. Here we use the Latvian manufacturing industry as a case to analyse how different macro-level factors have affected its energy use and how the industrial energy efficiency has progressed during the last decade. We apply the Log-Mean Divisia index decomposition method to decompose the energy use in the manufacturing subsectors over the period of the past ten years from 2010 to 2019. The findings unravel the key driving factors of industrial energy consumption, which could serve as a valuable basis for effective energy efficiency policymaking in the future. The results show that energy consumption trends differed across industrial subsectors and the effect of industrial energy efficiency improvements was more pronounced in the period following the entry into force of Energy Efficiency Law in Latvia. Significant increases in energy consumption are observed in the two largest Latvian manufacturing subsectors, such as the non-metallic minerals production sector and the wood processing sector, where the current pace of energy efficiency improvements cannot compensate for the effect of increasing industrial activity, which increases overall industrial energy consumption. The results suggest that the Latvian manufacturing industry is at the crossroads of the sustainability dilemma between economic gains and energy saving targets.**

***Keywords* – Energy efficiency; energy policy; decomposition analysis; LMDI; manufacturing industry**

1. INTRODUCTION

'Energy efficiency first' is a strategic priority and one of the key principles of the EU Climate Action Plan and the European Green Deal strategy [1]. In terms of energy consumption in the EU, the manufacturing industries represent 25 % [2] of the total energy consumption, for which reason energy efficiency improvements in this sector could have major positive effects for emission reductions. The ambitious energy savings targets of the EU are in particular challenging for the Latvian manufacturing industry, which represents 20 % of country's total energy use [2]. Consequently, the Latvian manufacturing industry needs to reduce its energy consumption while maintaining competitive economic growth and increasing production output, that is to achieve 'more with less energy'. At the same time,

* Corresponding author.
E-mail address: kristiana.dolge@rtu.lv

the Latvian industry sector showed the highest increase (+14 %) in energy consumption among all the EU member states during the period from 2005 to 2018 [3]. Investigating the reasons for the energy consumption changes in the Latvian manufacturing industry would therefore be of high interest, also to explain how energy efficiency measures have progressed.

Previous studies show that there are two main motives behind energy efficiency measures in manufacturing industry companies [3]. Firstly, energy efficiency helps to reduce the environmental impact from the production processes and the CO_2 emissions from fuel combustion and electricity consumption; Secondly, energy savings reduces the energy costs and improves both the financial and economic position of the company and its competitiveness on global markets. In the previous studies on energy efficiency in Latvian industry [4], [5], the authors started to investigate the differences in energy efficiency of individual subsectors using the composite index methodology. The results of these studies showed that there are sectoral heterogeneities in all dimensions of sustainability of the manufacturing sector, which should be considered when designing an effective energy efficiency policy.

Since the introduction of European Energy Efficiency Directive in 2012 and Latvian Energy Efficiency Law in 2016, academic studies and research have been conducted to analyse industrial energy efficiency in Latvia. Kubule *et al.* (2020) conduct a study analysing the preliminary results of the national energy efficiency monitoring program. The paper argues that the energy efficiency potential in Latvian manufacturing companies is significantly higher than indicated in the program's requirements. Indeed, the authors note that the technical potential reaches 40 % of total final energy consumption in a number of enterprises [6].

A study by Ločmelis *et al.* (2021) compares the energy intensity of Latvian industry with the Baltic States, Germany and the EU average [7]. The results show that Latvian industry has higher energy intensity at the macro level compared to its peers. The authors argue that sectoral differences should be taken into account to design more effective policy instruments. Given the already largely decarbonized energy mix of Latvia's manufacturing industry, a CO_2 tax may not be the most efficient instrument that makes the highest contribution [7].

Kubule & Blumberga (2019) conduct a sustainability analysis of the manufacturing sector in Latvia by selecting eight performance indicators and comparing different subsectors using multi-criteria decision analysis. The results show that the non-metallic minerals manufacturing sector achieves the lowest sustainability score compared to other sectors [8].

A study by Timma *et al*. (2016) analyses the impact of structural and technological changes on energy intensity in all Latvian economic sectors, including manufacturing, in the period from 2008 (during the global financial crisis) to 2012 (post-recession recovery period). The results show that the manufacturing sector was one of the main drivers of fluctuations in total energy consumption during this period. The technology effect in manufacturing was the main driver of the decline in total energy intensity [9].

Miskinis *et al.* (2020) conducts a study on energy efficiency trends in the Baltic States, which includes the analysis of industry. The results show that energy intensity in industry decreased significantly in both Estonia and Lithuania, while in Latvia the energy intensity of industry increased in the period from 2000 to 2018. The authors explain this by significant growth in the sector of non-metallic minerals production and wood processing, which are very energy intensive after the global recession in 2009. Moreover, the results of the study showed that modernisation and innovation in industry had the lowest impact on the overall energy intensity of the Latvian economy compared to other sectors during the period [10].

This paper aims to extend the scope of previous research by examining changes in manufacturing energy efficiency over time, thus unravelling the main drivers of industrial energy consumption in the past and discovering how these factors influence different industrial subsectors separately. The index decomposition analysis method is applied to measure the changes in energy consumption in all Latvian manufacturing subsectors over a ten-year period from 2010 to 2019. To the authors' knowledge, there is no such studies in Latvia that applies the Log-Mean Divisia index technique to investigate the trends in industrial energy efficiency over the last ten years, when an increasing urgency for energy efficiency was observed among Latvian manufacturing companies. Therefore, the results of this study could significantly contribute to the overall understanding of the key drivers of industrial energy efficiency and be used as a valuable tool for policy making. The competitive advantage of the decomposition analysis method is that it allows to perform an in-depth ex-post data analysis of the main drivers of industrial energy consumption, combining both - economic indicators and energy consumption indicators. The method enables an integrated assessment of the dynamics of industrial energy efficiency trends and thus provides a better understanding of how changes in industrial production volumes interact with the pace of energy efficiency improvements. Existing methods for assessing energy efficiency in industry analyse energy consumption trends using figures from a specifically chosen base year. However, decomposition analysis allows for a more detailed assessment by focusing on the study of the dynamic changes affecting industrial energy consumption trends.

2. METHODOLOGY

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. The decomposition analysis method was introduced in the late 1970s [11]; and its application was first demonstrated by Ehrlich and Holdren, who used the IPAT/Kaya identity framework to analyse the environmental and climate change impacts of changes in population, affluence and technology [12]. The decomposition analysis 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 to study progress towards the achievement of energy saving targets in the context of the Energy efficiency directive and National Energy and Climate plans[13]. Some of them include internationally recognized organizations such as the European Commission [14], the International Energy Agency [15], the European Commission's Joint Research Centre (JRC), the United Nations Industrial Development Organization [16], the Agency's for Ecological Transition (ADEME) project Odysee-Mure, and many others [17].

Index decomposition analysis (IDA) is based on the fundamental principle that changes in the aggregate indicator are determined by a list of carefully predefined factors such as economic activity, structural shift , energy consumption trends, technology improvement effect, and others depending on the dependent variable of the research study and fundamental governing function [11]. Theoretical foundation of IDA approaches in energy studies was summarized and described in a study by [11] that presented a methodological algorithm for choosing the most appropriate energy decomposition analysis method. The author discusses different aspects and properties of applying either the Divisia index or Laspeyres index decomposition techniques. The paper concludes that compared with other IDA approaches the 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 [11]. The advantageous properties of the LMDI I method is further demonstrated in numerous energy analysis and climate change assessment studies, including in-depth energy efficiency progress evaluation in manufacturing industry [18]–[21].

Moreover, in recent years, the application of IDA methods has skyrocketed in the field of energy policymaking [22]. IDA method is practically applied in the field of national energy efficiency progress tracking, energy generation and demand research, greenhouse gas emission reduction monitoring, as well as supply chain investigation and cross-country comparison [11]. The LMDI I approach is widely demonstrated in both – academic studies and global energy assessment reports [23]–[25]. Taking into account successful examples of LMDI I utilization and its competitive advantage over other index decomposition methods such as the arithmetic mean Divisia index method (AMDI), Fisher ideal index method, Marshall-Edgeworth method [11], the LMDI I method was chosen as the most appropriate technique to decompose energy consumption changes in Latvia over the period of 10 years. The LMDI I decomposition analysis was conducted to better understand the underlying factors for the changes in industrial energy demand in different industrial sub-sectors separately and their impact on the overall energy consumption trends in the industry. Prior to the decomposition analysis, the total energy consumption in the manufacturing industry is first determined as the sum of the energy consumption of each industrial sub-sector, which were selected according to NACE Rev. 2 classification and aggregated in groups according to the industry sector statistical division as reported in the international energy balance statistics [26]. The energy consumption of the industry is then decomposed as follows:

$$E = \sum\nolimits_i E_i = \sum\nolimits_i Q \frac{Q_i}{Q} \frac{E_i}{Q_i} = \sum\nolimits_i Q S_i I_i \, , \tag{1}$$

where

E is the total energy consumption;

Q is the total production output expressed as the total generated value added.

The subscript i denotes the representative value of a sub-sector. S_i (=Q_i/Q) and I_i (=E_i/Q_i) are the levels of production activity and the energy intensity of each industrial subsector, which represent the structural and energy intensity effects.

From Eq. (1), the energy consumption in the base year (0) is $E^0 = \sum\nolimits_i Q^0 S_i^0 I_i^0$ and future year (T) is $E^T = \sum\nolimits_i Q^T S_i^T I_i^T$. The changes over time in each of the components in Eq. (1) are determined using the LMDI I additive decomposition analysis technique given in Eq. (2).

$$\triangle E = E^T - E^0 = \triangle E_{act} + \triangle E_{str} + \triangle E_{int} \, , \tag{2}$$

where subscripts *act, str, int* represent the effects from changes in the industrial activity, structure and energy intensity. Each effect is further decomposed in Eqs. (3)–(5):

$$\triangle E_{akt} = \sum\nolimits_i \frac{E^T - E^0}{InE^T - InE^o} In \frac{Akt_1^T}{Akt_1^0} \tag{3}$$

$$\triangle E_{str} = \sum\nolimits_i \frac{E^T - E^0}{InE^T - InE^0} In \frac{Str_1^T}{Str_1^0} \tag{4}$$

$$\triangle E_{\text{int}} = \sum_i \frac{E^T - E^0}{InE^T - InE^0} In \frac{Int_1^T}{Int_1^0} \quad (5)$$

where

E^T represents the energy consumption in year T,

E^0 represents the energy consumption in initial year. The same notation applies for the activity, structure and energy intensity indicators.

The additive approach shown in Eq. (2) was chosen here instead of the multiplicative approach because the aim was to measure the absolute changes in the energy consumption instead of a relative change. Moreover, the additive approach offers a more comprehensive interpretation of the changes which is more desirable for decision making and policy making processes. Table 1 gives a summary of the decomposition analysis and factors and indicators considered.

TABLE 1. 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

*adjusted for price changes

The data used for the decomposition analysis was from the Eurostat and Central Statistical Bureau of Latvia (CSB) databases [2], [27]. To account for possible industry production output data fluctuations due to price changes, all data on sub-sectoral value added were adjusted to producer price changes in the industrial sector [28]. Therefore, the value-added data represent chain-linked volumes of the base year 2010. Moreover, the change index from the base year was constructed to compare the obtained adjusted value-added data with the volume indices of industrial production [29]. Since the available data on production volumes are expressed in the indices by adjusting the values to the base year 2015, the indices for the value-added figures are constructed in the same way. Therefore, the index number of the base year 2015 is set equal to 100 [30]. The comparison between the indices of the volume of production and the constructed indices of value added has shown that the adjusted value-added data at present represent the overall trend of changes in the volume of industrial production, and that only slight variations are observed which have no significant influence on the results. It is therefore justified that the values of total industrial value added can be used for the accurate representation of production volumes.

3. RESULTS

The decomposition method described above was applied to the Latvian manufacturing industry to analyse changes in the total industrial energy consumption during 2010–2019. The results of decomposition analysis are summarized for long-term (Table 2) and short-term (Table 3) aggregated values. The long-term analysis includes the whole period of the study that is a period from 2010 to 2019. The short-term analysis includes the period of past five years from 2015 to 2019. The results clearly show that the main driver for the increase in the energy consumption in the industry was the higher manufacturing activity and economic growth over the period. These results are also supported by the Central Statistical Bureau of Latvia (CSB) and the Macroeconomic Review of Latvia 2020 [31]. According to the CSB data on volume indices of the industrial production, the manufacturing industry was one of the fastest growing sectors in Latvia over the past ten years [29]. Growing demand in the largest export markets stimulated a rapid increase in manufacturing production [32]. Consequently, the manufacturing industry energy consumption increased from 30562 TJ in 2010 to 34133 TJ in 2019, indicting a 12 % increase over the 10-year period. In 2019, the wood products manufacturing (20432 TJ), non-metallic mineral manufacturing (6797 TJ), and food, beverages and tobacco manufacturing (3271 TJ) stood for 89 % of the total manufacturing industry energy end-use [2].

TABLE 2. LONG-TERM DECOMPOSITION FOR THE PERIOD FROM 2010 TO 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	10 243	485	–2281	8446
Textiles, leather, apparel	239	–133	–310	–203
Not elsewhere specified	471	201	176	848
Total	**18 622**	**–6762**	**–8290**	**3570**

The increase in the industrial activity has been the main factor driving up the total manufacturing industry energy consumption in Latvia. In terms of a sub-sectoral comparison, the energy consumption significantly increased in the wood products manufacturing sector (+ 70 %), non-metallic mineral products manufacturing sector (+21 %), and non-specified sectors (these include rubber, plastics, furniture and other manufacturing) (+217 %). The industrial activity in wood manufacturing sector was mostly driven by the increased demand over wood pellets and chips in global export markets. The growth rate in the construction sector also stimulated demand for cement and glass production, and other building materials [33].

The long-term structural effect was driven by two main factors. First, the bankruptcy and market exit of the largest metal manufacturer in Latvia [34] decreased the share of the metal manufacturing of the total industrial energy consumption to historically lowest level. Second, rapid growth of the wood processing industry stimulated the overall restructuring of the manufacturing industry. The manufacturing industry has shifted from one energy intensive sector (metal manufacturing) to another no less energy intensive sector (wood processing). However, a competitive advantage of the wood products manufacturing is the high share of renewable energy (bioenergy) utilization as CO_2 neutral wood residues and chips are used in thermal processes.

Sub-sectoral differences in energy intensity changes are illustrated in Fig. 1. All sectors, except for the wood processing and metal manufacturing sectors indicated a decrease in the energy intensity. The energy intensity of wood processing dropped only during 2015-2019 due to larger efforts in improving the energy efficiency. The same was observed in the manufacturing industry which is partly by the need of improving competitiveness, which can be achieved through reducing the energy costs. Also, policies may also have stimulated setting more ambitious energy efficiency targets in the manufacturing industry [35].

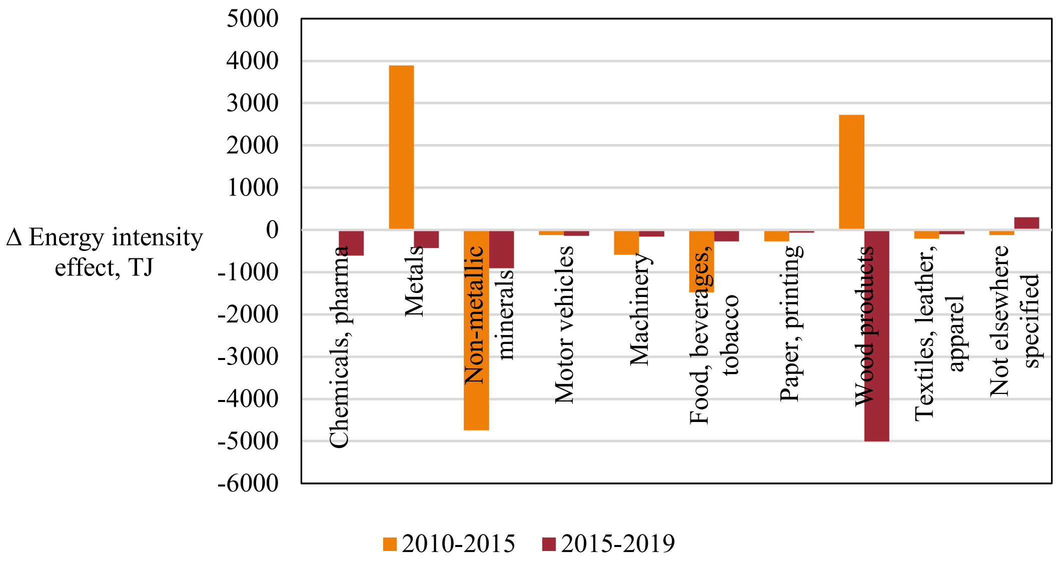


Fig. 1. Energy intensity effect in manufacturing sub-sectors 2010-2019.

TABLE 3. DECOMPOSITION OF ENERGY CONSUMPTION IN MANUFACTURING INDUSTRIES FROM 2015 TO 2019 (TJ)

Manufacturing sub-sector	**Δ Activity effect**	**Δ Structure effect**	**Δ Energy intensity effect**	**Δ Energy consumption**
Chemicals, pharmaceuticals	290	228	–607	–89
Metals	38	–164	–431	–557
Non–metallic minerals	1727	346	–908	1166
Motor vehicles, transportation	84	35	–142	–24
Machinery	199	–53	–156	–9
Food, beverages, tobacco	935	–601	–268	66
Paper, printing	61	13	–62	13
Wood products	5529	1093	–5007	1614
Textiles, leather, apparel	91	–14	–101	–24
Not elsewhere specified	321	131	302	753
Total	**9275**	**1015**	**–7379**	**2911**

The Energy Efficiency Law from 2016 introduced new legislation on energy efficiency in manufacturing industry which also affected the above outcomes [36]. Large manufacturing companies and electricity consumers were obliged to implement a certified energy management system or to carry out regular energy audits, but also to implement at least three energy efficiency measures with highest indicated energy saving potential or economic return [37]. Consequently, manufacturing industry has incorporated new energy efficiency measures such as lighting replacements, improvements in energy management, heating and ventilation, renovation of buildings and investments in energy-efficient equipment [6], [38], However, it seems that the overall energy savings from these measures may have been modest [38]. It has been estimated that the energy efficiency potential in the three largest manufacturing sub-sectors - wood processing, non-metallic mineral production and food and beverage processing – is 16 % if benchmarked with identified technical energy efficiency potentials from a similar program in Sweden, but only 5 % has been identified in Latvian energy audits. This shows that energy efficiency in industry is not fully exploited in Latvia.

