RIGA TECHNICAL UNIVERSITY

Līga Rozentāle

ELECTRICITY AND CLIMATE POLICY MEASURES: THE UNKNOWN KNOWN

Doctoral Thesis

RTU Press
Riga 2022

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

Līga Rozentāle
Doctoral Student of the Study Programme “Environmental Science”

ELECTRICITY AND CLIMATE POLICY MEASURES: THE UNKNOWN KNOWN

Doctoral Thesis

Scientific supervisor
Dr. habil. sc. ing., Professor
DAGNIJA BLUMBERGA

Riga 2022

Rozentāle L. Electricity and climate policy measures: The unknown known. Doctoral Thesis. Riga: RTU Press, 2022. 152 p.

Published in accordance with the decision of the Promotion Council “RTU P-19” of 25 February 2022, Minutes No. 152.

ACKNOWLEDGEMENTS

While a lot of valuable experience and knowledge has been gained in the last 4 years, this has definitely been a challenging time and there were moments where it seemed impossible to manage the Thesis, full-time job and personal life all together. But I am delighted that I did and for that I am first and foremost grateful to my supervisor professor Dagnija Blumberga, who has splendidly guided me through these years with the best advices and brain storms when I was not sure how to move forward with my research, amazingly fast ideas on how to improve it, encouragement to continue my work and the perfect amount of control so I would not lag behind in the moments of weakness. I admire your never-ending energy and I thank you for accepting being my supervisor starting from my master studies, which led to an excellent cooperation for many years.

Thank you to the professors, researchers and course mates at the Institute of Energy Systems and Environment, who have provided their advice and recommendations over the years as well as co-authored the scientific publications that compose my Thesis. I would not have managed it without you.

I am grateful to my whole family who has always truly supported me, also for the little sweet things like my father visiting me with snacks to cheer me up while I work on my Thesis at late evenings. But especially I want to say thank you to my mother prof. Baiba Rozentāle, who has always been my role model, provided constant support and has encouraged me to strive for my best since childhood when she taught me a poem by Latvian poet A.Eglītis that could be translated as:

"There is nothing one cannot deal with.
If there is a task – you have to manage it.
Even if you have to drain the sea with your palms
Or pick up the weight of the whole world."

I am also grateful to my friends Ance, Daira and Madara for the continuous moral support, comic relief and for the brilliant ideas in the moments when I had run out of the right words.

This work has been supported by the:

- National Research Program's project "Assessment of Latvia's renewable energy supply-demand economic potential and policy recommendations", project No. VPP-EM-2018/AER_1_001
- National Research Program's project "Sustainable and renewable transport policy formulation in Latvia (4muLATe)", project Nr. VPP-EM-2018/AER-2-003
- Riga Technical University's Doctoral Grant programme

ANOTĀCIJA

Eiropas Savienības enerģētikas un klimata politika pēdējo desmit gadu laikā ir bijusi viena no galvenajām prioritātēm tās dienaskārtībā. Kamēr dalībvalstis cenšas īstenot Eiropas Savienības līmeņa dokumentos noteiktos mērķus un nosacījumus, vietā parādās jauni likumdošanas priekšlikumi un dalībvalstīm ir jāizstrādā jauni nacionālie pasākumi kopējo mērķu sasniegšanai. Eiropas Savienības ambīcijas attiecībā uz klimata neitralitāti ir būtisks dzinējspēks, lai dalībvalstis pielāgotu savu enerģētikas politiku, lai samazinātu fosilā kurināmā izmantošanu, nodrošinātu papildu elektroenerģijas ražošanas iespējas un samazinātu enerģijas patēriņu kopumā.

Promocijas darbā ir sniegta visaptveroša un sistemātiska konkrētu elektroenerģijas politikas pasākumu analīze, izmantojot vairāku metodiku tvērumu, kas noslēgumā nonāk pie teorijā balstītās pieejas, lai integrētu visas elektroenerģijas politikas pasākumu pētījuma daļas.