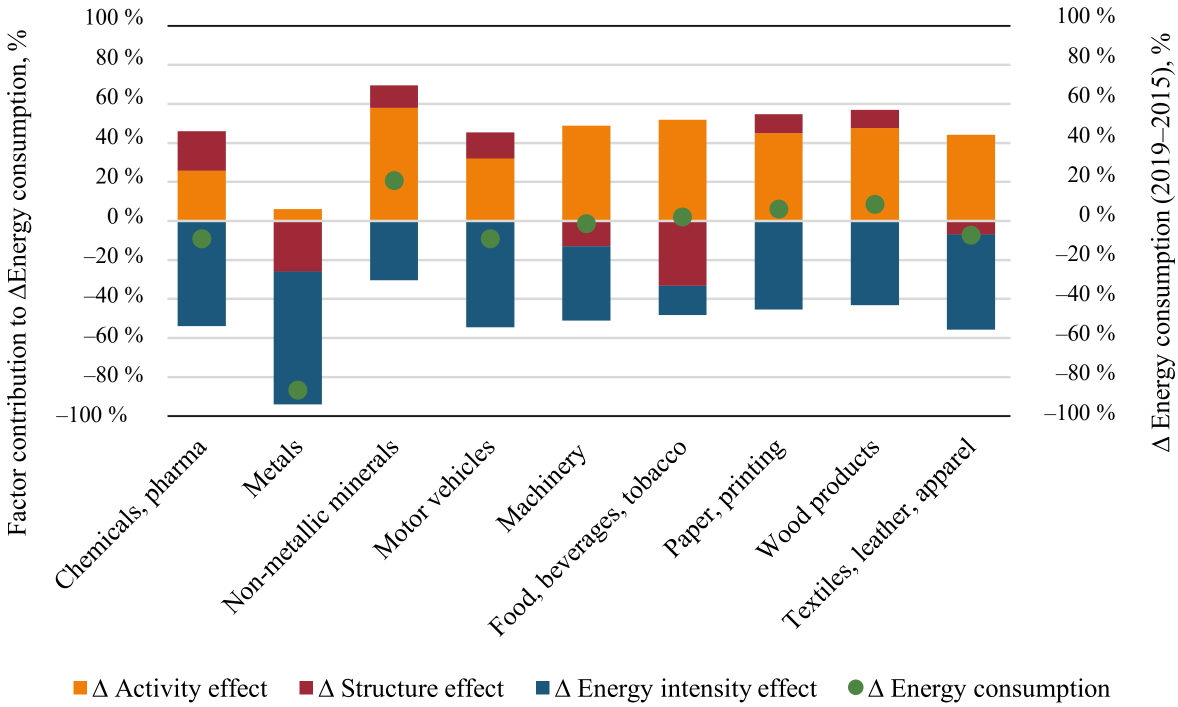


Fig. 2. Energy consumption decomposition for time period from 2015 to 2019.

Energy intensity effect, which also relates to energy efficiency, was the main driver that contributed to the reduction of energy consumption in all manufacturing sub-sectors (except for the non-specified sectors) during 2015–2019, shown in Fig. 2. The results show that despite significant energy efficiency improvements in the three largest manufacturing industry sub-sectors, the total increase in the industrial activity exceeded the positive energy intensity effect. Thus, the current energy efficiency improvements were not able to compensate for the industrial activity effect, which lead to an increase energy consumption. However, without the energy efficiency measures, the increase in the energy use would have been much higher, in some sub-sectors it could have even doubled.

Year-to-year changes in energy consumption for the three largest Latvian manufacturing industry sub-sectors – wood with NACE nomenclature code of C16 (Fig. 3(a)), non-metallic mineral with NACE code of C23 (Fig. 3(b)), and food processing with NACE code of C10-C12 (Fig. 3(c)) sectors were analysed in more detail. The activity effect was the most pronounced in the wood processing industry. Also, in the period from 2010 to 2014 the energy intensity of wood processing increased signalling for a negative energy efficiency trend, which was, however, reversed from 2014 onwards through stronger efforts to improve production efficiency, and consequently the energy intensity started to decrease. The non-metallic mineral production and food processing sector show a different trend as in both sectors higher energy efficiency improvements were already achieved during the first half of the 2010s. The increase in the energy intensity in the non-metallic mineral production sector from 2016 to 2018 could be partly explained by the increase in the energy costs (energy costs per turnover) and increased share of energy costs in overall production costs in the largest glass manufacturing company in the sector [39], [40]. The food processing sector managed to decrease its overall energy consumption despite the growth in overall industrial production output. Historically, the food processing sector had higher EU fund investment financing opportunities compared to other sectors in Latvia [41], [42] leading to modernization of processing lines and hence more efficient energy use [8].

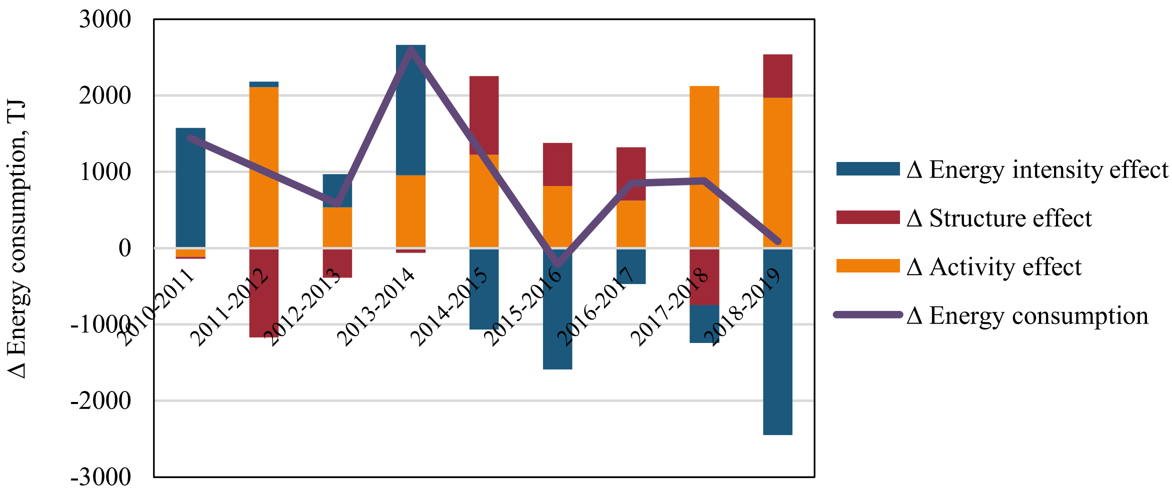


Fig. 3(a). Energy consumption decomposition for the wood processing sector (C16).

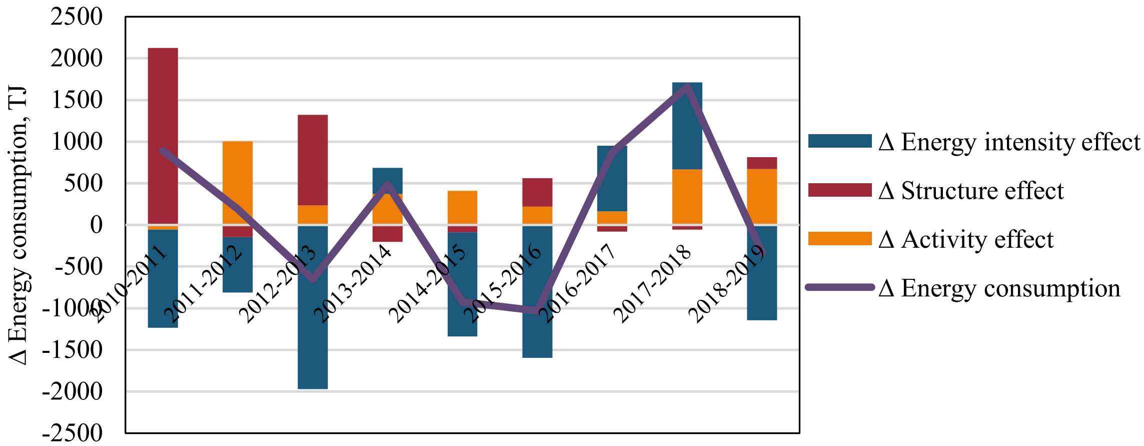


Fig. 3(b). Energy consumption decomposition for non-metallic mineral production sector (C23).

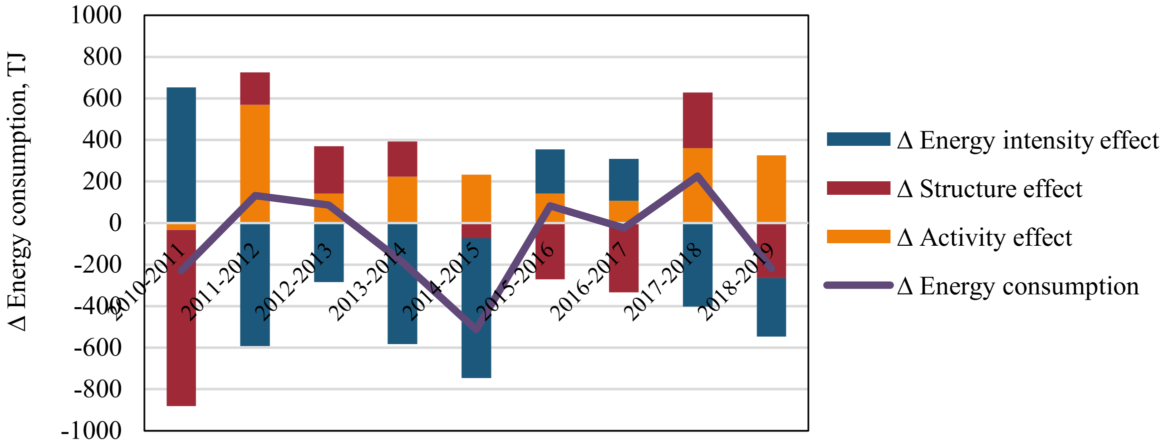


Fig. 3(c). Energy consumption decomposition for food processing sector (C10-C12).

4. Conclusions

In this study, the changes in the energy consumption of the Latvian manufacturing industries were analysed to better understand the factors that have influenced the energy use, but also to quantify the role of energy efficiency improvements. The Log-Mean Divisia index decomposition method was applied to determine the changes in the manufacturing energy consumption due to changes in manufacturing activity, structural effects, and energy efficiency improvements. The ex-post analysis was conducted for a ten-year period from 2010 to 2019.

The results showed that the industrial production activity was the main driver of changes in manufacturing energy consumption. Despite significant improvements in energy efficiency in most manufacturing subsectors, reductions in the energy intensity failed to counterbalance the effect of economic growth in manufacturing firms. Therefore, the current energy efficiency improvements in the Latvia's manufacturing industry need to be accelerated to compensate for the effect of increasing industrial activity. In the future, greater efforts and investments need to be made to implement energy efficiency measures in the manufacturing industry on a much larger scale in order to achieve the targets set by the strategy of the European Green Deal.

The results suggest that changes in the three largest Latvian manufacturing sectors: wood processing, non-metallic minerals production, and food processing, which together consume 89 % of total industrial energy consumption - have a significant impact on the energy performance of the industry. Therefore, sectoral heterogeneity should be better considered in energy policy design. Different incentives could be applied to carbon intensive sectors such as non-metallic mineral production (ETS scheme) and lower carbon intensity sectors such as wood processing (commitment schemes, financing opportunities for factory upgrades).

The approach used in this study allows for an integrated assessment of industrial energy efficiency for more effective policy making and decision making. The same approach could be used to assess industrial energy efficiency in other countries to monitor trends and progress towards regulatory requirements regarding climate neutrality targets. The case of Latvia has shown that the effect of industrial activity in combination with the structural effect plays a crucial role in determining changes in energy consumption. Therefore, energy efficiency should be assessed with a multidisciplinary approach by analysing not only energy consumption data but also economic performance indicators. The results of this study have shown that targets to reduce energy consumption can lead to a sustainability dilemma for fastgrowing industrial sectors where there are opposing effects between production volume and energy use.

The study was limited by having access to the monetary-based industry production data only expressed as adjusted value added. If physical production data form industries were publicly available, more detailed in-depth analyses could be conducted in the future.

ACKNOWLEDGEMENT

This research is funded by the Ministry of Economics of the Republic of Latvia, project 'The pathway to energy efficient future for Latvia (EnergyPath)', project No. VPP-EM-EE-2018/1-0006.

REFERENCES

[1] European Commission. Energy efficiency first: accelerating towards a 2030 objective of 32.5%. 25 September 2019. [Online]. Available: https://ec.europa.eu/info/news/energy-efficiency-first-accelerating-towards-2030-objective-2019-sep-25_en
[2] Eurostat. Complete energy balances [nrg_bal_c]. [Online]. Available: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_bal_c&lang=en
[3] European Commission. REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL 2018 assessment of the progress made by Member States towards the national energy efficiency targets for 2020 and towards the implementation of the Energy Efficiency Directive as required by Article 24(3) of the Energy Efficiency Directive 2012/27/EU pp. 1–19, 2020, [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1574945294711&uri=CELEX:52019DC0224
[4] Dolge K., Kubule A., Rozakis S., Gulbe I., Blumberga D., Krievs O. Towards Industrial Energy Efficiency Index, *Environmental and Climate Technologies* 2020:24(1):419–430. https://doi.org/10.2478/rtuect-2020-0025
[5] Dolge K., Kubule A., Blumberga D. Composite index for energy efficiency evaluation of industrial sector: sub-sectoral comparison. *Environmental and Sustainability Indicators* 2020:8:100062. https://doi.org/10.1016/j.indic.2020.100062
[6] Kubule A., Locmelis K., Blumberga D. Analysis of the results of national energy audit program in Latvia. *Energy* 2020:202:117679. https://doi.org/10.1016/j.energy.2020.117679
[7] Locmelis K., Blumberga A., Bariss U., Blumberga D., Balode L. Industrial Energy Efficiency Towards Green Deal Transition. Case of Latvia. *Environmental and Climate Technologies* 2021:25(1):42–57. https://doi.org/10.2478/rtuect-2021-0004
[8] Kubule A., Blumberga D. Sustainability Analysis of Manufacturing Industry. *Environmental and Climate Technologies* 2019:23(3):159–169. https://doi.org/10.2478/rtuect-2019-0086
[9] Timma L., Zoss T., Blumberga D. Life after the financial crisis. Energy intensity and energy use decomposition on sectorial level in Latvia. *Applied Energy* 2016:162:1586–1592. https://doi.org/10.1016/j.apenergy.2015.04.021
[10] Miskinis V., Galinis A., Konstantinaviciute I., Lekavicius V. Comparative analysis of energy efficiency trends and driving factors in the Baltic States. *Energy Strategy Reviews* 2020:30:100514. https://doi.org/10.1016/j.esr.2020.100514
[11] Ang B. W. Decomposition analysis for policymaking in energy: which is the preferred method? *Energy Policy* 2004:32(9):1131–1139. https://doi.org/10.1016/S0301-4215(03)00076-4
[12] Chontanawat J. Driving Forces of Energy-Related CO_2 Emissions Based on Expanded IPAT Decomposition Analysis: Evidence from ASEAN and Four Selected Countries. *Energies* 2019:12(4):764. https://doi.org/10.3390/en12040764
[13] Economidou M., Román-Collado R. Assessing the progress towards the EU energy efficiency targets using index decomposition analysis in 2005–2016. *Publications Office of the European Union*, 2019. https://doi.org/10.2760/61167
[14] European Commission. Report From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions. Cambridge University Press, 2019.
[15] Ang W. B., Liu N. Energy decomposition analysis: IEA model versus other methods. *Energy Policy* 2007:35(3):1426–1432. https://doi.org/10.1016/j.enpol.2006.04.020
[16] United Nations Industrial Development Organization. Structural decompositions of energy consumption, energy intensity, emissions and emission intensity A sectoral perspective: empirical evidence from WIOD over 1995 to 2009. Vienna, 2015. Available: https://www.unido.org/sites/default/files/2015-12/WP_11_0.pdf

[17] Odysee-Mure. Understanding variation in energy consumption. Methodology, 2020. [Online]. Available: https://www.indicators.odyssee-mure.eu/php/odyssee-decomposition/documents/interpretation-of-the-energy-consumption-variation-glossary.pdf
[18] Talaei A., Gemechu E., Kumar A. Key factors affecting greenhouse gas emissions in the Canadian industrial sector: A decomposition analysis. *Journal of Cleaner Production* 2020:246:119026. https://doi.org/10.1016/j.jclepro.2019.119026
[19] Ang W. B. The LMDI approach to decomposition analysis : a practical guide. *Energy Policy* 2005:33(7):867–871. https://doi.org/10.1016/j.enpol.2003.10.010
[20] Liu N., Ang W. B. Factors shaping aggregate energy intensity trend for industry : Energy intensity versus product mix. *Energy Economic* 2007:29:609–635. https://doi.org/10.1016/j.eneco.2006.12.004
[21] Voigt S., De Cian E., Schymura M.,Verdolini E. Energy intensity developments in 40 major economies: Structural change or technology improvement ? *Energy Economics* 2014:41:47–62. https://doi.org/10.1016/j.eneco.2013.10.015
[22] De Boer P., Rodrigues J. F. D. Decomposition analysis: when to use which method? *Economic Systems Research* 2019:32(1)1–28. https://doi.org/10.1080/09535314.2019.1652571
[23] Ang B. W., Xu X. Y. Tracking industrial energy effi ciency trends using index decomposition analysis, *Energy Economics* 2013:40:1014–1021. https://doi.org/10.1016/j.eneco.2013.05.014
[24] Norman J. B. Measuring improvements in industrial energy efficiency: A decomposition analysis applied to the UK. *Energy* 2017:137:1144–1151. https://doi.org/10.1016/j.energy.2017.04.163
[25] Trotta G. Assessing energy efficiency improvements and related energy security and climate benefits in Finland: An ex post multi-sectoral decomposition analysis. *Energy Economics* 2020:86:104640. https://doi.org/10.1016/j.eneco.2019.104640
[26] Eurostat. Energy balance guide - Methodology guide for the construction of energy balances & Operational guide for the energy balance builder tool, 2019:52. [Online]. Available: https://ec.europa.eu/eurostat/documents/38154/4956218/
[27] Central Statistics Bureau of Latvia. Entrepreneurship indicators of enterprises (SBG010), 2020. [Accessed 10.02.2020]. https://data.stat.gov.lv/pxweb/lv/OSP_PUB/START__ENT__UF__UFR/UFR010
[28] Central Statistics Bureau of Latvia, Producer price changes in industry sector, as per cent of previous year [RCG020]. [Accessed 21.03.2021]. https://data.stat.gov.lv/pxweb/lv/OSP_PUB/START__VEK__RC__RCI/RCI020
[29] Central Statistics Bureau of Latvia, Volume indices of industrial production [RUG031]. [Accessed 21.03.2021]. https://data.stat.gov.lv/pxweb/lv/OSP_PUB/START__NOZ__RU__RUI/RUI020m/
[30] Eurostat. Glossary: Base year, 2021. [Online]. [Accessed 07.06.2021]. Available: https://ec.europa.eu/eurostat/statistics-explained/SEPDF/cache/13447.pdf
[31] Ministry of Economics of the Republic of Latvia. Macroeconomic Review of Latvia, 2020. [Online]. Available: https://www.em.gov.lv/en/media/1477/download
[32] Central Statistics Bureau of Latvia, Export unit value and import price index weights by sections and divisions of CPA by Index, Market area and Time period [RCE010c]. [Accessed 21.03.2021]. https://data.stat.gov.lv/pxweb/en/OSP_PUB/START__VEK__RC__RCE/RCE010c
[33] Central Statistics Bureau of Latvia, Volume indices and changes in volume of construction production by economic activity [BU010c]. https://data.stat.gov.lv/pxweb/en/OSP_PUB/START__NOZ__BU__BUP/BUP010c
[34] Fastmarkets. Latvian steelmaker Liepajas Metalurgs applies for bankruptcy. https://www.metalbulletin.com/Article/3275040/Latvian-steelmaker-Liepajas-Metalurgs-applies-for-bankruptcy.html
[35] Reuter M., Patel M., Eichhammer W. Applying ex post index decomposition analysis to final energy consumption for evaluating European energy efficiency policies and targets, *Energy Efficiency* 2019:12:1329–1357. https://doi.org/10.1007/s12053-018-09772-w
[36] Locmelis K., Blumberga D., Bariss U. Energy efficiency in large industrial plants. Legislative aspects, *Energy Procedia* 2018:147:202–206. https://doi.org/10.1016/j.egypro.2018.07.058
[37] Saeima. Energy Efficiency Law, 2016. [Online]. Available: https://likumi.lv/ta/id/280932-energoefektivitates-likums
[38] Locmelis K., Blumberga D., Blumberga A., Kubule A. Benchmarking of Industrial Energy Efficiency. Outcomes of an Energy Audit Policy Program. *Energies* 2020:13(9):2210. https://doi.org/10.3390/en13092210
[39] AS Valmieras Stikla Šķiedra. Consolidated financial statements and separate financial statements (Konsolidētais finanšu pārskats un atsevišķais finanšu pārskats), 2017. [Online]. Available: https://www.nasdaqbaltic.com/market/upload/reports/vss/2018_ar_lv_eur_con_ias.pdf
[40] AS Valmieras Stikla Šķiedra. Consolidated financial statements and separate financial statements (Konsolidētais finanšu pārskats un atsevišķais finanšu pārskats), 2018. [Online]. Available: https://www.nasdaqbaltic.com/market/upload/reports/vss/2018_ar_lv_eur_con_ias.pdf
[41] ODYSSEE-MURE. Energy efficiency trends and policies. Latvia. Energy profile. 2020. [Online]. Available: https://www.odyssee-mure.eu/publications/efficiency-trends-policies-profiles/latvia.html#industry
[42] Rural Support Service of the Republic of Latvia, State & EU Support. [Online]. Available: https://www.lad.gov.lv/lv/atbalsta-veidi/projekti-un-investicijas/lap-investiciju-pasakumi/

THE BRIGHT AND DARK SIDES OF ENERGY EFFICIENCY OBLIGATION SCHEME: THE CASE OF LATVIA

energies

MDPI

Article

The Bright and Dark Sides of Energy Efficiency Obligation Scheme: The Case of Latvia

Andra Blumberga, Reinis Āzis, Dāvis Reinbergs, Ieva Pakere * and Dagnija Blumberga

Institute of Energy Systems and Environment, Riga Technical University, Azenes Street 12/1, LV-1050 Riga, Latvia; andra.blumberga@rtu.lv (A.B.); reinis.azis@edu.rtu.lv (R.Ā.); davis.reinbergs@edu.rtu.lv (D.R.); dagnija.blumberga@rtu.lv (D.B.)

* Correspondence: ieva.pakere@rtu.lv

check for updates

Citation: Blumberga, A.; Āzis, R.; Reinbergs, D.; Pakere, I.; Blumberga, D. The Bright and Dark Sides of Energy Efficiency Obligation Scheme: The Case of Latvia. *Energies* **2021**, *14*, 4467. https://doi.org/10.3390/en14154467

Academic Editors: Carlos Rodríguez-Monroy and José Balibrea

Received: 16 June 2021
Accepted: 22 July 2021
Published: 23 July 2021

Abstract: Evidence collected by researchers over several decades suggests that the successful implementation of the Energy Efficiency Obligation Scheme (EEOS) may deliver significant, cost-effective energy savings over many years. However, before starting EEOS in Latvia, predictions by energy efficiency policy researchers envisaged that it is at high risk of savings shortfalls. This study aims to carry out an ex-post policy evaluation of EEOS in Latvia and assess its ability to deliver significant savings in the first phase of the new EEOS. This paper questions whether the new EEOS can reach savings goals without prior experience with voluntary agreement schemes and emulation of successful EEOS from other countries. The second goal of the research is to create a web-based optimization tool as an Interactive Learning Environment to help policymakers and EEOS-obliged parties to create goal-oriented strategies. The study has found that, contrary to expectations, Latvia has reached and even overfulfilled EEOS saving goals. Estimated cumulative savings obtained during the starting phase (329.2 GWh) are 68% higher than the cumulative savings planned by the policymakers for 2020 (234 GWh). This success is related to the enforcement of a stick-type approach in the policy. However, the study also revealed the dark side of EEOS implementation by discussing different types of energy efficiency measures applied by EEOS and the role of implementing and monitoring institutions. The ex-ante evaluation projected that 50% of the EEOS savings would be derived from information and education measures and 50% through contributions to the Energy Efficiency Fund or by implementing the most cost-effective energy efficiency measures. The ex-post evaluation shows that around 95% of savings are achieved through information measures and the rest by introducing energy efficiency measures on the consumer side. EEOS parties do not contribute to the Fund because the cost of information measures (on average 4 EUR/MWh) is significantly lower than the contribution to the Fund (70 EUR/MWh).

Keywords: energy efficiency obligation scheme; energy savings; energy efficiency; system dynamics; energy policy analyses

1. Introduction

Energy efficiency is one of the critical points of focus in achieving the overall energy and climate goals. The European Union (EU) Energy Efficiency Directive 2018/2002 (EED) has established an energy efficiency target for 2030 of at least 32.5% (compared to projections of the expected energy consumption in 2030) [1]. EU member states shall achieve the amount of energy savings required by the EED either by establishing an energy efficiency obligation scheme (EEOS) or by adopting alternative policy measures or by combining them both. According to the EED, the obligation can be assigned to energy distributors, retail energy companies, transport fuel distributors, or transport fuel retailers operating in their territory.

Before the introduction of EED, five European countries (Denmark, France, Italy, the UK, and the Flanders region of Belgium) were already implementing EEOS [2], which includes about 40% of the EU population [3]. The first country in Europe that introduced an obligation on suppliers to save energy among final customers was the UK in 1994 [4]. The introduction of EED in 2012 led to a rapid increase in EEOS. As a result, in 2018, already 12 EU countries had active EEOSs (Austria, Bulgaria, Denmark, France, Ireland, Italy, Luxembourg, Malta, Poland, Slovenia, Spain, UK), while another 3 were intending to start shortly (Croatia, Greece, Latvia) [5]. In April 2020, there were 16 active EEOSs in the EU Member States and the UK, with other countries still planning implementation [6]. EEOS is used relatively rarely compared to all the policy instruments used to comply with the target set out in EED. Meanwhile, grant schemes are the most common in all sectors [5]. However, the frequency of policy measures used to comply with the EED energy efficiency target does not always represent proportional energy savings. According to the European Commission's report in 2020 [1], EEOS is the most crucial policy measure regarding cumulative energy savings and delivered more than one-third (35.59%) of all cumulative energy savings during the period from 2014 to 2017. EEOS delivers more than twice the savings from energy or CO_2 taxes (16.07%), followed by financing scheme/instrument (13.12%) and regulation (9.75%).

The summary of EEOS in selected EU countries and the UK compiled by [7] represents the differences between EEOSs. Regarding the obligated parties, all energy suppliers were set as obligated in France, while in Belgium, for instance, only electricity distributors are obligated. In Italy, energy-saving measures refer to all sectors, including transport, while only residential customers are eligible in the UK. In Denmark, France, and the UK, savings are attributed to the delivered energy. Meanwhile, in Italy, Belgium, and Poland, it is primary energy. The target amount of energy savings is difficult to compare as the final consumption of energy is an important factor [8]. Denmark, France, and Belgium have set a fixed penalty per kWh for the shortfall of savings, while in Italy and Poland, the penalty can vary widely, but the UK only determines a possibility to impose a penalty [9]. Nearly all selected countries allow some trading of the white certificates, except for Belgium. Overall, costs are passed on to the end-users through energy bills, and this is the primary source for funding the programs among these countries [10].

The success of EEOS implementation depends on various factors, such as policy design, implementation, governance, and market structure and conditions [11]. Bertoldi et al. [12] concluded that although supplier obligations seem to be well-suited for the residential sector, end-user saving obligations may also offer advantages to the industrial and commercial sectors. Oftentimes, EEOS are coupled with a trading system, and one of the leading trading options is white certificates [13].

Fawcett et al. [11] provided evidence that a good quality EEOS may deliver significant, cost-effective energy savings over many years. The overall benefits of EEOS are distributed over different domains, such as energy end-users, utilities, and society [5,14]. However, these benefits are not automatically guaranteed with every launch of EEOS. For example, while theoretically, energy savings under the EED should be about 10.5% by 2020 (1.5% per year for seven years), in practice, these savings are expected to be about half this amount [2]. In addition, the European Commission reported that 13 EU Member States risked not meeting their national energy savings obligation by December 2020 [1], including Latvia.

The most important disadvantages of EEOS are considered to be transaction costs and administration costs [3]. Furthermore, it is suggested that the accredited savings in the course of the scheme are likely to be higher than the actual savings achieved due to possible bargains during negotiations between stakeholders. Another view suggests that efficiency measures might not deliver the theoretically estimated range of efficiency because of the rebound effect [15,16]. Finally, the duration of the policy is shown to be more important than the mere existence of the policy in demonstrating the policy's effectiveness [17].

Another study [18] analyzed the distributional effects of EEOS derived by analysis on delivery and financing of measures and concluded that high-income households and large enterprises are the beneficiaries. In contrast, low-income households and small enterprises are the ones to pay. Other studies have also found that the effects of EEOS may be regressive for low-income households [19]. The previous statement suggests that such a scheme is not well balanced, and thus, its success might be questionable in some cases.

Despite many studies on the evaluation of energy efficiency policy impact that have been carried out over the past several decades, there is a gap of knowledge about the role of policy and market interventions in delivering energy savings and emissions reduction [20].

Following the introduction of EED in 2012, the Latvian government has conceptually decided to introduce EEOS in 2013 [21]. The scheme officially started in 2017. A forecast on the implementation success of EEOS in Latvia presented by [13] predicted that Latvia is at high risk of savings shortfalls because it may not deliver savings at the predicted rate. This statement was built on the arguments that the Latvian scheme was originally neither built on the existing experience of a voluntary scheme for obligated parties nor did it adopt (and adapt) a successful EEOS design from another country.

In this study, we have two goals. The first goal is to assess the implementation of EEOS in Latvia and its ability to deliver significant savings in the first phase of the new EEOS. Thus, this paper questions whether a new EEOS can reach saving goals without prior experiences with voluntary agreement schemes and emulation of successful EEOS from other countries. The second goal is to create a web-based optimization tool as an Interactive Learning Environment to help both policymakers and EEOS obliged parties to create a goal-reaching strategy based on the most cost-effective energy efficiency measures in the framework of the current EEOS legislation. The paper starts with a description of the methodology. This is followed by a chapter presenting results from the ex-post evaluation and simulation results. Furthermore, the obtained results are discussed. Finally, the conclusions and implications for policymakers are presented.

2. Methodology

An ex-post evaluation of EEOS is carried out by combining a theory-based policy analysis method to reach the first goal of the study [22,23] with the criteria from the Better Regulation Agenda (BRA) guidelines [24]. 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 the 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. System dynamics modeling is used to reach the second goal of the study.

2.1. Combined Ex-Post Evaluation Method

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. This is an approach to describe how the policy measure is expected to reach energy efficiency goals. Figure 1 illustrates the different steps of this method. First, all steps of the implementation process are listed. It is presented in the form of a cause–impact relationship between the 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. Second, the major success and factors of failure in policy implementation are identified for each step of the policy theory. Finally, the 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 draw it up. The theory-based policy evaluation is presented as a flow chart.

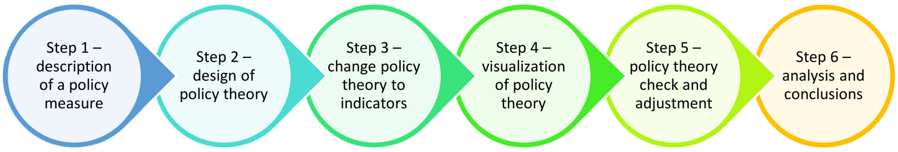


Figure 1. Theory-based policy analysis method.

In this study, the policy theory is transformed into indicators for each causal relation by applying "The Better Regulation Agenda" evaluation criteria:

- Effectiveness—determines progress towards achieving the goal. It should be based on evidence on why, whether, and how these changes are related to a policy measure;
- Efficiency—assesses both the costs and the benefits of the measure, as they arise to different stakeholders, by determining what these costs/benefits are and how these factors are related to the policy measure;
- Relevance—assesses how well objectives of the policy measure meet the needs and challenges;
- Coherence—determines how well the policy measure works internally and with other policy measures;
- Value-added—consider arguments on the value of a policy measure, which is in addition to the value that could be created by policy measures initiated at regional or national level by both public authorities and the private sector;
- Validity—assesses to what extent the policy measure does or does not satisfy the needs of stakeholders and what is the difference between the satisfaction of the various stakeholders;
- Equality—assesses how fairly the effects are shared between different groups of society;
- Sustainability—assesses the likelihood that the effect of the policy measure continues after the end of the measure;
- Acceptability—assesses to what extent a change in the perception of a policy measure in the target audience and in general in society is reached;

In addition to the criteria mentioned above, the institutional capacity was studied, and three indicators reflect it:

- Clear objectives and powers of the policy implementing body;
- Ability to balance and consolidate both flexibility (the ability to adapt to changing conditions and reducing potential failure factors in the implementation process) and continuity (stable and predictable conditions);
- Degree of involvement of stakeholders in the design and implementation of the policy measure.

2.2. Data Collection for the Evaluation

The verification of the policy theory was carried out with mixed methods, in which quantitative and qualitative methods are 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.

The quantitative method included data collection from different data sources:

- Regulations No. 226 annotation [21] was used to build policy theory;
- Data obtained during interviews with obliged parties;
- Information available on the Ministry of Economics website [25];
- Information available on web pages of obliged parties subjected to this policy measure, e.g., [26];
- Other publicly available information related to this policy measure.

As qualitative research focuses on in-depth exploration, a small but diverse sample is recommended, for example, [27] suggests that eight long interviews are a sufficient basis for qualitative research. In 2019, 15 companies were eligible as EEOS parties. From the 15 companies, 9 had to fulfill EEOS obligations. In total, seven in-depth interviews with EEOS responsible parties were conducted from September to December 2019. Their particular knowledge and understanding were valuable sources of information to gain insight into the nature of problems and give recommendations for solutions. Semi-structured interviews were conducted face-to-face with each participant at a time and place chosen by the interviewee. The interviews focused on extracting specific energy efficiency-related information from stakeholders and understanding the knowledge held by those stakeholders. Interviews lasted on average 95 min and were digitally recorded for transcription purposes.

An interview guide with eight questions was used: (1) Could you describe what you do here? (2) What happened in your company after the government issued the Law on Energy Efficiency with defined obligations for EEOS parties? Can you walk me through the process? (3) What happened in your company after it became an EEOS obliged party? Can you walk me through the process? (4) Has the process always worked this way? If it has changed, can you tell me about when that happened and how it went? (5) What challenges have you experienced during the process? (6) What role do technology suppliers, energy consultants, and researchers play? (7) Do you see any added value of the EEOS? (8) Would you continue the energy efficiency program in your company if the government withdraws the obligations? Can you elaborate on this? A deductive coding approach with a pre-selected coding pattern was applied.

Pre-selected coding was developed based on the literature review ([2,13,18]). Following each interview, the recording was transcribed verbatim and an analysis was conducted. The credibility of the results was increased by both the pilot interviews and the triangulation method.

2.3. System Dynamics Model

The annotation of Regulation No. 226 [21] states that the EEOS obliged parties are interested in finding the most cost-effective solutions for implementing energy efficiency measures in the free electricity market. Thus, no significant impact on the final consumer's electricity costs is expected. According to legislation, the EEOS party can fulfill the obligation in several ways. It can either carry out information dissemination and educational activities, implement energy efficiency measures at the end-user, or pay a 70 EUR per MWh fee to fund the state or municipal Energy Efficiency Fund. All three approaches can be combined. The Ministry of Economics, which is the administrator of the EEOS, has developed the Energy Savings Catalogue [28]. It facilitates the accounting of deemed energy savings for the EEOS parties if they carry out standard energy efficiency measures. Costs for information and education activities can be included in the energy tariff via operational costs, but energy efficiency measures have to be included in the bill of an individual consumer who receives these measures. EEOS parties are obliged to deliver energy savings in the household sector and among small and medium companies.

The legal framework defined by the government has several limitations that should be taken into account when EEOS parties design their strategies. First, the intensity of information dissemination and educational activities is limited by the maximum frequency of events per year. If the frequency is too high, the customer of the EEOS party is overflooded with information, e.g., several e-mails sent every day, which might lead to losing attention to this information. Second, costs for energy efficiency measures have to be included in the bill of an individual consumer who receives these measures, which means that the obliged party has either to sell ESCO services or sell products directly or via leasing contracts. In other words, the EEOS obliged party has to invest resources in selling products or ESCO services. This calls for an optimization tool to search for the most cost-effective strategy to reach the goal set by the government. Apart from that, this tool can also be used to simulate different scenarios to develop a goal-reaching strategy. Both policymakers and EEOS obliged parties could use such a web-based, freely accessible simulation tool.

For this purpose, system dynamics modeling is used in this study. This mathematical modeling approach created by Jay Forrester [29] is used to study the dynamics of complex systems with feedbacks, nonlinearities, and delays. Stocks and flows are the main building blocks of the model. Stocks are accumulations, and they are filled in or depleted over time through inflows and outflows. The stock and flow structure of systems helps to carry out a quantitative analysis. *Stella Architect* has been used as the software tool for building stock and flow structure, generating simulations of the system's behavior, and creating an Interactive Learning Environment. An optimization function was used for optimization scenarios. The model is made as a generic structure that can be adapted and applied to different cases and countries. The model was populated with data from interviews of EEOS parties as default, but it is built to input their values.

3. Results

3.1. Description of the Policy Measure

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 [30].