Darba mērķis ir izpētīt tās Latvijas elektroenerģijas politikas jomas, kuras pašreizējā elektroenerģijas politikas ietvarā ir maz attīstītas vai aizmirstas, lai definētu iespējamos politikas uzlabojumus no klimata mērķu sasniegšanas perspektīvas. Promocijas darba mērķa sasniegšanai tika noteikti šādi uzdevumi: izvērtēt pašreizējos elektroenerģijas politikas pasākumus Latvijā un klimata aspektu lomu tajā; izvērtēt ekonomiskās un tehniskās perspektīvas elektroenerģijas ražošanas veicināšanai no saules paneļiem un vēja parkos Latvijā, ņemot vērā šo jaudu potenciālu enerģētisko kopienu veidošanā; analizēt fosilā kurināmā patēriņa samazināšanas iespējas, ņemot vērā gan energointensitāti ražošanas sektorā Latvijā, gan arī iespējamos ieguvumus no dzelzceļa elektrifikācijas, vienlaikus apsverot arī kopējo elektroenerģijas patēriņa samazinājumu, iesaistot agregatorus; pamatojoties uz iepriekšējo uzdevumu secinājumiem, piedāvāt jaunus elektroenerģijas politikas pasākumus Latvijas Nacionālajam enerģētikas un klimata plānam, sniedzot kvantitatīvus pieņēmumus par šo pasākumu ietekmi.

Autore izvirzīja hipotēzi, ka līdz šim pienācīgi nenovērtētajiem elektroenerģijas politikas pasākumiem Latvijas Nacionālajā enerģētikas un klimata plānā var būt nozīmīga loma ceļā uz klimata neitralitātes sasniegšanu.

Promocijas darbā sniegti praktiski priekšlikumi izmērāmiem uzlabojumiem Latvijas Nacionālajā enerģētikas un klimata plānā. Turklāt promocijas darba ietvaros tika izveidoti divi dažādi modeļi – viens var tikt izmantots kā instruments saules paneļu investīciju atdeves novērtēšanai un otrs ir sistēmdinamikas modelis, kas izveidots, lai novērtētu dzelzceļa elektrifikācijas ietekmi uz klimatu, ko var piemērot arī citu valstu izvērtējumā.

Promocijas darbs ir balstīts uz tematiski saistītām 9 zinātniskām publikācijām. Publikāciju galvenais mērķis bija atsevišķi aplūkot dažādus elektroenerģijas politikas pasākumus, kas ļāva individuāli aprobēt katra Nacionālā enerģētikas un klimata plānā piedāvātā pasākuma ietekmi. Pētījuma rezultāti aprobēti 8 starptautiskās zinātniskās konferencēs un 9 pilna garuma zinātniskajos rakstos.

Sekojoši aiz ievada 1.nodaļā ir sniegts pārskats par pētāmo jomu, t.i., elektroenerģijas politiku Latvijā un autores publikācijās aplūkotajiem atbilstošajiem politikas pasākumiem. 2.nodaļā aprakstīta metodika, kas tika izmantota visās publikācijās, lai izvērtētu dažādus elektroenerģijas politikas pasākumus, kas šobrīd Latvijas elektroenerģijas politikā nav pietiekami attīstīti. 3. nodaļā sniegti pētījuma rezultāti, kas balstīti uz iepriekš minētajām metodikām, kas ļauj autorei noslēgt promocijas darbu ar secinājumiem.

ANNOTATION

European Union’s energy and climate policy has been one of the major priorities on the its’ agenda for the last decade. While the member states try to implement the goals and rules stipulated in European Union level documents, new legislative proposals keep coming up and member states need to elaborate new national actions to fulfil the common goals. The European Union’s ambition towards climate neutrality is a major driving force for the member states to adjust their energy policies in order to reduce the usage of fossil fuels, provide additional means of electricity production and reduce energy consumption in general.

Thesis provides a comprehensive and systematic analysis of specific electricity policy measures with different methodological approaches coming down to the final theory-based approach to integrate all parts of the research on electricity policy measures.

The aim of the Thesis is to research those Latvian electricity policy areas which are underdeveloped or overlooked in the current electricity policy framework in order to define the possible improvements from the perspective of achieving climate targets. The following tasks were defined to achieve the aim of the Thesis: to evaluate the current electricity policy measures in Latvia and the role of climate aspects in it; to assess the economic and technical prospects for accelerating electricity generation from solar panels and wind parks in Latvia while considering these capacities as the potential for creating energy communities; to analyse the possibilities of decreasing the consumption of fossil fuels by taking into account the energy intensity in manufacturing in Latvia as well as the possible benefits from railway electrification while also considering the overall electricity consumption reduction by involvement of aggregators; to propose new electricity policy measures for the National Energy and Climate Plan of Latvia based on the conclusions from previous tasks while providing quantitative assumptions on the effect of these measures.