The EEOS in Latvia entered into force in 2017. The EEOS was introduced in accordance with the Energy Efficiency Law [31] and under the Cabinet of Ministers Regulation No.226 Rules for the Energy Efficiency Obligation Scheme [21]. The legislation stipulates that during the initial (2014–2017) and first (2018–2021) commitment periods of EEOS, the responsible parties of EEOS are electricity retailers. The criterion for the inclusion of responsible parties is the amount of electricity sold per year, and it should be over 10 GWh. EEOS parties are obliged to achieve the following amount of energy savings:

For year 2018: $P_{2018} = 1.5\% \times A_{2018}$;
For year 2019: $P_{2019} = 1.5\% \times (A_{2018} + A_{2019})$;
For year 2020: $P_{2020} = 1.5\% \times (A_{2018} + A_{2019} + A_{2020})$,

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 fulfill 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 centers, 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, and heat recovery units for ventilation. The 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.

To assess the costs included in the energy tariff and ensure their transparency and reliability, the EEOS responsible party should draw up an energy efficiency action plan for each commitment period. It should include information on the costs of the measures and the contribution to the Energy efficiency Fund if applicable. The plan should be submitted to the Ministry of Economics for comment and adjusted based on comments and feedback. EEOS parties can adjust their plans every year.

Deemed savings have to be calculated and reported every year based on the Energy Savings Catalogue. Implementation of energy efficiency measures has to be demonstrated by supporting documents, e.g., contracts concluded by the EEOS party to introduce energy efficiency measures to final energy consumers. If the savings goal is overachieved, the savings goal is reduced for the following year. If the party has achieved at least 80% of the committed goal, the gap is added to the following year's goal. If it is less than 80%, a penalty of 125 EUR per MWh should be paid to the Energy Efficiency Fund. If a party has fulfilled more than 100% of the amount of the obligation, the excess part is removed from the amount of the obligation for the following year. The Ministry of Economics has an obligation to publish savings on its webpage.

The annual electricity sales of nine electricity retailers exceeded 10 GWh in 2015 and 15 in 2019 [32]. Total sales of these retailers amount to 99.2% of the total national final electricity consumption. The objective set by the Cabinet of Ministers in the annotation of Regulations for this policy measure [21] is to achieve total energy savings of 234 GWh by 2020 as a result of the introduction of the EEOS. This amount equals 2.4% of Latvia's binding energy efficiency goal by 2020 [30]. EEOS energy savings targets were initially low to reduce potential uncertainties and risks related to the impact of the EEOS on administrative resources and energy costs for different energy users. Initial assumptions forecasted that half of all EEOS savings would come from information and education activities carried out by EEOS parties, and the other half from the contribution to the Energy Efficiency Fund or the implementation of the most cost-effective energy efficiency measures, the cost of which is equivalent to the contribution to the Fund. The ex-ante evaluation estimated indicative total annual costs for EEOS administration and regulation by the Ministry of Economics in the amount of 17,135 EUR, which includes audit costs, review of energy efficiency plans and their amendment, review, calculation of required data processing of annual reports, etc. Planned indicative costs of EEOS parties (average costs per party) are around 4700 EUR per year, covering the planning costs and costs for collecting and reporting information on the energy savings achieved.

3.2. Combined Ex-Post Evaluation Method

The annotation of Regulation No. 226 [21] was used to build the policy theory for this case study, and it was detailed enough to build an explicit political theory. A theory-based policy analysis chart for the EEOS is presented in Figure 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 the Energy Efficiency Law, the Cabinet of Ministers issued a regulation, which stipulates that the Ministry of Economics determines the EEOS obliged parties, the criteria for each commitment period, and the scope of the obligation. 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 the plans in accordance with regulations and, if necessary, informs the participants regarding the non-compliance of the plan with the requirements. 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 insert information regarding the annual savings into 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 the policy measure is that which 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 [33].

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.

3.3. 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 [13].

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 [25], the estimated new and cumulative savings achieved by the EEOS during the starting period (2014–2017) are presented (see Table 1). Estimated cumulative savings obtained during starting phase are 68% higher (329.2 GWh) than the cumulative savings planned for 2020 (234 GWh).

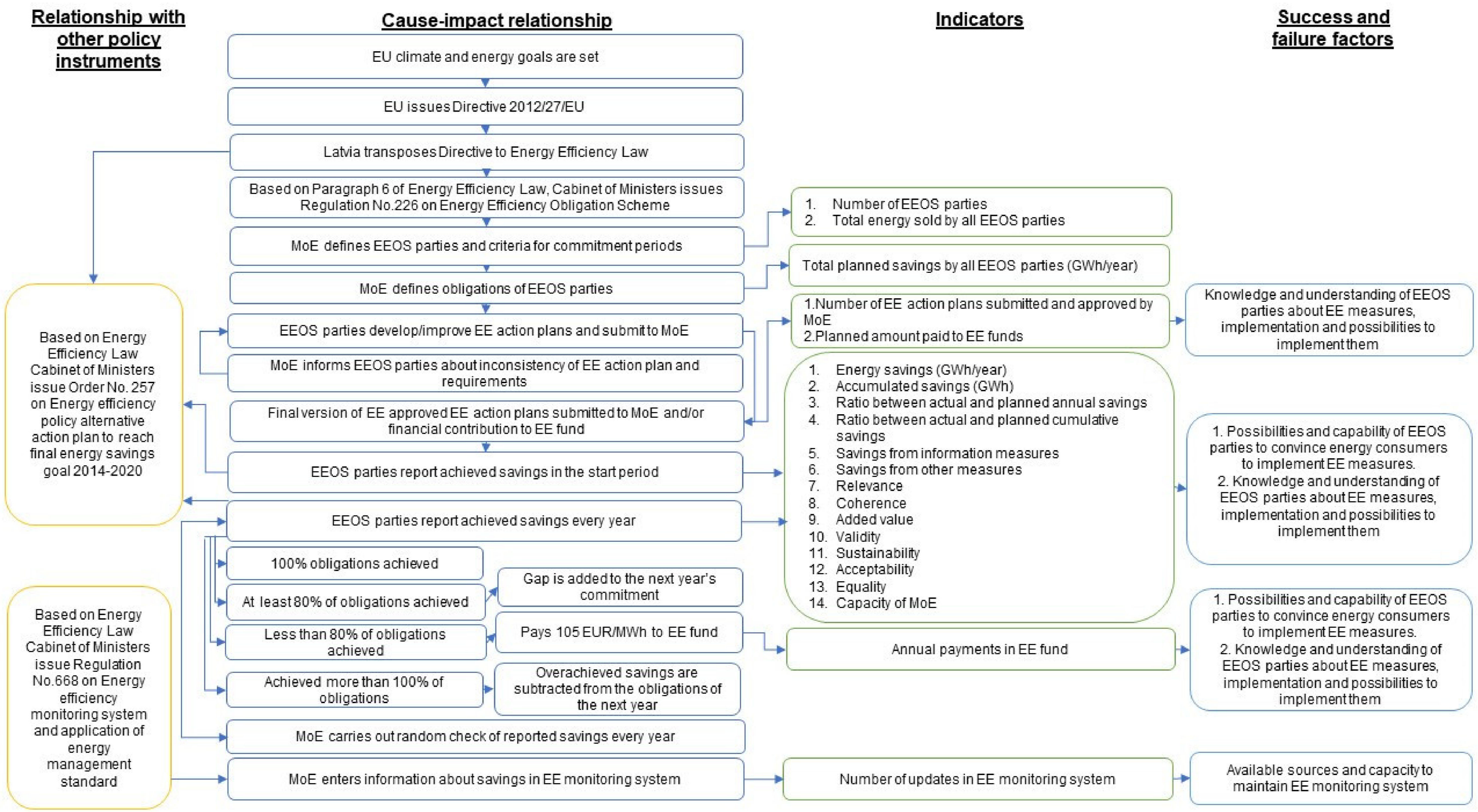


Figure 2. Theory-based policy analysis flowchart for the implementation of EEOS (MoE—Ministry of Economics, EE—energy efficiency, EEOS—energy efficiency obligation scheme).

Table 1. Energy savings achieved by the EEOS parties during the starting period [25].

Activity	New Savings in 2014, GWh	New Savings in 2015, GWh	New Savings in 2016, GWh	New Savings in 2017	Cumulative Savings in 2020, GWh
Information activities	3.4	23.5	21.8	106	154.7
Setting up smart meters	5.0	5.5	13.7	10	68.4
Other measures	0	0	0	26.7	106.1
Total	8.4	29	35.5	142.7	329.2

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

- 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.

In assessing the possibilities and capabilities of EEOS parties to convince energy end-users of the implementation of energy efficiency measures, the EEOS parties provided the following information:

- Perform surveys of the target audience on the main reasons for selecting an energy efficiency measure and then take targeted actions based on the results of the surveys. Surveys show that major barriers are related to costs and a lack of information;
- General marketing techniques are used to promote energy efficiency measures;
- Energy-efficient products are offered for a distributed payment on the home page or directly to customers.

The expertise, understanding, and feasibility of energy efficiency measures and their implementation significantly impact developing and implementing a 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.

In 2019, the Ministry of Economics reported that the functions of administration of the EEOS are not fully achieved because of the lack of capacity [25]. All reports received from EEOS parties are being compiled as far as possible, but no qualitative and detailed evaluation and analysis of these reports has been carried out. Furthermore, no reports on the success or failure of the EEOS have been prepared and published. It also revealed a lack of feedback from the Ministry on the reports and revisions, if needed. The report concludes that the capacity of the Ministry has to be increased. In December 2019, the monitoring function of EEOS was transferred to the Latvian State Construction Control Bureau.

3.4. Efficiency

The cost of saved energy is a typical metric used to assess the energy efficiency costs across different EEOS [34].

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 the energy utility *Latvenergo* shows that in 2018:

- Costs of information and educational measures to improve energy efficiency implemented 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 4043 EUR;
- The average cost of savings reported is 4.78 EUR/MWh [26].

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, and 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 on the administration of the scheme have not been obtained.

3.5. Relevance

Interviews show that EEOS parties analyze target audience needs based on surveys, interviews, and individual communication. The household sector surveys reveal that it is essential to provide information and measures that are economically viable. On the other hand, the most valuable information for companies is the increase of capacity, economically viable measures, and available funding. The EEOS ensures that both these needs are met. They also ensure that the policy measure is adapted to technological, scientific, environmental, and social changes. This is done by following the latest technological solutions in cooperation with technology producers and analyzing changes in target audience interests.

3.6. 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 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.

3.7. Added Value

EEOS parties see the added value of this policy measure as a trigger in changing other habits of energy end-users, such as green thinking, reducing waste, etc. They also noted that boosting energy efficiency increases customer loyalty to the EEOS's parties, which is a critical aspect of the market competition.

3.8. Complementarity

The introduction of the EEOS was significantly hampered by poor communication from the Ministry of Economics side. Many important aspects were not described sufficiently. As a result, the legislative documents were widely interpreted by EEOS parties. For example, the methodology for evaluating information campaigns was published only at the end of 2018. The lack of feedback from the Ministry of Economics after the approval of the initial plans confused the EEOS parties. There was no information available on the overall progress and data of the implementation of the EEOS. The Ministry also did not provide information on whether the parties' performance complies with the requirements for energy efficiency measures to achieve Latvia's overall objective. The legislation does not provide the procedure for revising a savings report, i.e., whether the report has been approved or corrections are needed. This led to the situation when the EEOS parties were not provided with information on whether the activities carried out were in line with the overall objectives and if any adjustment has to be made for further activities.

3.9. Equality

EEOS parties indicate that they focus on all households under the EEOS scheme. No special attention is paid to fuel poverty. Costs for information measures are included in the operating costs of EEOS parties, thus impacting overall tariffs. However, due to the low values of cost efficiency of measures, the impact is marginal. If the large consumers request information on energy efficiency measures, the EEOS parties provide this information. The EEOS parties ensure that information is provided in Latvian, Russian, and English.

3.10. Sustainability

The sustainability of this policy measure depends on the capacity of each EEOS party to continue this measure. For example, the energy utility *Latvenergo* has been operating an Energy Efficiency Centre for the last two decades and would continue to deal with energy efficiency issues without the EEOS. Other EEOS parties also confirm that the resources invested in human resources during the first phase of EEOS and accumulated knowledge would be applied further. However, smaller retailers with insufficient resources would suspend further energy efficiency measures if the EEOS were to be discontinued.

3.11. Compliance

EEOS parties mentioned that the policy measure is being seen more and more positively as energy efficiency becomes an integral part of life. The change of perception about energy efficiency is experienced within the EEOS obliged parties as increased interest and awareness among employees. If the EEOS party has fulfilled its obligation before the deadline, it continues energy efficiency activities. The EEOS parties have observed that the interest in energy efficiency is increasing when energy price increases.

3.12. System Dynamics Model and Simulation Results

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 for 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 a free 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: 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 the cost-effectiveness, taking into account limitations set for different activities.

Figure 3 shows the stock and flow structure of the savings module, which includes the cumulative savings goal that depends on the amount of energy sold and the savings goal set by the government. The actual cumulative savings accumulate over the years as the sum of savings delivered by individual measures. The model then calculates the gap between cumulative saving goal and actual cumulative savings. The savings goal can be increased or decreased by changing the growth rate. The annual energy sales can also be increased or decreased by adjusting the growth rate fraction.

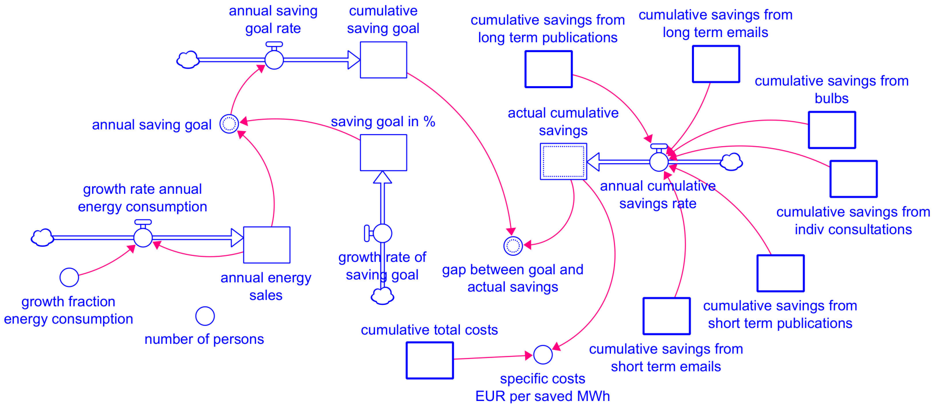


Figure 3. Stock and flow structure for the EEOS savings sub-module.

Figure 4 shows the stock and flow structure of the one-time publication in the mass media module. It includes the savings of a single publication, costs, the size of the target audience, its impact on costs, and the impact of the measure on the savings target. The values of these parameters can be changed during the application of the model. The logit function is used to calculate the share of a particular measure in the overall target. The Alfa value used for the logit function can be adjusted. The same stock and flow structure is used for other types of information activities. For example, both single e-mails and e-mail campaigns sub-model are supplemented with additional parameters required by the Ministry of Economics that define the opening rate of e-mails.

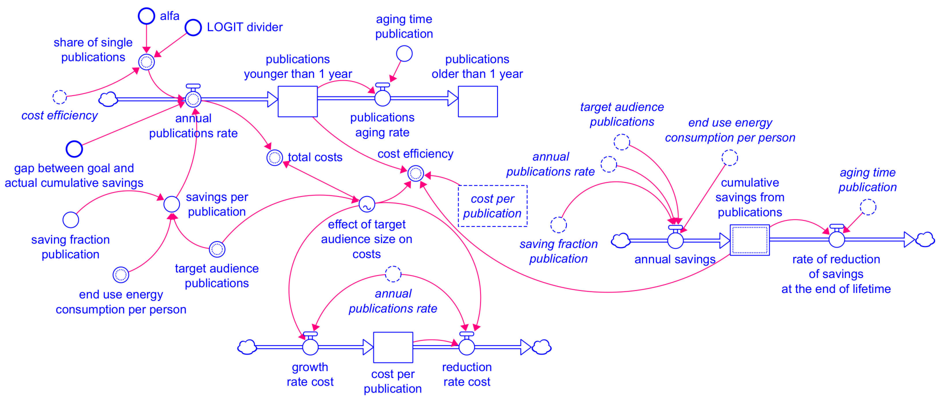


Figure 4. One-time publications in mass media module.

The stock and flow structure of the energy efficiency technological measures sub-module is presented in Figure 5. It can be applied to any technology that is replaced by more energy efficient technology, including efficiency, planned savings, costs, a lifetime measure, and the share allocated to the measure from the overall target, which is calculated as the logit function.

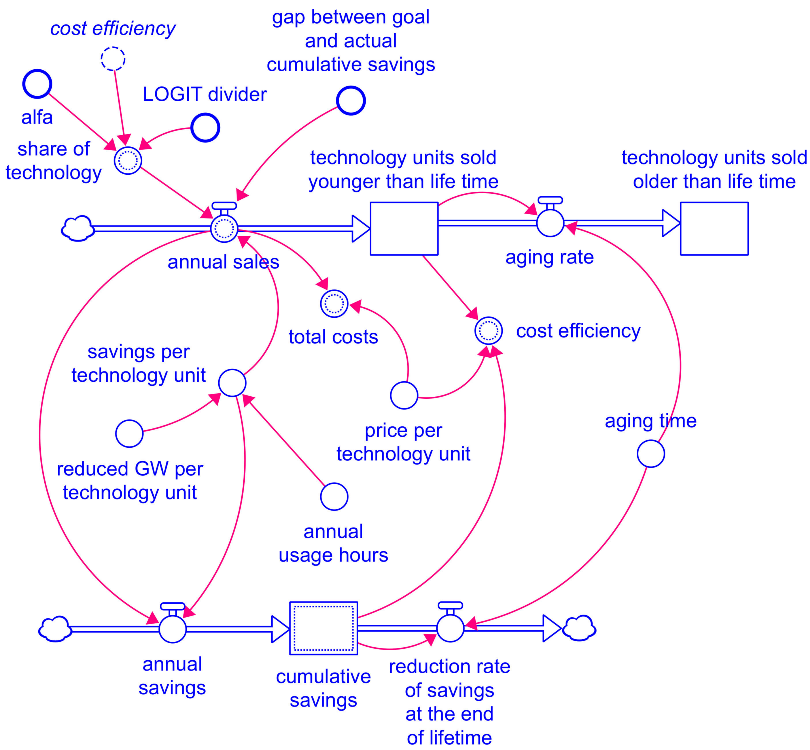


Figure 5. Stock and flow structure of the energy efficiency technological measure sub-module.

Validation of the model was carried out for both structure and behavior [35]. Structure validity tests included direct structure tests, structure-oriented behavior tests. Behavior tests were carried out after structure tests were finished.

Figure 6 illustrates the main page of the free access Internet-based interface tool (https://exchange.iseesystems.com/public/andra/eps/index.html#page1, accessed on 23 July 2021), where users can manually insert input parameters (savings obligation per year, number of clients, average annual energy consumption per client) and calculate annual energy sales volume. The illustration presents a graphical presentation of EEOS obligations.

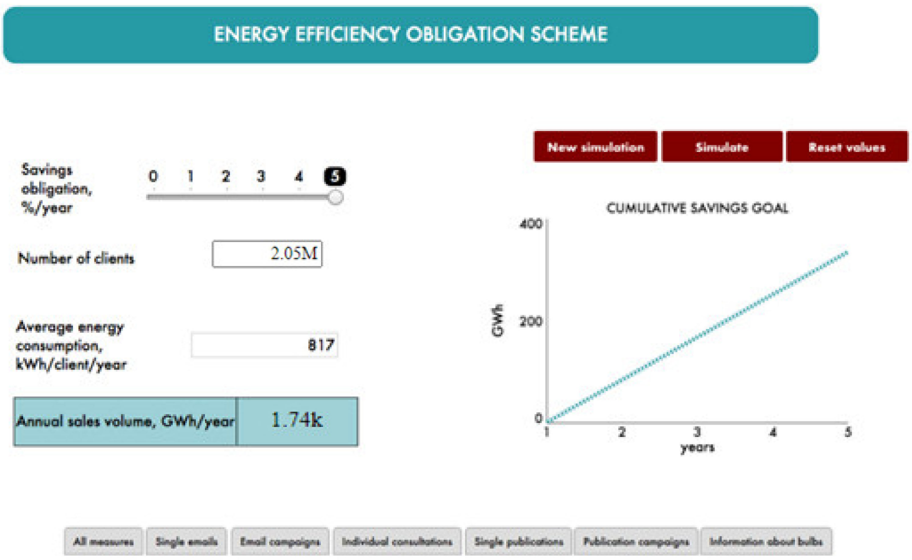


Figure 6. The main page of the free access Internet-based interface tool.

The second page of the interface (Figure 7) is dedicated to all measures defined by the legislation. In the first phase of the EEOS in Latvia, only information activities are applied by EEOS parties. Therefore, the interface can be easily supplemented with energy efficiency technological measures. The user can either manually find the set of measures to reach the savings goal or run the optimization model. Users can change the costs of a single unit and the size of the audience from the total number of clients per particular measure. The graphs show the dynamics of the impact of choice on cumulative savings, cumulative costs, the share of measures, cost-effectiveness, and annual costs in a live mode. Other pages of the tool provide more internal details of each of the measures.

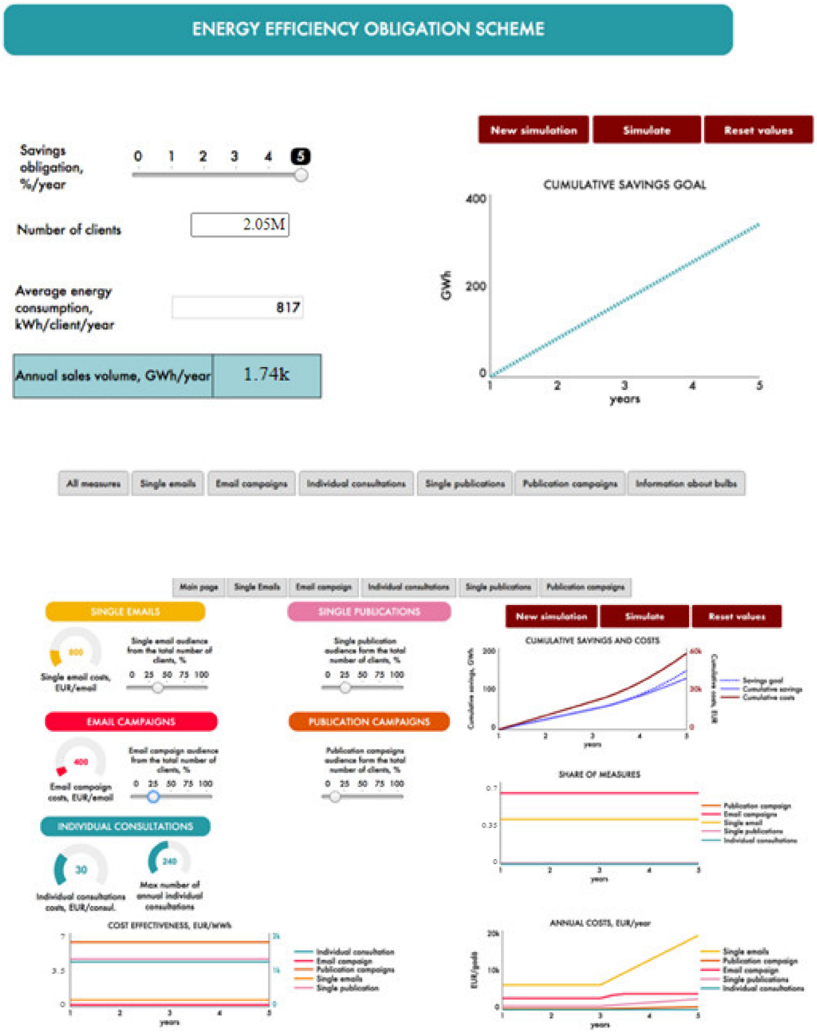


Figure 7. The second page of the interface of all measures as defined by the legislation.

3.13. Model Input Variables and Their Values

The 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%, and individual consultation 3%. The maximum number of units per year was obtained during the interviews with EEOS parties and are 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 kEUR per single publication (depends on the target audience size), and up to 40 kEUR per publication campaign (depends from 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 energy unit (EUR/MWh) by closing the gap between savings goal and actual savings.

Figure 8 illustrates cumulative savings for both scenarios. Scenario 1 does not reach the saving 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 behavior as the target increases every year.

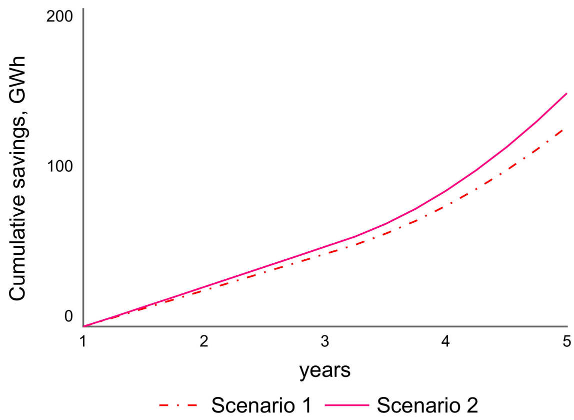
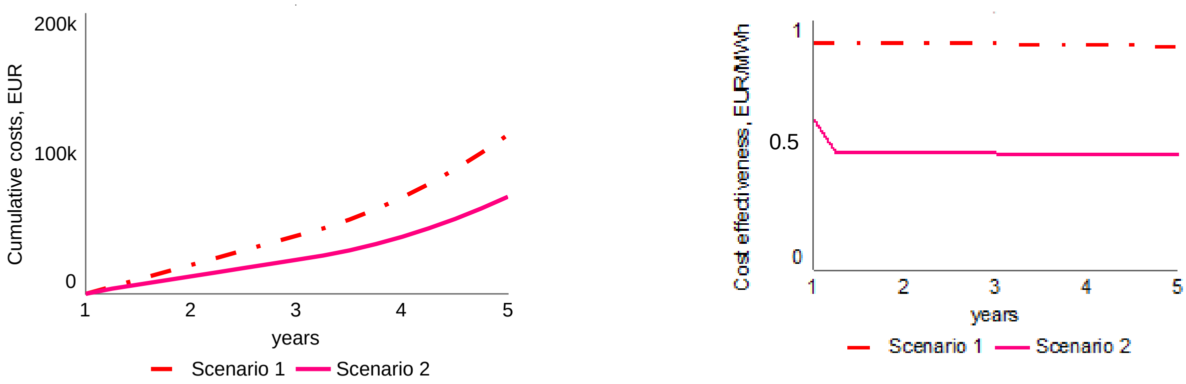


Figure 8. Cumulative savings for both scenarios.

Figure 9 presents simulation results for both scenarios. In Scenario 1, cumulative costs in year 5 reach 114 kEUR, while in Scenario 2, only 70 kEUR. The cost-efficiency for Scenario 1 is 0.9 EUR/MWh, while for Scenario 2 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% 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 a 65% share from 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.



(**a**) (**b**)

Figure 9. Actual cumulative costs (**a**) and cost-effectiveness for simulation scenarios (**b**).

4. Discussion

This study adds to the existing research on the EEOS. It is one of the policy tools to enhance the diffusion of energy savings. The applied mixed research method allowed an in-depth analysis of the causal relationships and developed an understanding of how the goal set by the government was reached.

At first glance, the goal set by the Latvian government for the starting and first phase of EEOS has been reached and even overfulfilled. It might lead to the conclusion that the concerns about the implementation success of EEOS in Latvia (high risk of savings shortfalls) described by [13] has not been met. However, arguments for failure are used by [13], namely, that the Latvian scheme was originally neither built on the existing experience of a voluntary scheme for obligated parties nor adopted (and adapted) based on a successful EEOS design from another country, are still valid. There are several reasons for that, as described in the next sections.

4.1. Types of Energy Efficiency Measures

First, the Latvian EEOS legislation defines that costs for information and education activities can be included in the energy tariff, whereas energy efficiency measures have to be included in the bill of an individual consumer. This leads to the situation whereby retailers have a clear incentive only to do informational programs, which, given their high cost-effectiveness, will only increase average energy prices marginally. Convincing their customers to actually 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 being printed, without any evidence of whether any real effect on achieved energy savings has occurred.

4.2. 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 (see, e.g., [36,37]).

Moreover, no incentives are provided to Latvian EEOS parties to diffuse energy efficiency technologies that would bring actual energy savings. Behavioral 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 the least cost-effective but have higher energy savings potential [20,38].

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

4.3. Limitations of the Study

Although different approaches were used to enhance the rigor of findings, this study has several limitations.

The problems related to the caveat that the data used are self-reported utility data are mentioned in the literature [20]. However, this risk is eliminated by the reporting requirements set by the legislation, which require providing documented evidence for each measure.

Parameters for the model were obtained from EEOS obliged parties, leading to a bias in the parameter estimates. This bias was reduced by comparing the obtained data with publicly available information on the costs of information activities in other domains in Latvia.

Social desirability bias comes from the respondents' tendency to give answers to portray themselves in a socially desirable manner. In this study, the authors tried to reduce this bias by asking probing questions to spot inconsistent answers during interviews. Recall bias was reduced by anchoring the respondent's memory in specific events rather than asking them to recall their perceptions and motivations from memory.

The study does not include interviews with the policymakers from the Ministry of Economics due to a lack of response from the Ministry. There could be several reasons for this: lack of capacity, the high turnover rate of Ministry employees, or pluralism anxiety. An extensive study of publicly available documents from and about Ministry activities was used to substitute for the lack of interviews. Additionally, interviews with EEOS parties provided helpful information about governance issues. Still, some bias may exist.

5. Conclusions, Policy Implications, and Recommendations

Information gathered and analyzed within this study shows that EEOS implementation in the electricity retail sector in Latvia as the policy measure has reached its goal during the starting and first phases of EEOS, contrary to the concerns by researchers (see, e.g., [13]).

EEOS is a policy tool with a stick approach as it demands companies to reach specific goals by punishing them if it is not reached. It is based on the rational choice theory, where the decision is made solely on the highest benefits. An EEOS party can choose to implement either information activities and energy efficiency measures, transfer the obligation to Energy Efficiency Fund, or pay the penalty. In the ex-ante evaluation, the Ministry of Economics projected that 50% of the total EEOS savings would be derived from information and educational measures and 50% through contributions to the Energy Efficiency Fund or by implementing the most cost-effective energy efficiency measures. The ex-post evaluation shows that around 95% of savings are achieved through information measures and the rest by introducing energy efficiency measures on the consumer side. EEOS parties do not contribute to the Fund because the cost of information measures (on average 4 EUR/MWh) is significantly lower than the amount of contributions to the Fund (70 EUR/MWh) or the penalty for not fulfilling obligation (125 EUR/MWh).

The dominance of information measures over other measures is determined by the legislation, which implies that the costs for information measures can be included in EEOS parties' operational costs. In contrast, the costs for energy-efficient technologies should be covered solely by the energy end-users. This fact hinders the development of technological measures and the achievement of the goal with an actual reduction in consumption. Experience of other countries and scientific research shows that providing the information is an essential "nudging" measure of energy efficiency policy. However, while it changes people's attitudes only in the short-term, it does not change their behavior. Therefore, the Ministry of Economics has to assess the share of various measures in total savings. An analysis should be carried out whether a limitation should be set on the share of information measures in total savings. In addition to that, during the next EEOS phase, other measures, such as financial incentives, should be added to information measures.

Interviews with EEOS parties revealed that the fear of punishment had triggered innovations and creativity on both positive and negative sides. On the positive side, EEOS parties have invested resources to develop new products for their customers, including applications for advice on energy efficiency, feedback-based information tools, financial tools for purchasing energy-efficient technologies, etc. They also investigate further the habits and preferences of energy end-users. In turn, this increases customer loyalty and provides EEOS parties with additional power in the market competition. However, in some cases, adverse side effects were noticed when innovation and creativity are used by EEOS parties to find ways to avoid or reduce activities but still reach the goal. Moreover, the lack of feedback from the Ministry of Economics, which administrates the EEOS, has reinforced this adverse effect, e.g., due to lack of information in the starting period, the EEOS parties were interpreting the regulatory framework differently.

Lack of feedback and cooperation from the Ministry during the implementation process has confused the meaning and necessity of this policy measure. It gives an impression that legislation has been introduced formally to meet the requirements.

This study has found several added values. Namely, the attitude, capacity, knowledge, and awareness of energy efficiency measures of the stakeholders responsible for the EEOS have improved significantly. In addition, energy consumers who received information on energy efficiency are changing their habits towards a better environment.

The Internet-based free access simulation tool developed in the scope of this study provides both EEOS parties and policymakers with valuable insights into different measures that can be applied in the EEOS.

Latvia plans to start the second phase of EEOS in 2021, and it is vital to base the next steps on what was learned during the first phase. Policymakers have to decide whether to enlarge the scope of the EEOS to all fuel suppliers in all energy demand sectors or to do it partly. Our findings suggest that obligations can be placed on all fuel suppliers in households and small and medium enterprises unless three main obstacles are removed prior to that. First, limitations on information measures have to be set. Second, financial support for energy consumers should be provided. Finally, the Ministry has to increase the capacity and ability to communicate and support EEOS parties actively. This will be in line with experience gained in other countries that have successfully implemented an EEOS, such as France, Denmark, UK, USA, Italy, and Australia [5,6,8–10].

Author Contributions: Conceptualization, A.B. and D.B.; methodology, A.B., R.Ā. and D.R.; validation, A.B.; formal analysis, A.B., R.Ā. and D.R.; investigation, A.B., R.Ā. and D.R.; resources, D.B.; data curation, A.B., R.Ā. and D.R.; writing—original draft preparation, A.B., R.Ā., D.R. and I.P.; writing—review and editing, A.B., D.R. and I.P.; visualization, A.B., D.R. and I.P.; supervision, A.B. and D.B.; project administration, A.B. and D.B.; funding acquisition, D.B. All authors have read and agreed to the published version of the manuscript.

Funding: The research is funded by the Ministry of Economics of the Republic of Latvia, project "Assessment and analysis of Energy Efficiency Policy" project No. VPPEM-EE-2018/1-000.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are not publicly available.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. European Commission. Report from the Commission to the European Parliament and the Council. In Proceedings of the 2019 Assessment of the Progress Made by Member States Towards the National Energy Efficiency Targets for 2020 and Towards the Implementation of the Energy Efficiency Directive, Brussels, Belgium, 20 July 2020.
2. Nadel, S.; Cowart, R.; Crossley, D.; Rosenow, J. Energy saving obligations across three continents: Contrasting approaches and results. *Proc. ECEEE Summer Study* **2017**, 295–308.
3. Moser, S. Overestimation of savings in energy efficiency obligation schemes. *Energy* **2017**, *121*, 599–605. [CrossRef]
4. Rosenow, J. Energy savings obligations in the UK-A history of change. *Energy Policy* **2012**, *49*, 373–382. [CrossRef]
5. Rosenow, J.; Bayer, E. Costs and benefits of Energy Efficiency Obligations: A review of European programmes. *Energy Policy* **2017**, *107*, 53–62. [CrossRef]
6. Rosenow, J.; Skoczkowski, T.; Thomas, S.; Węglarz, A.; Stańczyk, W.; Jędra, M. Evaluating the Polish White Certificate scheme. *Energy Policy* **2020**, *144*, 111689. [CrossRef]
7. Duzgun, B.; Komurgoz, G. Turkey's energy efficiency assessment: White certificates systems and their applicability in Turkey. *Energy Policy* **2014**, *65*, 465–474. [CrossRef]
8. Bertoldi, P.; Rezessy, S.; Lees, E.; Baudry, P.; Jeandel, A.; Labanca, N. Energy supplier obligations and white certificate schemes: Comparative analysis of experiences in the European Union. *Energy Policy* **2010**, *38*, 1455–1469. [CrossRef]
9. ATEE. Snapshot of Energy Efficiency Obligations schemes in Europe: 2017 update. In Proceedings of the Fourth European Workshop of the White Certificates Club, Paris, France, 30 June 2017; p. 282.