Author developed a hypothesis that additional overlooked electricity policy measures in the National Energy and Climate Plan of Latvia can play an important role in the way towards achieving climate neutrality.

Doctoral Thesis provides practical proposals for the measurable improvements in the National Energy and Climate Plan of Latvia. Moreover, within the framework of doctoral Thesis two different models were created – one can be used as a tool for estimating the return of investments in solar panels and the other one is a system dynamics model created to evaluate the impact of railway electrification on climate that can also be applicable for other countries.

Doctoral Thesis is based on thematically linked 9 scientific publications. The main purpose of the publications was to separately examine different electricity policy measures that allowed to individually approbate the impact of each of the measures proposed for the National Energy and Climate Plan. The research results have been approbated in 8 international scientific conferences and 9 full-length articles.

Followed the introduction, Chapter 1 consists of an overview of the area of research, i.e. the electricity policy in Latvia and the relevant policy measures discussed in the author’s publications. Chapter 2 describes the methodology that was used in all of the publications in order the evaluate the different electricity policy measures that are currently underdeveloped in the Latvian electricity policy. Chapter 3 provides the results of the research based on the previously mentioned methodologies, which allows the author to finalise the Doctoral Thesis with conclusions.

TABLE OF CONTENT

NOMENCLATURE

BESS	Battery energy storage system
CEC	Citizen energy community
CO_2	Carbon dioxide
EU	European Union
GHG	Greenhouse gas
GW	Gigawatt
GWh	Gigawatt hour
LCOE	Levelized cost of electricity
MCA	Multi-criteria analysis
CBA	Cost-benefit analysis
MPC	Mandatory procurement component
MW	Megawatt
MWh	Megawatt hour
NECP	National Energy and Climate Plan
OPEX	Operational and maintenance costs
PU	Pollution Units
PV	Photovoltaic
REC	Renewable energy community
RES	Renewable energy sources
TSO	Transmission system operator
VAT	Value added tax
WPP	Wind power plant

INTRODUCTION

EU's energy and climate policy has been one of the major priorities on the EU agenda for the last decade. While the EU member states try to implement the goals and rules stipulated in EU level documents, new legislative proposals keep coming up and member states need to elaborate new national actions to fulfil the common EU plans.

As has been stated by the EU's statistical office Eurostat, all the EU's member states in 2019 generated 3.8 billion tonnes of CO_2 equivalents, which is the most GHG in the EU [1]. The EU's energy sector is the area of economic activity with the highest share of GHG emissions. There is a continuous increase in demand of electricity due to the growth of population and the interlinked growth of economy [2]. The EU's ambition towards climate neutrality is a major driving force for the EU's member states to adjust their energy policies and provide other means of electricity production.

The aim of the Thesis is to research those Latvian electricity policy areas which are underdeveloped or overlooked in the current electricity policy framework in order to define the possible improvements from the perspective of achieving climate targets.

The topicality of this research comes not only from the EU climate targets but also considering the review of the NECP that is coming up in 2023 for all EU member states, as well as the increased energy prices in years 2021/2022 that have urged many electricity consumers to switch to electricity generation for self-consumption. This has been further promoted also by the EU level legislation that has been trying to impower the electricity consumers to produce their own electricity and to cooperate with other self-consumers. Moreover, increased local electricity generation is also an important aspect of energy independency, which is a topical issue in the geopolitical context. Thus, electricity policy measures are as topical as never before.

The following tasks were defined to achieve the aim of the Thesis:

1. To evaluate the current electricity policy measures in Latvia and the role of climate aspects in it.
2. To assess the economic and technical prospects for accelerating electricity generation from solar panels and wind parks in Latvia while considering these capacities as the potential for creating energy communities.
3. To analyse the possibilities of decreasing the consumption of fossil fuels by taking into account the energy intensity in manufacturing in Latvia as well as the possible benefits from railway electrification while also considering the overall electricity consumption reduction by involvement of aggregators.
4. To propose new electricity policy measures for the National Energy and Climate Plan of Latvia based on the conclusions from Tasks 2 and 3 while providing quantitative assumptions on the effect of these measures.

Author has developed a hypothesis that additional overlooked electricity policy measures in the National Energy and Climate Plan of Latvia can play an important role in the way towards achieving climate neutrality.

The research has a direct application possibility for improving the NECP of Latvia in the area of electricity policy not only to foster the achievement of the existing climate targets but also in order to set new, more ambitious targets.

Scientific Significance of the Doctoral Thesis

The research is of scientific significance in terms of comprehensive and systematic analysis of the underdeveloped electricity policy measures with different methodological approaches coming down to the final theory-based approach to integrate all parts of the research.

The research is focused on linking theory on electricity policy to practical electricity policy results, while providing a cross-cut approach in combining energy, economic, social research aspects for specific electricity policy improvements from climate perspective.

The overall study is based on multiple methodologies to evaluate electricity policy from different angles, thus, it provides a separate investigation of each potential policy measure before utilizing theory-based approach to combine the research results.

Practical Significance of the Doctoral Thesis

The practical significance of the research is that it provides practical proposals for the improvements in the review of NECP in 2023. The current NECP of Latvia has served for two years now and it has been possible to compare the Latvian NECP with the NECP of other EU members states and to assess what are the missing aspects that could provide benefit for Latvia if included in the NECP.

At the same time, as part of the research, a practical mathematical model has been developed that can be used as a tool for estimating the return of investments in solar panels. At the same time a system dynamics model was created to evaluate the impacts of railway electrification that can be applicable also to other countries.

Approbation of the Research Results

The research results have been approbated in 8 international scientific conferences and 9 full-length articles, 8 articles have been published (7 in SCOPUS database and 6 in ISI Web of Science database) and 1 final article is under review.

Reports at International Scientific Conferences

1. Rozentale L., Blumberga D. Potential role of energy communities in the way towards climate neutrality // 62th International Scientific Conference on Power and Electrical Engineering, Riga Technical University, 2021.

2. Rozentale L., Blumberga D. Cost-benefit and multi-criteria analysis of wind energy parks' development potential in Latvia // International Scientific Conference of Environmental and Climate Technologies – CONECT 2021, Riga Technical University, 2021.

3. Rozentale L., Blumberga D. Aggregator as a new electricity market player. Case study of Latvia. // 61th International Scientific Conference on Power and Electrical Engineering, Riga Technical University, 2020.

4. Rozentale L., Mo G., Gravelsins A., Rochas C., Pubule J., Blumberga D. System Dynamics Modelling of Railway Electrification in Latvia. // International Scientific Conference of Environmental and Climate Technologies – CONECT 2020, Riga Technical University, 2020.

5. Rozentale L., Blumberga D. Energy Intensive Manufacturers in State Economy: Case study of Latvia. // 60th International Scientific Conference on Power and Electrical Engineering, Riga Technical University, 2019.

6. Rozentale L., Blumberga D. Methods to Evaluate Electricity Policy from Climate Perspective. // International Scientific Conference of Environmental and Climate Technologies – CONECT 2019, Riga Technical University, 2019.

7. Rozentale L., Lauka D., Blumberga D. Accelerating Power Generation with Solar Panels. Case in Latvia. // Vilnius Gediminas Technical University 21st Conference of Lithuanian Junior Researchers "Science – Future of Lithuania. Environmental protection engineering", Vilnius, Lithuania, 2018.

8. Rozentale L., Lauka D., Blumberga D. Accelerating Power Generation with Solar Panels. Case in Latvia. // International Scientific Conference of Environmental and Climate Technologies – CONECT 2018, Riga Technical University, 2018.

Publications by the Author

1. Rozentale L., Blumberga D. Electricity policy solutions in Latvia from climate perspective // 2022 – Article submitted for review.
2. Rozentale L., Blumberga D. Potential role of energy communities in the way towards climate neutrality. Case study of Latvia // 62nd International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), IEEE - 2021, pp. 1-6. DOI: https://doi.org/10.1109/RTUCON53541.2021.9711724.
3. Pakere I., Gravelsins A., Bohvalovs G., Rozentale L., Blumberga D. Will Aggregator Reduce Renewable Power Surpluses? A System Dynamics Approach for the Latvia Case Study // Energies (EISSN 1996-1073) – 2021. DOI: https://doi.org/10.3390/en14237900.
4. Rozentale L., Blumberga D. Cost-benefit and multi-criteria analysis of wind energy parks' development potential in Latvia // Environmental and Climate Technologies - vol.25 - no.1 – 2021 - pp.1229-1240. DOI: https://doi.org/10.2478/rtuect-2021-0093.