10. ADEME. Synthesis: Energy Efficiency Trends and Policies in the EU an Analysis Based on the ODYSSEE and MURE Databases. 2015. Available online: https://www.ademe.fr/sites/default/files/assets/documents/energy_efficiency_trends_policies_8604.pdf (accessed on 23 July 2021).
11. Fawcett, T.; Rosenow, J.; Bertoldi, P. Energy efficiency obligation schemes: Their future in the EU. *Energy Effic.* **2019**, *12*, 57–71. [CrossRef]
12. Bertoldi, P.; Labanca, N.; Rezessy, S.; Steuwer, S.; Oikonomou, V. Where to place the saving obligation: Energy end-users or suppliers? *Energy Policy* **2013**, *63*, 328–337. [CrossRef]
13. Aldrich, E.L.; Koerner, C.L. White certificate trading: A dying concept or just making its debut? Part II: Challenges to trading white certificates. *Electr. J.* **2018**, *31*, 41–47. [CrossRef]
14. Reuter, M.; Patel, M.K.; Eichhammer, W.; Lapillonne, B.; Pollier, K. A comprehensive indicator set for measuring multiple benefits of energy efficiency. *Energy Policy* **2020**, *139*, 111284. [CrossRef]
15. Kamal, A.; Al-Ghamdi, S.G.; Koc, M. Revaluing the costs and benefits of energy efficiency: A systematic review. *Energy Res. Soc. Sci.* **2019**, *54*, 68–84. [CrossRef]
16. Font Vivanco, D.; Kemp, R.; van der Voet, E. How to deal with the rebound effect? A policy-oriented approach. *Energy Policy* **2016**, *94*, 114–125. [CrossRef]
17. Azhgaliyeva, D.; Liu, Y.; Liddle, B. An empirical analysis of energy intensity and the role of policy instruments. *Energy Policy* **2020**, *145*, 111773. [CrossRef]
18. Moser, S. Poor energy poor: Energy saving obligations, distributional effects, and the malfunction of the priority group. *Energy Policy* **2013**, *61*, 1003–1010. [CrossRef]
19. Mundaca, L. Markets for energy efficiency: Exploring the implications of an EU-wide "Tradable White Certificate" scheme. *Energy Econ.* **2008**, *30*, 3016–3043. [CrossRef]
20. Gillingham, K.; Keyes, A.; Palmer, K. Advances in Evaluating Energy Efficiency Policies and Programs. *Annu. Rev. Resour. Econ.* **2018**, *10*, 511–532. [CrossRef]
21. Cabinet of Ministers. Regulation No. 226. Regulations Regarding the Energy Efficiency Obligation Scheme. *Latv. Vēstnesis* **2017**, *97*.
22. Harmelink, M.; Nilsson, L.; Harmsen, R. Theory-based policy evaluation of 20 energy efficiency instruments. *Energy Effic.* **2008**, *1*, 131–148. [CrossRef]
23. Blumstein, C.G. A theory-based approach to market transformation. *Energy Policy* **2000**, *28*, 137–144. [CrossRef]
24. European Commission. Commission Staff Working Document. Better Regulation Guidelines. SWD (2017) 350. Available online: https://ec.europa.eu/info/sites/info/files/better-regulation-guidelines.pdf (accessed on 7 July 2017).
25. Ministry of Economics Report on Progress Towards Meeting the National Energy Efficiency Targets for 2020 for 2017. Year in Accordance with the Requirements of Article 24(1) and Part 1 of Annex XIV to Directive 2012/27/EU. 2019. Available online: https://em.gov.lv/files/energetika/2019-09-17_10_04_22_LV_EEDZin_2019_par_2017_30042019.pdf (accessed on 16 September 2020).
26. Elektrum. Energy Savings Achieved through Energy Efficiency Measures. 2019. Available online: https://www.elektrum.lv/lv/majai/energoefektivitate/energoefektivitates-centru/pasakumu-sasniegtais-energijas-ietaupijums/ (accessed on 23 July 2021).
27. McCracken, G. *The Long Interview Qualitative Research Methods*; Series 13; Sage Publishing: New York, NY, USA, 1988; pp. 1–88.
28. Ministry of Economics the Energy Savings Catalogue. 2017. Available online: https://www.bvkb.gov.lv/lv/media/883/download (accessed on 20 June 2017).
29. Forrester, J. *Industrial Dynamics*; Martino Fine Books: Eastford, CT, USA, 1961; pp. 1–482.
30. Cabinet of Ministers. No. 257. On the Plan of Alternative Measures of the Energy Efficiency Policy for the Energy End-Use Savings Target 2014–2020. *Latv. Vēstnesis* **2017**, *104*.
31. Saeima. Energy Efficiency Law. *Latv. Vēstnesis*, 2016; 52.
32. CSB. Central Statistical Bureau of Latvia, Energy Balance, TJ, thsd toe (NACE Rev.2). 2020. Available online: http://data1.csb.gov.lv/pxweb/en/vide/vide__energetika__ikgad/ENG020.px/ (accessed on 23 July 2021).
33. State Audit Office. Is a Targeted Energy Efficiency Policy in Place to Achieve the Planned Energy End-Use Savings? 2018. Available online: http://www.lrvk.gov.lv/uploads/reviziju-zinojumi/2017/2.4.1-14_2017/Kop\includegraphics[scale=1]{Definitions/symbol.pdf}jaisZi\includegraphics[scale=1]{Definitions/symbol2.pdf}ojums-bezIP.pdf (accessed on 23 July 2021).
34. Billingsley, M.A.; Hoffman, I.M.; Stuart, E.; Schiller, S.R.; Goldman, C.A.; LaCommare, K.H. *The Program Administrator Cost of Saved Energy for Utility Customer-Funded Energy Efficiency Programs*; No. LBNL-6595E; Lawrence Berkeley National Laboratory: Berkeley, CA, USA, 2014.
35. Barlas, Y. Formal aspects of model validity and validation in system dynamics. *Syst. Dyn. Rev.* **1996**, *12*, 183–210. [CrossRef]
36. ENSPOL. Report on Existing and Planned EEOs in the EU–Part II: Description of Planned Schemes. 2015. Available online: https://energypedia.info/wiki/ENSPOL_Report_on_Existing_and_Planned_EEOs_in_the_EU_-_Part_II:_Description_of_Planned_Schemes (accessed on 23 July 2021).
37. Gardner, G.T.; Stern, P.C. *Environmental Problems and Human Behavior*; Allyn & Bacon: Boston, MA, USA, 2002; Volume 2015, pp. 1–187.
38. Hoffman, I.M.; Rybka, G.M.; Leventis, G.; Goldman, C.A.; Schwartz, L.C.; Billingsley, M.A.; Schiller, S.R. *The Total Cost of Saving Electricity through Utility Customer-Funded Energy Efficiency Programs: Estimates at the National, State, Sector and Program Level*; The Electricity Markets & Policy Group: San Francisco, CA, USA, 2015.

THE ROLE OF FOREST BIOTECHONOMY INDUSTRY IN THE MACROECONOMIC DEVELOPMENT MODEL OF THE NATIONAL ECONOMY OF LATVIA: A SYSTEM DYNAMICS APPROACH

Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 128 (2017) 32–37

Energy Procedia

www.elsevier.com/locate/procedia

International Scientific Conference "Environmental and Climate Technologies", CONECT 2017, 10–12 May 2017, Riga, Latvia

The role of forest biotechonomy industry in the macroeconomic development model of the national economy of Latvia: a system dynamics approach

Reinis Azis*, Andra Blumberga, Gatis Bazbauers

Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia

Abstract

With a rapidly expanding global economic growth, issues of sustainability and potential impact on environment become more pressing. While it is clear that future growth should focus on more efficient exploitation of natural resources and higher added-value in processing of biological goods (referred to as biotechonomy), there is an avenue for future research investigating the role of biotechonomic sectors' contribution to national economies. This research attempts to fill that gap.

By using system dynamics, this research evaluates the role of Latvian forest biotechonomic industry in macroeconomic development model of the national economy of Latvia. In addition, research primarily focusses on three notable macroeconomic sectors – natural resource exploitation, education and healthcare. It is assumed that these, as well as other essential segments of national economies, are linked in an endogenous system, constantly reinforcing each other and being subject to certain causalities among them.

For the purposes of investigation, a causal loop diagram and corresponding system dynamics model of the national economy of Latvia was developed. By introduction of forest biotechonomy in the national economic model, indicative results show that financial resources become more available for education and healthcare. Furthermore, biotechonomy introduction also reinforces further development of high-added value industries and general economic growth via productivity increase and prolonging of total working hours, based on health improvement. This is achieved while proportionally diminishing impact of growth on environment and generally decarbonizing traditional bio-economic sectors.

Peer review statement - Peer-review under responsibility of the scientific committee of the International Scientific Conference "Environmental and Climate Technologies".

Keywords: system dynamics; macroeconomic model; environmental modelling; biotechonomy

* Corresponding author.
E-mail address: reinis.azis@gmail.com

1876-6102
Peer review statement - Peer-review under responsibility of the scientific committee of the International Scientific Conference "Environmental and Climate Technologies".
10.1016/j.egypro.2017.09.011

1. Introduction

For almost 20 years since 1989, global world markets experienced growth never witnessed before. The promises of better life and global scale introduction of democracy and economic growth went hand-in-hand with individual per capita consumption and gross domestic product (GDP) ratings flowing off charts. The recent global economic recession of 2008 however came as a cold shower for most economies and there are plenty of societies today still facing related challenges.

Since then various scholars and other members of societies' have questioned the structures and the dynamics of mainstream modern-day economies. On a general note, criticisms have focused on lack of normative values of capital markets, as well as complete disregard of traditional, cultural values and growing impact on environment unwitnessed before. Furthermore, most entrepreneurs are continuing to avoid, arguably, the most crucial criticism of mainstream corporate businesses to-date – the extensive impact of business activities on environment and the irreversibility of it [1, 2].

Over last couple of years a more pragmatic approach has been taken by various academics in order to offer solutions to economies that would combine economic growth together with environmental considerations and more efficient exploitation of natural resources [3]. In respect to particular investigation, a system dynamic approach for *biotechonomy* modelling in Latvia should be explored further.

In short, while *biotechonomy* as a field includes technologies and related economic and non-economic processes for extraction, exploitation and processing of biological resources, the system dynamic model for analysis of Latvian biotechonomic potential was developed to test and explore capacity of the national economy of Latvia to become a stand-out example of high added-value and sustainable manufacturing economy [4, 5]. Acknowledging paramount academic success that former model brings in modelling separate sub-sectors of Latvian biotechonomy and related environmental and monetary gains [6], a significant limitation of the research is the inability of the model to incorporate the particular benefits of biotechonomic development in reference to other macro-economic segments of the national economy of Latvia. This research is an attempt to fill this gap while using a forest sector as the case.

2. Brief overview of related previous studies

To begin with, Jay W. Forrester's *The System Dynamic National Model* should be mentioned [7]. Arguably being the frontrunner of the field, already in 1989 particular research focussed on interlinks between national macroeconomics and microeconomic policy decisions. Furthermore, this research focussed on paradigmatic processes of any economy – business cycles, inflation, and stagflation, the economic long wave and growth as such [7].

Not only was the application of the method for the process analysis remarkable on its own, but also definition and inclusion for the first time of economic subsectors in an endogenous, single, bounded system. These included production sector, household sector, labour sector, financial and governmental sector. Such approach has arguably served as the foundation of any further macroeconomic system dynamic modelling.

As another exceptionally influential study should be considered David Wheat's research on teaching macro-economic theory while using system dynamic modelling. What sets apart unique contribution by the scholar is the role solely addressed to feedback loops as separate units of analysis [8]. Particularly successful is also the application of loops in explaining the self-regulating principles of market economies – arguably few other system examples could reflect the nature of complex systems better as self-regulating market.

In reference to particular investigation the *Threshold 21 (T21)* system dynamics model, developed by the *Millennium Institute*, must be explored. This model was the first *all*-encompassing system dynamics framework. It was designed to be universally applicable to various national economies in order to design and implement various macro level policy changes and evaluate different policy scenarios [9]. Even though developed solely for sustainable policy considerations, it does elaborate on three main sectors of any national economy – economy, environment and society – and allows deepening structural understanding in short and long term provisions [9].

Another influential academic investigation was developed by Bernardo and D'Alessandro in 2016, where by system dynamic modelling application impact of low carbon investments on employment and inequality was assessed. The proposed model brings economic growth, carbon emissions, unemployment and related income distribution combined on a macro-level analysis [10], which, in principle, was similarly carried out during the modelling of the national economy model of Latvia.

While previously mentioned models is of relative importance to the investigation, the taken approach to correlate GDP growth with other macro level components was carried out differently. One of the most essential conclusions of Italian research was that carbon emission control mechanism investment has a negative impact on GDP growth and salary structure [10]; however, the particular investigation has contested this argument.

By far, the most influential academic for this particular investigation should be considered Andrea M. Bassi, one of the co-authors of the *T21* model discussed earlier who has participated in multiple macro level system dynamic modelling investigations [11]. The research carried out by Musango, Brent and Bassi focussed on exploring the contribution of technology policies to the transfer to *a green economy* model of South Africa via integrated, system dynamics approach [12].

While, on a general note, many of research mathematical assumptions were considered before the development of the national Latvian model, the most essential takeaway was the unshed loop of particular micro segment of the macro model. One of the greatest challenges of Latvian investigation was to address and to incorporate (via system dynamics model) segments of economies not analytically combined in academic research before via modelling (i.e. healthcare-education-production-labour) and the South African model [12] was used as a conceptual example.

Crucial insight is also the actual division of macro-economic sectors for the purposes of system dynamic modelling which is done in the study. While all in all there were 31 different sub sectors of macro-economic reflection, the crucial division focuses on 14 central sectors, including natural resources (land, water, emissions, and minerals), population, health, education and separate branch of energy [12]. The latter is elaborated even in greater depth, but such a level of detail could be also attributed to Bassi's academic interest in the energy macro modelling as such, considering his paramount doctoral dissertation model for energy outputs within the *T21* model [13].

All in all, there are numerous scholars that have attempted to analyse macroeconomics via system dynamics in reference to green and sustainable economies, but due to paper limitations only the most notable were acknowledged. While this paper contributes to a particular former investigations of Riga Technical University on the role of biotechonomy in the national economic development model of the Republic of Latvia [14, 15], broader novelty of the research includes evaluating the impact of biotechonomic investment on social welfare allocation mechanisms in national economies (i.e. healthcare and education), as well as assessing the role of biotechonomy regarding fostering economic growth and decarbonizing economies simultaneously.

3. Methodology

The study was carried out by implementing a numerical experiment, while using system dynamics modelling. System dynamics as a research discipline allows focusing attention particularly to causalities rather than correlations [16]; hence, explaining complex phenomenon with endogenous factors contributing to overall behaviour of systems.

3.1. Dynamic problem

The dynamic problem of the investigation was defined as stumbling growth rates enforcing gradually increasing pressure on environment, as well as other aspects of economies, namely, healthcare and education.

3.2. Dynamic hypothesis

For the purposes of system dynamic modelling and framing dynamic hypothesis a causal loop diagram was developed, see Fig. 1. Bearing in mind the fact that investigation focused on three main realms: (I) natural resource exploitation intensity dynamics, (II) healthcare and (III) education budget impact and dynamics, hypothesis was put forward accordingly and is twofold.

With the inclusion of biotechonomic forest industry segments in the macroeconomic development framework, every additional financial wealth unit generated comes with significantly less carbon intensive means and improved natural resource consumption efficiency.

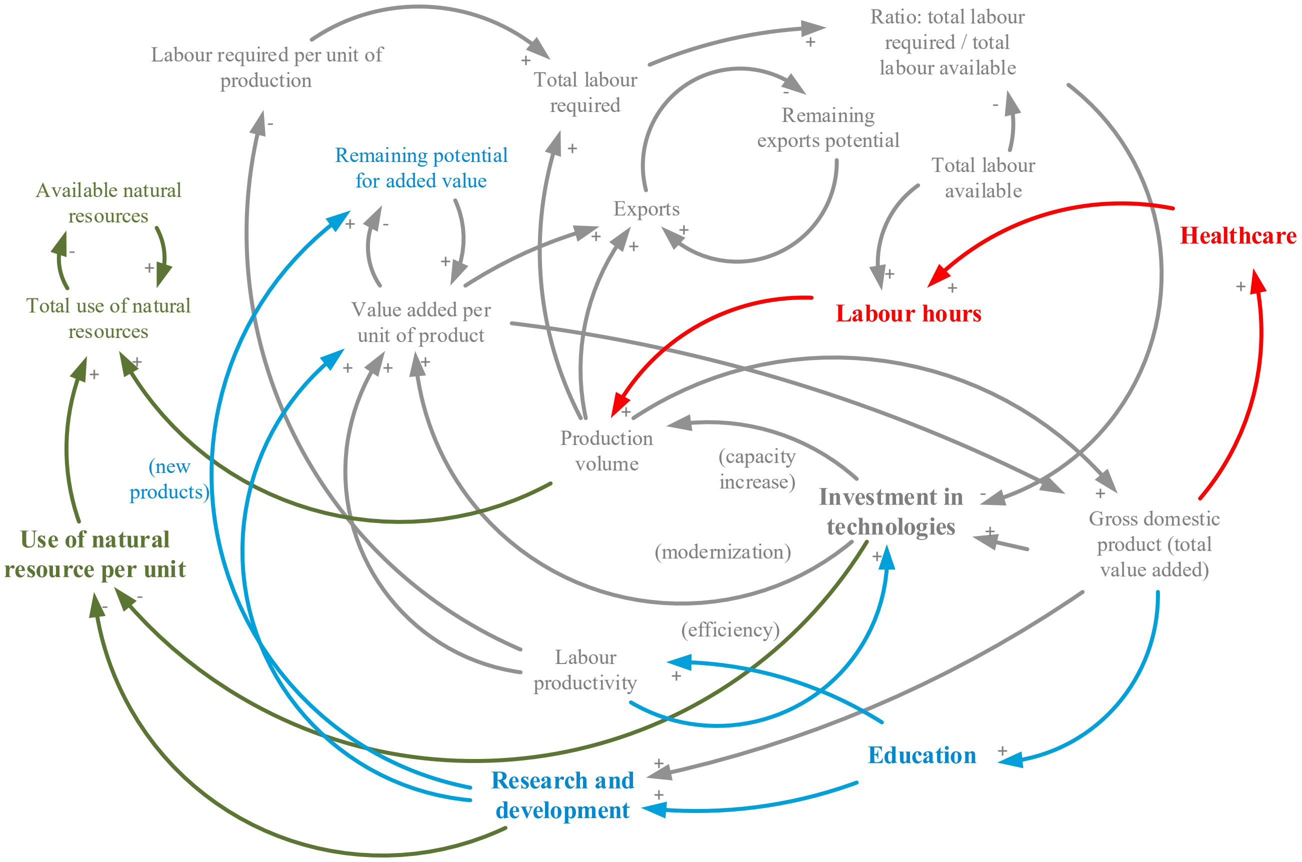


Fig. 1. Causal loop diagram of the macroeconomic system dynamics model of the national economy of Latvia.

With the inclusion of biotechonomic forest industry segments in the macroeconomic development framework, healthcare and education expenditure increases and improves production output via absolute working hours and labour productivity increase.

3.3. Model formulation, simulation and testing

Two key aspects of the model formulation included already the existing model structures elaborated by scholars from the Riga Technical University [17] and macro system dynamic model of the national Latvian economy.

Regarding the latter as a basis was taken the Latvian governmental annual budget structure and related stocks and flows of various sub-sections both for income and expenditure aspects. Furthermore, the fact that political documentation was used for model formulation also enabled final model testing via financially compatible data from the Ministry of Finance of the Republic of Latvia starting from 2004 [18].

As for the former, out of various stocks and flows the most central should be considered a production capacity for every forest biotechonomic segment, as well as the total annual governmental payments and taxes. The model was constructed so that the financial dynamic contribution to the national economy would be transferred via education and healthcare segments as indicators, developed by contrasting the initial financial flow versus the dynamic flow. Hence, also the connection to the formerly developed model was of significant importance, as particular flow to stock structure should include essential environmental aspects for further evaluation purposes, developed in the former model.

Links shown in the Fig. 1 were represented as mathematical considerations dynamic in time. In reference to the healthcare sector improvement by the biotechonomic industry, causality was transferred most notably via increased labour hours due to a better health conditions of the working population, resulting in increasing production output and relieving stress from a ratio of the desired labour (and other resource) capacity and the available capacity. In reference to education dynamic improvements, the causality included improved productivity indicators as well as higher potential for research and development. In turn, this could be transferred to monetary production output increase and decreased environmental exploitation by constant or gradually diminishing labour availability and technological modernization.