5. Rozentale, L., Blumberga, D. Aggregator as a new electricity market player. Case study of Latvia. // 61th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), IEEE - 2020, pp. 1-6, DOI: 10.1109/RTUCON51174.2020.9316486.
6. Rozentale L., Blumberga, D. Energy Intensive Manufacturers in State Economy: Case study of Latvia. // 60th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), Riga, Latvia, IEEE – 2019 - pp. 1-6. DOI: https://doi.org/10.1109/RTUCON48111.2019.8982318.
7. Rozentale L., Mo G., Gravelsins A., Rochas C,. Pubule J., Blumberga D. System Dynamics Modelling of Railway Electrification in Latvia. // Environmental and Climate Technologies – 2020 - Vol. 24 - No.2 - pp. 247-257. DOI: https://doi.org/10.2478/rtuect-2020-0070.
8. Rozentale L., Blumberga D. Methods to Evaluate Electricity Policy from Climate Perspective. // Environmental and Climate Technologies (ISSN 1691-5208) – 2019 - Vol. 23 - No. 2, pp. 131.-147. DOI: https://doi.org/10.2478/rtuect-2019-0060.
9. Rozentale L., Lauka D., Blumberga D. Accelerating Power Generation with Solar Panels. Case in Latvia. // Energy Procedia (ISSN 1876-6102) – 2018 - Vol. 147 - pp. 600-606. DOI: https://doi.org/10.1016/j.egypro.2018.07.077.

Structure and Description of the Doctoral Thesis

The Doctoral Thesis is based on thematically linked 9 scientific publications, which are published in various scientific journals and are accessible on different scientific databases available for citation. Eight of the publications research different electricity policy measures, and the ninth publication provides a summary and proposals for the National Energy and Climate Plan of Latvia considering the aspects that have been reviewed in the previous publications.

The Doctoral Thesis comprises an introduction and three chapters:

1. Literature review.
2. Research methodologies.
3. Results and discussion.

The introduction provides the aim of the Doctoral Thesis, which is followed by the tasks for achieving the aim. The introduction also provides a hypothesis and describes the scientific and practical significance of the Thesis. This is followed by the information on approbation of the research results by participating in international scientific conferences and published scientific publications.

The literature review in Chapter 1 consists of an overview of the area of research, i.e., the electricity policy in Latvia and the relevant policy measures discussed in the author's publications. Chapter 2 describes the methodology that was used in all of the publications in order the evaluate the different electricity policy measures that are currently underdeveloped in the Latvian electricity policy. Chapter 3 provides the results of the research based on the previously mentioned methodology, which allows the author to finalise the Doctoral Thesis with conclusions.

The structure of the Thesis is displayed in Fig. 1, showing that, firstly, the current electricity policy measures are evaluated, then, the focus is turned to additional electricity production measures, additional electricity consumption measures and additional measures in switching from fossil fuels to electricity. Policy measures in these three groups are researched by 7 different methodologies that allow to apply theory-based approach in the end to assess the practical potential of these measures in the review of National Climate and Energy Plan in 2023.

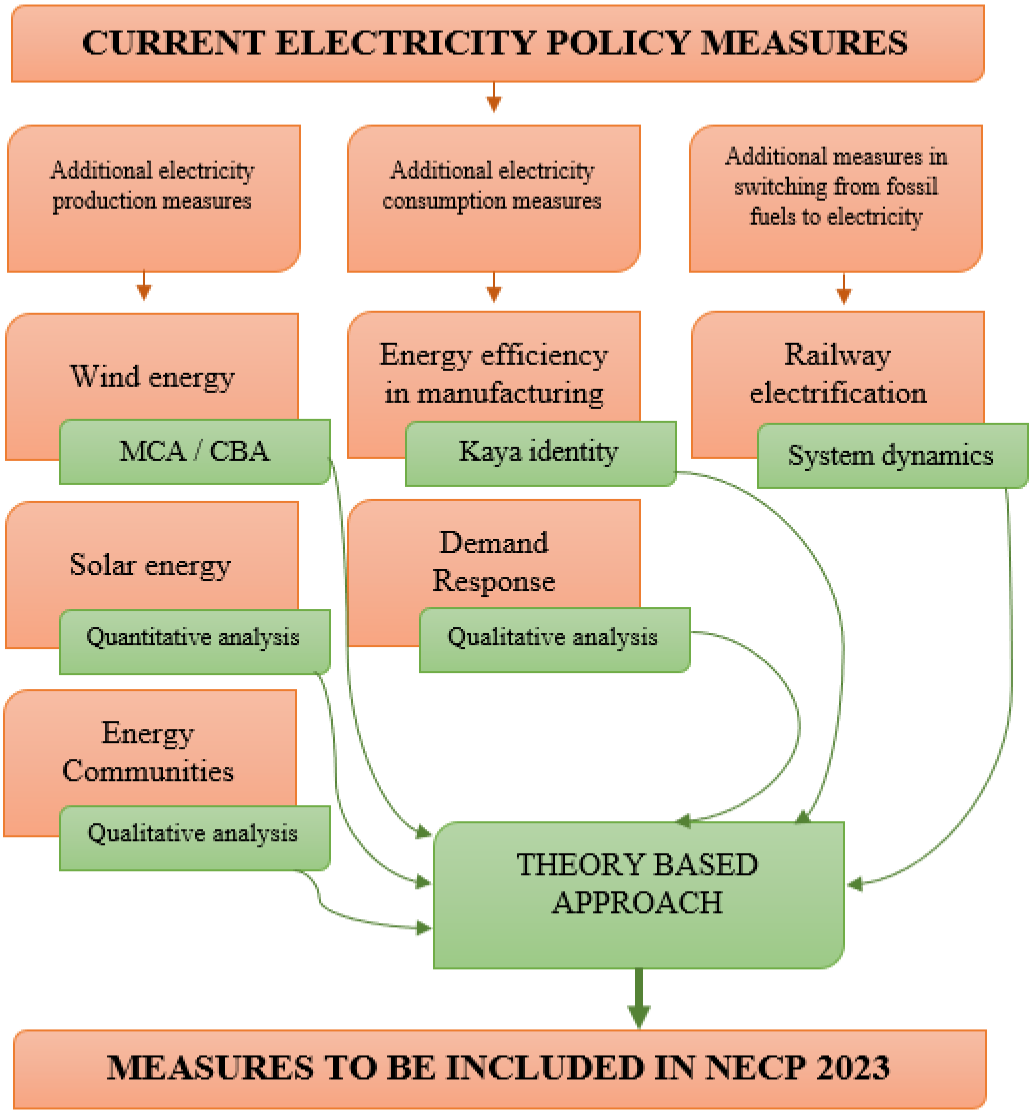


Fig. 1. Structure of the Thesis.

1. LITERATURE REVIEW

A well-functioning internal energy market is crucial to provide Europe with secure, sustainable and affordable energy supplies [3]. To ensure such internal energy market, it is necessary to implement a sound national electricity policy, which may include development of national legislation, regional cooperation, and different political decisions (such as development of national and cross border infrastructure). All these actions are closely related to different monetary investments both from the national and EU financial resources. The EU internal energy market can be related to both electricity and gas market; however, to narrow down the research, the Thesis focus is on the internal electricity market. All the actions performed to ensure a well-functioning internal energy market can be viewed and evaluated from different perspectives: How much will it cost? Will it be sustainable? What political or technical problems of the internal electricity market will it solve? etc.

Fig. 1.1. shows the energy mix in Latvia in 2020, providing what are the shares of fuels in gross available energy. It can be seen that 39.61 % in gross available energy is renewable energy and biofuels. In comparison, in Estonia the renewable energy share in energy mix was 27.4 % in 2020, while in Lithuania 21.2 % showing a good tendency for Latvia [4].