In general, the structure of the model is constructed by four main reinforcing loops:

- From variable *gross domestic product (GDP)* to variable *Investment in Technologies*;
- From *GDP* to *Research and Development (R&D)*;
- From *GDP* to *Healthcare*;
- From *GDP* to *Education*.

Regarding balancing or negative loops, most crucial include linking variables related to (I) natural resources; (II) labour availability and (III) remaining capacity for R&D. These are further discussed below.

While most causalities in the study were explained via generally accepted accounting principles or formulas of the Ministry of Finance, the core assumptions for the model formulation were derived while using *the labour and production functions*, first developed by Victor in 2008 [19] and Jackson and Victor in 2011 [20].

$$L = h \cdot e \cdot F \tag{1}$$

where
h the average number of working hours per employee per year;
e the employment number or fraction of available labour force;
F the total number of people in the labour force.

$$GDP = P_L \cdot L \tag{2}$$

where
P_L the productivity of labour expressed in Euros per working hour;
L the annual labour expressed in total number of working hours per year.

4. Initial approximations and discussion

While full-scale modelling is yet to be completed, indicative results show justification of both hypotheses. It can be observed that an extra investment in healthcare and education segments even without inclusion of biotechonomic realms in the model already foster both labour productivity and available working hours, despite usual macroeconomic conduct. Nevertheless, natural resource exploitation rate remains the same, indicating inevitable pressure on the environment throughout economic development.

Once the biotechonomic segments are also included within the model structure, labour productivity and working hour indicators continue to increase in steeper manner. Furthermore, additional economic growth, expressed throughout various governmental budget revenues via taxation or direct payments – increase more rapidly, impacting the environment (natural resources and greenhouse gas (GHG) emissions) significantly less in comparison to the case of non-biotechonomic sectors included whatsoever.

As it can be noticed in the Fig. 1, most of the model causality relationships consist of positive flows, with only few negative loops, which are commonly assessed to balance out any dynamic system. In the case of particular investigation, most essential balancing or containing loops include: (I) available natural resources, (II) total labour available and (III) remaining potential for R&D. Nevertheless, there are several other balancing loops in the model that would also serve to contain the system – arguably to lesser extent – which should be incorporated in any further modelling. Namely, export potential limitations for goods of similar function.

Another essential aspect to be covered is the fact that the endogenous financial resources are included in the model and form the core of it, while the external financial resources are neither modelled nor taken as a constant variable. The main argumentation for it is twofold. First, while it would be a time-consuming investigation, external financial resource modelling would arguably not have any significant impact on the phenomenon primarily investigated in this research. Second, in case of healthy and relatively rapidly developing European economy (indicative result of modelling with biotechonomic segments included), it is assumed that various financial resources – either via governmental funds or, for example, via foreign direct investment – would be allocated by markets to the economy in any case.

5. Conclusions

To conclude, system dynamic modelling of forest biotechonomic sectors within the economic model of the national economy of Latvia indicates several significant improvements to the prospect of high-added value economic growth.

First, inclusion of biotechonomy segments may lead to an increased governmental expenditure in healthcare and education. In turn, these investments reinforce resource availability for biotechonomic manufacturing – namely, via increased labour productivity and prolonged working hours of the already existing workforce – therefore further increasing the added value of manufactured goods and allowing the national economy to escape *the middle income trap*.

Second, as biotechonomy sectors focuses on as efficient exploitation of natural resources as possible and limiting GHG emissions of manufacturing processes, increased and sustainable economic growth is developed by a significantly diminishing impact and stress on environment.

Acknowledgements

The work has been supported by the National Research Program “Energy efficient and low-carbon solutions for a secure, sustainable and climate variability reducing energy supply (LATENERGI)”.

References

[1] Perman R, Ma Y, Common M, Maddison D, McGilvray J. Natural Resource and Environmental Economics. 4th ed. Edinburgh: Person; 2011.
[2] Muizniece I, Timma L, Blumberga A, Blumberga D. The methodology of assessment of bioeconomy efficiency. Energy Procedia 2015;95:482– 486.
[3] Cilinksis E, Vesere R, Blumberga A, Blumberga D. Sustainable national policy planning with conflicting goals. Energy Procedia 2016;113:259 –264.
[4] Blumberga A, Bazbauers G, Davidsen P, Blumberga D, Gravelsnins A, Prodanuks T. Sistēmdinamika biotehonomikas modelēšanai (in Latvian). Rīga: RTU; 2016.
[5] Runge K, Blumberga A, Blumberga D. Bioeconomy Growth in Latvia. System-dynamics Model for High-value Added Products in Fisheries. Energy Procedia 2017;113:339–345.
[6] Blumberga D, Indzere Z, Muizniece I, Blumberga A, Bazbauers G, Gravelsins A. Why bioeconomy is actual for Latvia. Research achievements in Institute of Energy Systems and Environment. Energy Procedia 2016;113:460–465.
[7] Forrester JW. The System Dynamics National Model: Macrobehaviour from Microstructure. In: Milling P. M. and Zahn E. O. K. (eds). Computer-Based Management of Complex Systems. Berlin: Springer; 1989.
[8] Wheat D. The Feedback Method of Teaching Macroeconomics: Is it Effective? PhD Dissertation. University of Bergen; 2007.
[9] The Millennium Institute. Implementing a T21 Project, 2016. Available: http:// millennium-institute.org/projects/index.html
[10] Bernardo G, D’Alessandro S. System-dynamic analysis of employment and inequality impacts of low-carbon investments. Environmental Innovation and Societal Transitions 2016;21:123–144.
[11] Bassi AM. Moving Towards Integrated Policy Formulation and Evaluation: The green Economy Model. Environmental and Climate Technologies 2016;16(1):5–19.
[12] Musango JK, Brent AC, Bassi AM. Modelling the transition towards a green economy in South Africa. Technological Forecasting and Social Change 2014;87:257–273.
[13] Bassi AM. An Integrated Approach to Support Energy Policy Formulation and Evaluation. PhD Dissertation. University of Bergen; 2009.
[14] Zihare L, Blumberga D. Market Opportunities for Cellulose Products From Combined Renewable Resources. Environment and Climate Technologies 2017;19(1):33–38.
[15] Blumberga D, Muizniece I, Blumberga A, Baranenko A. Biotechonomy framework for bioenergy use. Energy Procedia 2015;95:76–80.
[16] Blumberga A, Blumberga D, Bazbauers G, Davidsen PI, Moxnes E, Dzene I, Barisa A, Zogla G, Dace E, Berzina A. Sistemdinamika vides inzenierzinatnu studentiem (in Latvian). Riga: RTU; 2010.
[17] Blumberga A, Bazbauers G, Davidsen PI, Blumberga D, Gravelsnins A, Prodanuks T. System dynamics model of a biotechonomy. Journal of Cleaner Production 2017;1–15.
[18] Ministry of Finance of the Republic of Latvia. 2017. Valsts budzets (in Latvian). Available: http://www.fm.gov.lv/lv/sadalas/valsts_budzets/
[19] Victor P. Managing Without Growth – Slower by Design, not by Disaster. Cheltenham: Edward Elgar; 2008.
[20] Jackson T, Victor P. Productivity and work in the ‘green economy’ – Some theoretical reflections and empirical tests. Environmental Innovation and Societal Transitions 2011;1:101–108.

THE ROLE OF FOREST BIOTECHONOMY INDUSTRY IN THE MACROECONOMIC DEVELOPMENT MODEL OF THE NATIONAL ECONOMY OF LATVIA: AN IN-DEPTH INSIGHT AND RESULTS

Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 147 (2018) 25–33

Energy Procedia

www.elsevier.com/locate/procedia

International Scientific Conference "Environmental and Climate Technologies", CONECT 2018

The role of forest biotechonomy industry in the macroeconomic development model of the national economy of Latvia: an in-depth insight and results

Reinis Azis*, Andra Blumberga, Gatis Bazbauers

Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia

Abstract

By using system dynamic modelling, this research evaluates the role of Latvian forest biotechonomic – more efficient exploitation of natural resources and higher added-value in processing of biological goods – industry in the macroeconomic development model of the national economy of Latvia by year 2047. In addition, research primarily focusses on three notable macroeconomic sectors – natural resource exploitation, education and healthcare.

For the purposes of investigation, a causal loop diagram and corresponding system dynamics model of the national economy of Latvia was developed. By introduction of forest biotechonomy in the national economic model, results show that financial resources become more available for education and healthcare sectors; however, not to the significant level formerly anticipated.

Furthermore, forest biotechonomy introduction also reinforces further development of high-added value industries and general economic growth via relative productivity increase and prolonging of relative working hours. Such results are achieved while proportionally diminishing impact of economic growth on environment

This research indicates that forest biotechonomy could be considered an influential and sustainable additional driver of economic growth in Latvia in the years to come. Furthermore, by highlighting certain limitations of the particular investigation, this research sets out potential realms of further research to come.

Keywords: system dynamics; macroeconomic model; environmental modelling; biotechonomy

* Corresponding author.
E-mail address: reinis.azis@gmail.com

1876-6102
10.1016/j.egypro.2018.07.029

1. Introduction

At the beginning of 2018, oil prices for the first time in past three years reached 70 dollars per barrel [1], again emphasizing not only ecologic, but financial importance of continual global energy industry's shift towards renewable energy and sustainability. While a lot of academic debate has focused on pioneers of renewables – wind and solar – the role of biomass, and forest industry in particular, has been relatively left aside. Author's continuous research of the role of forest biotechonomy industry in national macroeconomics, including energy, attempts to reverse this malevolence.

Forest biotechonomy refers to efficient discovery, extraction and processing of mainly local biological forest resources into high-added value products [2]. While the term biotechonomy on the first glimpse does not differ from the concept of bio-economy as such, in contrast to the sole emphasis on efficient biological resource transformation, biotechonomy tackles also the issues of processing technologies and in-depth evaluation of them [3]. Hence, the discipline encompasses both the field of natural resource economics and technical engineering aspects.

While the former research on the topic [4] focused on theoretical aspects and conceptual explanation of the role taken by forest biotechonomy in macroeconomic dynamics, this research builds on previously developed theoretical framework and delivers analytical results of the particular financial role that could be taken by forest biotechonomy in the national economy of Latvia by year 2047.

Research primarily focused on three notable macroeconomic sectors – natural resource exploitation, education and healthcare. It was assumed that these, as well as other essential segments of national economies, are linked in an endogenous system, constantly reinforcing each other and being subject to certain causalities among them. System dynamics as an academic method allows such systems to be analyzed both in time and space.

On another note, there have been numerous other scholars that have attempted to analyze macroeconomics via system dynamics in reference to green and sustainable economies. While several essential conclusions and propositions in reference to green economy solutions in macroeconomic context have been proposed, there is fairly limited number of scholars assessing the role of particular bio economic sectors in reference to macroeconomic benefits.

In reference to particular investigation most notable former researches include:

- The Threshold 21 (T21) system dynamics model, developed by the Millennium Institute [5] – first all-encompassing system dynamics framework in reference to bio-economy, even though developed solely for sustainable policy application considerations;
- Academic investigation by Bernardo and D'Alessandro [6], where by system dynamic modelling application impact of low carbon investments on employment and inequality was assessed;
- Various researches by Mr. Andrea M. Bassi, one of the co-authors of the T21 model, on exploration of the contribution of technology policies to the transfer to a green economy model in South Africa [7], the US [8] and other case studies [9];
- Also, several Latvian scholars have attempted to use system dynamics [10] or other methods for evaluation of impact of bio and energy-efficiency technology on economy [11, 12].

However, not assessing particular macroeconomic benefits and providing insights about the dynamics of change that this paper clearly tackles.

The relative vacuum of academic thought in the particular research field therefore justifies investigation and gives solid ground for analysis and discussion of results portrayed below.

Nomenclature

BIF	biotechonomy improvement factor
BIF(e)	biotechonomy improvement factor, excluded from the dynamic modelling
BIF(i)	biotechonomy improvement factor, included in the dynamic modelling
CIT	corporate income tax
EBITDA	financial revenues before application of taxes
GDP	gross domestic product
T21	system dynamics model *Threshold 21*

2. Methodology

To begin with, particular investigation was carried out by implementing a theoretical experiment, while using system dynamics modelling. System dynamics as a research discipline allows focusing attention particularly to causalities rather than correlations [13]. Hence, explaining complex phenomenon with endogenous factors contributing to the overall behaviour of systems rather than exogenous factors.

While the main conceptual causal loop diagram of the macro-model can be found in former publications [4], sub-models should be briefly explored here. Namely, causal loop diagram of education (elaborating on the impact of the quality of education on national economics), healthcare (impact of healthcare quality) and natural resources (impact of availability of resources).

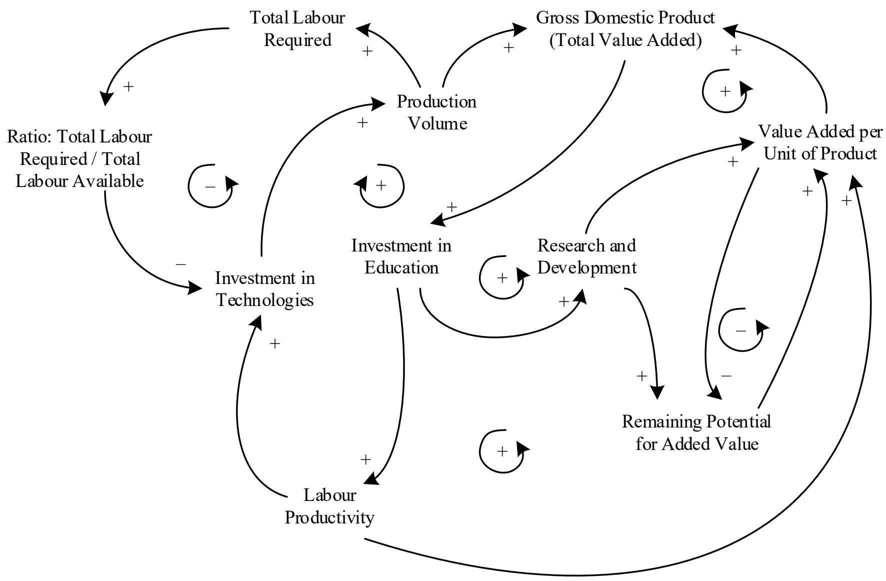


Fig. 1. Causal loop diagram of education segment.

In brief, central to the theoretical models represented by the causal loop diagrams in Fig. 1, Fig. 2 and Fig. 3, were balancing (negative) loops, limiting the reinforcement or growth of economic parameters. These were:

- The limited availability of natural resources;
- The eventually limited capacity for generated added-value in an economy (education);
- The total availability of labour force (healthcare).

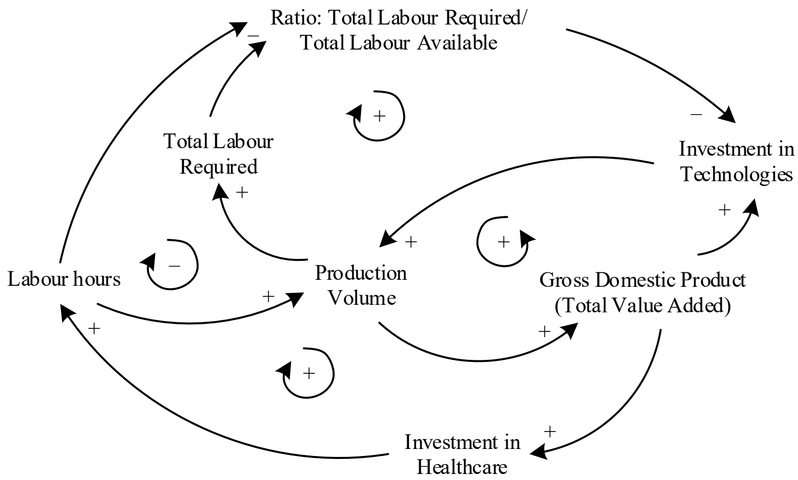


Fig. 2. Causal loop diagram of health segment.

Regarding natural resources, the growth is eventually limited due to eventual scarcity of resources in any limited space. In reference to higher-added value (education), the limiting factors include technological limits of development at a given time and limits of research and development activities that can be conducted in a finite system. Finally, regarding healthcare – it was the finite number of labour hours per worker due to primary health related aspects – aging, mundane health, flexibility and labour quantity impacting parameters related to healthcare.

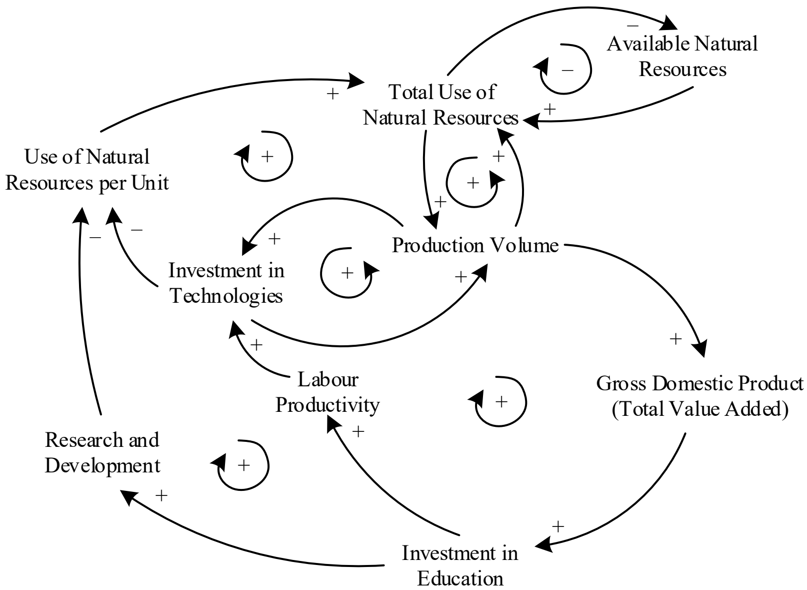


Fig. 3. Causal loop diagram of resources segment.

While, to some extent, most of these limitations are conceptually complex and beyond the scope of this investigation, the aspect of limited use of natural resources stood out as the most crucial limitation to be included in the macroeconomic development model. To similar extent, another crucial limiting concept was population (and deriving labour pool availability), while financial flow was assumed as self-regulating, with substantial annual growth rate (1.5 %) taken as an exogenous factor.

For the purposes of mathematic modelling, based on the causal loop diagrams above, three different modelling scenarios were introduced in order to dynamically reflect the improvements of total macroeconomic development by inclusion of forest biotechonomy products (base scenario, scenario BIF(e) and scenario BIF(i)).

Based on former academic research [14, 15], it was qualitatively assumed that by inclusion of biotechonomy profit into national economy, additional funds available to education and healthcare segments would create additional, reinforcing economy improvement factor – i.e. due to increased healthcare and education funding, labour force would be capable of improving efficiency, based on improved health and education. Modelling scenarios reflect this potential.

Table 1. Modelling scenarios' goals and descriptions of particular research.