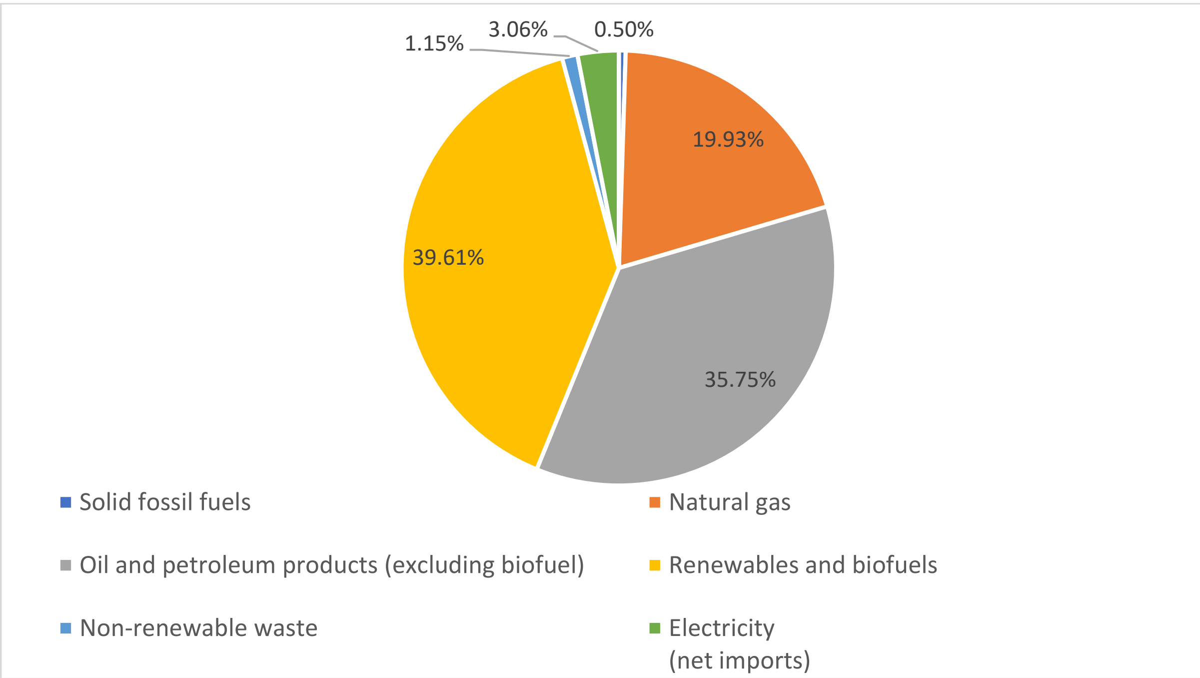


Fig.1.1. Energy mix in Latvia in 2020, %.

In this time of climate change and ever-increasing EU-level ambitions for mitigating these climate changes until 2030 by reducing the greenhouse gas emissions, by increasing the usage of renewable energy, and by improving the energy efficiency [5], it would be essential to evaluate both the political and technical actions in the electricity sector from the climate perspective, i.e., to measure the impact on the climate.

EU Regulation 2018/1999 [6] determines that each EU member state must draw up a NECP for the period 2021–2030 in order to achieve targets in the above-mentioned areas. NECPs provide a roadmap for achieving those targets. The current NECPs were finalised in 2019 [7]. Though Regulation 2018/1999 provided a framework and the European Commission provided guidance and assessment of the NECPs, each member state was free to choose on which policy areas to put more emphasis. This has led to circumstances where some of the policy areas are overlooked. For example, Latvia is the only EU member state that has not set a solar energy capacity goal for 2030 [8].

This study further on focuses on the measures that are more or less overlooked in Latvian current NECP, while being an important trend in the EU, creating concern, why Latvia is not putting more emphasis on those areas and what would be the impact if we did include these electricity policy measures in the NECP that will be reviewed in 2023 providing an excellent possibility for improvements.

The electricity policy areas that were reviewed in the study and will be further detailed are the following:

- Potential of wind energy in Latvia;
- Potential of solar energy in Latvia;
- Potential benefits of railway electrification;
- Potential of reducing energy intensity in manufacturing;
- Potential provided by energy communities;
- Potential benefits from introducing aggregators (demand response) in Latvia.

As the list suggests, there is of lot of potential that is not fully utilised yet in Latvia, starting from increasing renewable electricity generation, then switching from using fossil fuels to using electricity and finally moving forward to reducing electricity consumption in general.

1.1. Wind energy in Latvia

The share of RES utilized in Latvia is rather high, in accordance with the data of 2020, when RES in final consumption was 42.1 %, which is the third best score in the EU following Sweden and Finland [9]. This is mostly due to the hydroelectric power plants, which produce most of the electricity produced in Latvia, as well as the high usage of biomass for the fuel considering Latvia’s advantage of highly afforested lands [10].