Modelling scenario	Modelling scenario description	Modelling scenario goal and related considerations
Base scenario – traditional economic development	Construction of macroeconomic development model of the national economy of Latvia (with 1.5 % GDP growth) and related system dynamic modelling	The goal of the modelling scenario was to set a base-line to which both remaining forest biotechonomy scenarios and related macroeconomic inputs would be evaluated
BIF(e)	Construction of macroeconomic development model of the national economy of Latvia, with incorporating financial benefits brought by the inclusion of forest biotechonomy industry in the national macroeconomic framework	The goal of the modelling scenario is to evaluate the macroeconomic role of forest biotechonomy industry and its output in total annual governmental budget revenues. Nine clusters of forest biotechonomy products were evaluated
BIF(i)	Construction of macroeconomic development model and incorporation of forest biotechonomy industry in the national economy of Latvia. Furthermore, modelling of so called biotechonomy improvement factors (BIFs) in education and healthcare segments, in order to evaluate the reinforcing impact of economic improvements in education and healthcare on national economy	The goal of the modelling scenario was not only to evaluate the role of forest biotechonomy and related benefits in reference to national economy of Latvia, but also to assess the role of BIFs in forest biotechonomy production industry and related additional marginal benefits

In Fig. 4, a capture of the model can be observed. Via structure as represented in the figure, the overall added wealth to the annual budget was deducted; hence, in the outflow block incorporating proportional expenditure levels based on former governmental spending, it was possible to assess the role of biotechonomic forestry sector in various other macroeconomic fields. In turn, dynamic hypothesis was formed, based on the assumptions of how the macroeconomic model would react either with or without biotechonomic segment added.

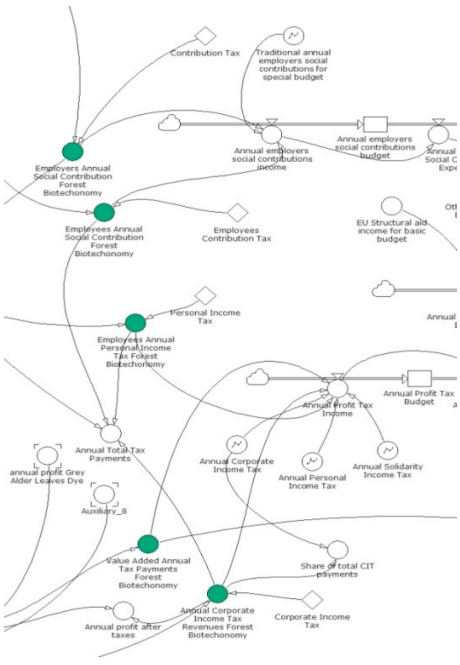


Fig. 4. Capture of the system dynamic model.

3. Results and discussion

In order to assess the role of forest biotechonomy industry on the development of related education and healthcare governmental budget incomes refer to Fig. 5 below. The macro-level impact of forest biotechonomy on education and healthcare budgets while should be considered below the level of expectations, indicates notable improvement tendencies. For instance, graphical improvement on healthcare budget can be observed starting from approximate year of 2030 and leads to notable improvement – approximately 20 million euros per year by 2047. Nevertheless, education budget additions of 5 million euros annually closer to year 2047 in best-case scenario.

Even though the improvement in final year of modelling for both sectors is 20 and 5 million euros accordingly, on macro-level scale, where annual governmental budget expenditure will be considered to reach almost 12 billion in 2047 such improvement should be considered at least notable for healthcare sector, but questionably adequate for education budget segment.

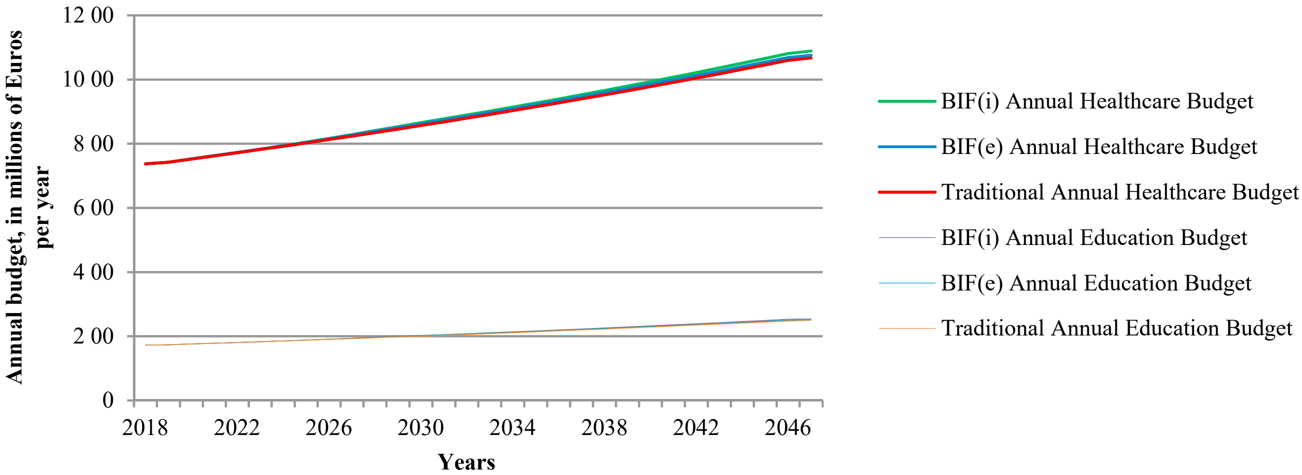


Fig. 5. Education and healthcare annual budget revenues with and without the impact of forest biotechonomy industry.

To continue with, the impact of forest biotechonomy inclusion on share of corporate income tax (CIT) generated revenues, as well as on energy (electricity) intensity per 1 euro of EBITDA generated should be explored. While the former allows assessing the additional role of improved education and healthcare sectors on an economy, energy intensity was chosen as a variable to reflect the limiting impact on environment, while developing forest biotechonomy.

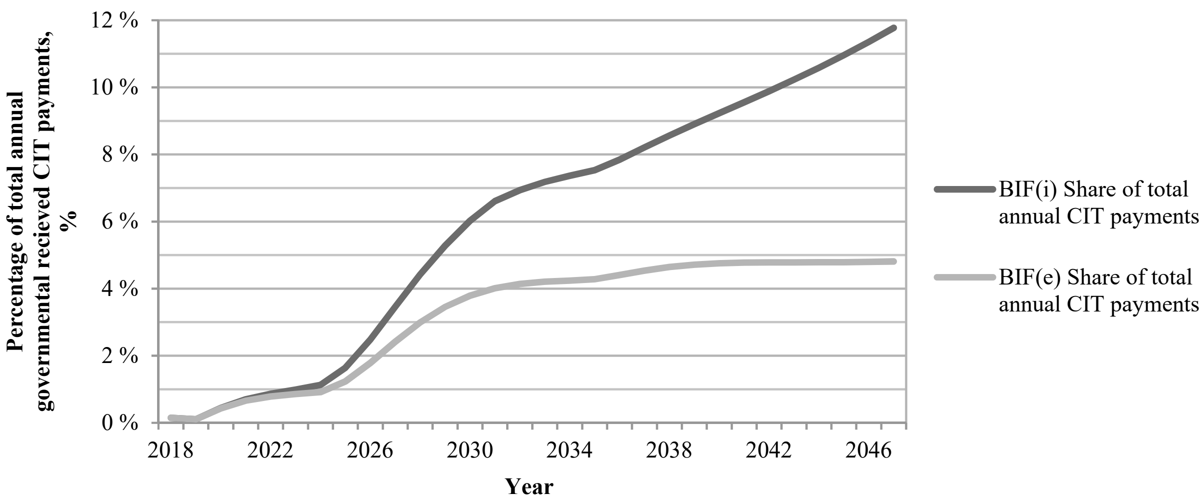


Fig. 6. The share of forest biotechonomy CIT payments in reference to total annual CIT revenues in Latvia.

As it can be observed in Fig. 6 above, already in the case of plain forest biotechonomy sector inclusion in the macroeconomic model, the sector plays important role in separate annual governmental revenues – reaching nearly 5 % of the total corporate income tax revenues paid. Furthermore, by year 2024 both forest biotechonomy inclusion scenarios (with or without dynamic inclusion) generate similar results of the proportion of CIT paid in reference to total CIT revenues – approximately 1 %.

Beyond doubt, these results reveal the essential role of BIF played in the case of the inclusion of this factor in the feed-back loop within the macroeconomic development model. The share of CIT paid reaches almost 12 % in 2047, indicating the significant role that forest biotechonomy can take in reference to total Latvian economic revenues.

From the graph shown above four particular graphical tendencies start to take shape:

- Essentially linear growth starting from year 2025;
- Settling down or more gradual growth in case of BIF(i) starting from year 2030 onwards;
- Another common growth surge in years 2035–2036;
- The levelling of BIF(e) scenario from 2035 onwards.

In reference to the former trend, first it has to be mentioned that the initial three paradigmatic forest biotechonomy segments with profitable indicators are:

- Furfural production from grey alder;
- Oil extract production from pine needles;
- Betulin and lupeol production from birch.

While two of the former sub-sectors initiate operation almost immediately from the modelled year 2018, for birch product manufacturing there is a necessity for accumulation of particular amount of veneer log annual supply and deriving birch bark accessibility (approximately 5 thousand tons annually), once these indicators are reached, in addition to capital investments the growth of the crucial betulin and lupeol manufacturing begins, starting from year 2023.

Regarding the settling down tendency after year 2030 in case of BIF(e) and slower pace or gradual growth in case of BIF(i), again birch betulin production is of crucial importance. If independent growth rates of forest biotechonomy product EBITDAs (profits before taxes) are explored, it can be seen that throughout 2025–2030 betulin by far exceeds all other products in reaching almost 80 million euros per year in scenario BIF(e). For frame of reference, second most profitable product – birch flavonoid – reaches 15 million euros per year, and gradually declines. Key to the gradual growth or stagnation in this stage is the fact that for betulin production after 2030 manufacturing capacity meets potential capacity as the limiting loop; hence, the production in place meets its optimum in relation to limits of available raw materials. Therefore, while containing more or less stable annual growth, after this stage in time other products start playing more central role in growth and decline tendencies.

The growth or the gradual leap from 2035 can be best explained by the dynamic growth surge of furfural. When operational capacity meets the potential capacity of particular production around year 2035, the capital costs experience a sharp decline by roughly 10 million euros per year which is the most crucial push factor for the exponential growth tendency.

In case of scenario BIF(i), furfural and other products' manufacturing, experiencing continuing improvement factor of education (via production rates) and labour hours (via desired capacity) ensure gradual, but stable and consistent growth. In case of scenario BIF(e), where improvement factors are absent, the limitation is met relatively faster and the growth of particular furfural sub-section is levelled out by either gradually declining or consistent tendencies of other products.

Hence, by closer analysis of the data it can be stated that indeed the biotechonomy improvement factor can provide a significant influence in segments development trend by pushing the limiting out borders at least for additional 10 years, from 2035 to roughly mid-2040s.

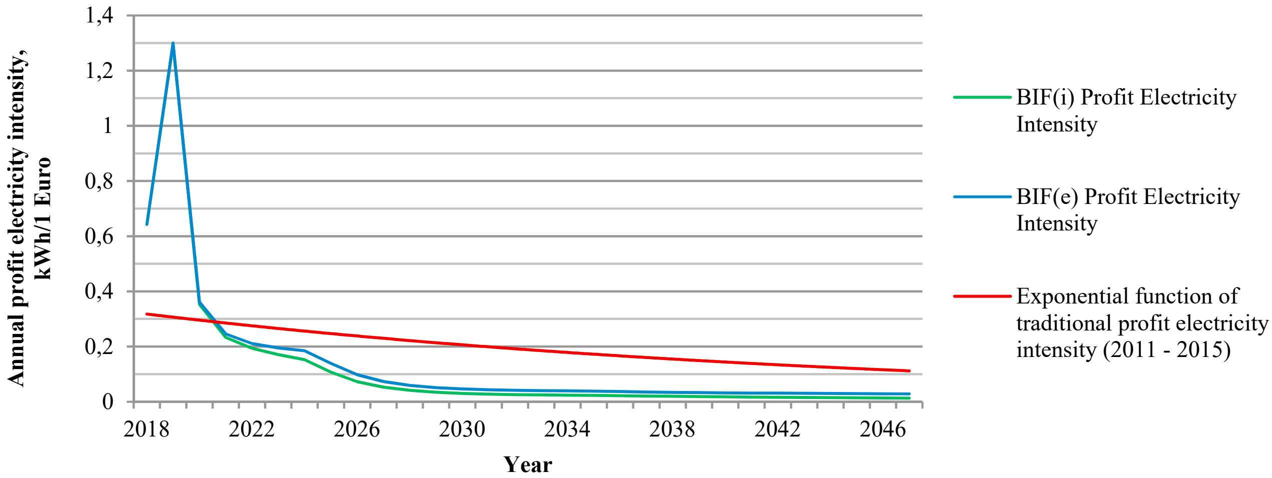


Fig. 7. Electricity intensity per euro generated (sales) in forest biotechonomy and traditional processing industry in Latvia.

When considering profit energy intensity, found in Fig. 7 and Eq. (1), it can be observed that in long term forest biotechonomic industry provides significantly higher electricity consumption efficiency in comparison to the best case scenario of traditional processing industry. Energy intensity, arguably, allows exploring the carbon intensity of an economy – evaluating environmental impact – when translated via energy generation carbon footprint of a given market. In the particular research carbon intensity of Latvian electricity consumption was assumed 150.18 carbon dioxide grams per kWh [16].

Even though traditional industry is also closing on the 0.1 kWh/per 1 euro benchmark by 2047, both biotechonomy scenarios reach equivalent level already in mid 2020s and reaching their optimal consumption of approximately 0.02–0.04 kWh/per 1 euro by the beginning of 2030s, indicating significantly lower general impact of economic activities on environment and climate.

$$Intensity_{bio}^{el} = \frac{\sum electricit\,y\ consumptio\,n\ biotechono\,my}{\sum EBITDA_{bio}} \quad (1)$$

where

$Intensity^{el}_{bio}$	electricity intensity per 1 euro generated in forest biotechonomy, kWh/EUR;
Electricity consumption biotechonomy	total electricity consumption of forest biotechonomy manufacturing segments per year, kWh/year;
$EBITDA_{bio}$	total annual revenues before taxes of forest biotechonomy segment, EUR/year.

Furthermore, it can be argued that the sharp increase at the very beginning of operational cycle is related to capacity instalment and relatively limited initial production sales turnover.

4. Conclusion and further research

The particular investigation contributed to revealing general aspects of any kind of bio-economic manufacturing inclusion in a national macro-level economy. In addition to the conceptual causal loop diagram that could be considered applicable to a wide range of mature economies and one of the strengths of particular paper, the research also revealed the dilemma between high-added value biotechonomic manufacturing with less labour intensive means of production (resulting with less labour taxes and more prominent role of VAT and CIT) and traditional economy with higher contributions of labour taxes, but significantly lower profit and VAT ratios, as well as greater impact on the environment and climate.

In reference to the particular setting of the national macroeconomic development model of Latvia, this research indicated and lead to conclusion that forest biotechonomy, indeed, could not only be a notable and, in some cases, a significant additional driver for macroeconomic growth of the Latvian economy, but it also should be considered truly sustainable over time, with more efficient usage of resources and leaving considerably lower impact on climate and environment. To some extent, a prominent role is also devoted to the well-developed Latvian forestry sector, providing long-term and environmentally aware biological resource management strategy.

Nevertheless, this research also points out several limitations of exercised investigation. Most notably – in reference to financing and marketing of the forest biotechonomy products and the unexplored potential competition dynamics for various resources between traditional and biotechonomy forest processing sectors.

The latter, in turn, paves way for further research in energy sector as such – with competition between various sectors (i.e. manufacturing and energy) for same biological resources, it is possible to argue that the overall structure of Latvian energy balance would be changed. Furthermore, with general transition to renewables on national macroeconomic energy level, a question arises how and when would this transition take place, how would it look like and what role in the transition to renewable economy will be played by forest biological resources.

References

[1] Smith G, Sharples B. Oil Reaches $70 a Barrel for First Time in Three Years. Bloomberg, 2018.

[2] Blumberga A, Bazbauers G, Davidsen PI, Blumberga D, Gravelsnins A, Prodanuks T. System dynamics model of a biotechonomy. Journal of Cleaner Production 2018;172:4018–32.

[3] Blumberga A, Bazbauers G, Davidsen P, Blumberga D, Gravelsnins A, Prodanuks T. Sistemdinamika biotehonomikas modelesanai. Riga: RTU; 2016.

[4] Azis R, Blumberga A, Bazbauers G. The Role of Forest Biotechonomy Industry in the Macroeconomic Development Model of the National Economy of Latvia: A System Dynamics Approach. Energy Procedia 2017;128:32–7.

[5] Bassi A, Lusaka MP. Threshold 21 (T21) Framework. The Millennium Institute, 2007.

[6] Bernardo G, D'Alessandro S. System-dynamic analysis of employment and inequality impacts of low-carbon investments. Environmental Innovation and Societal Transitions 2016;21:123–44.

[7] Bassi AM, Tan Z, Mbi A. Estimating the impact of investing in a resource efficient, resilient global energy-intensive manufacturing industry. Technological Forecast and Social Change 2012;79:69–84.

[8] Bassi AM, Shilling JD. Informing the US Energy Debate with Threshold 21. Technological Forecasting and Social Change 2010;77:396–410.

[9] Bassi AM, Yudken JS, Ruth M. Climate policy impacts on the competitiveness of energy-intensive manufacturing sectors. Energy Policy 2009;37:3052–60.

[10] Allena-Ozolina S, Bazbauers G. System dynamics model of research, innovation and education system for efficient use of bio-resources. Energy Procedia 2017;128:350–7.

[11] Blumberga D, Muizniece I, Zihare L, Sniega L. Bioeconomy mapping indicators and methodology. Case study about forest sector in Latvia. Energy Procedia 2017;128:363–7.

[12] Locmelis K, Blumberga A, Bariss U, Blumberga D. Energy policy for energy intensive manufacturing companies and its impact on energy efficiency improvements. System dynamics approach. Energy Procedia 2017;128:10–6.

[13] Blumberga A, Blumberga D, Bazbauers G, Davidsen PI, Moxnes E, Dzene I, Barisa A, Zogla G, Dace E, Berziņa A. Sistemdinamika vides inzenierzinatnu studentiem. Riga: RTU; 2010.

[14] Sachs J, Warner A. Sources of slow growth in African economies. Journal of African Economics 1997;6:335–7.

[15] Barro R. Health and economic Growth. Cambridge: Harvard University; 1996.

[16] European Environment Agency. CO_2 electricity per kWh. Available: https://www.eea.europa.eu/data-and-maps/figures/co2-electricity-g-per-kwh/co2-per-electricity-kwh-fig-1_2010_qa.xls