Meanwhile, NECP of Latvia sets a target that the RES share should be 50 % by 2030. Moreover, NECP also stipulate that by 2030, there should be installed 800 MW capacity wind parks offshore, however there is no separated target for the onshore wind [11]. It’s important to mention that currently there are no offshore wind parks in Latvia and rather few onshore wind parks, mostly small scale that are connected to the distribution grid (as of the beginning of 2022, 90 wind parks with the total generation capacity of 51 MW are connected to the distribution grid, showing that the average capacity of a wind park is far below 1 MW) [12].

On the other hand, the EU member states in total would need to install 30 GW of wind energy every year to achieve the 2030 target on 40 % renewable energy. However, the EU built only 11 GW of new wind energy parks in 2021 [13]. Most of that was installed by Sweden, Germany, Netherlands and France followed by Denmark, Spain, Finland and Poland [14].

The current total wind energy capacity in Latvia is 78.6 MW (for instance, Lithuania has more than 500 MW [15] and Estonia more than 300 MW [16]), which include the above-mentioned small wind parks, wind micro-generators (i.e. generators that have capacity of up to 11.1 kW) and wind parks that are connected to the transmission system operator's grid. Thus, large scale wind parks have a very underdeveloped sector in Latvia. The reasoning for that is partly because there are no state grants or feed-in tariff possibilities as the state's position is that the electricity producers have to compete on market-based rules.

At the same time, taking into account the RES targets, Latvian and Estonian government in collaboration are working on a common offshore wind park "ELWIND" with the total capacity of about 1000 MW (to be determined during the feasibility studies). In September 2020 both governments signed a memorandum of understanding and have begun active work on the project that could be ready by 2030 [12]. Another, newly approved concept by the Cabinet of Ministers is the cooperation project between state-owned electricity supplier JSC "Latvenergo" and JSC "Latvijas valsts meži" (Latvia's State Forests), where JSC "Latvenergo" plans to develop large scale wind parks in the state forests by 2027 [17].

The process of developing a wind park is a legally challenging action in Latvia considering the procedures that have to be fulfilled both at municipal and state institutions, moreover currently there is a low level of public acceptance both for onshore and offshore wind parks. Further practical aspects of developing a wind park have been reviewed in Paper 2.

1.2. Solar energy in Latvia

Solar energy, among other forms of renewable energy sources, is promising and freely available, which in long-term could also play an important role in minimizing the usage pf fossil fuels. The solar industry is constantly evolving around the world as there is a high demand for energy, but the main source of energy – fossil fuels – is limited and other sources are more expensive [18].

The range for annual effective solar irradiance is between 60 and 250 watt per square metre, which depends from the location in the world, but there are several factors that influence the amount of solar irradiance that arrives through the atmosphere of Earth. As regards solar technologies, there are two types of solar energy technologies – passive and active. Passive technology means that the solar energy, which is accumulated, is not transformed from thermal or light energy into a different form. For example, the collection of solar energy, the storage of it and then distribution as the heat for houses during winter is a passive solar technology form. Meanwhile, active technologies accumulate the solar radiation and by using such mechanical and electrical equipment as pumps or fans, converts the solar energy into heat or electric power. The active solar energy technologies are also distinguished into two categories – PV technologies and solar thermal technologies. In the renewable energy sector PV technologies with semiconductors that convert the solar energy into electrical energy have become very well recognized over time and have a high potential in the market. Considering the above mentioned, as well as the large investments that are now involved in the PV sector, the PV market is very competitive, especially in such regions as Europe, China and the Unites states [18],[19],[20],[21],[22],[23].

While in general the renewable energy sector in Latvia is currently rather advanced, the usage of solar energy in Latvia could be described as underdeveloped. The Central Statistical Bureau of Latvia does not include solar energy in the statistics of national energy mix, because it is less than 0.1 %. The current installed solar capacity for microgenerators is 13.9 MW (as of December 2021) and for solar power plants – 6.9 MW. Thus, the total installed solar capacity is 20.8 MW. In comparison, the current installed solar capacity in Lithuania is around 150 MW [24], while in Estonia around 130 MW [16], showing that in the Baltic region Latvia is largely lagging in this policy area. Therefore, Paper 3 analyses the possibilities of accelerating the solar electricity production.

1.3. Railway electrification in Latvia

Transport and logistics are the second largest sector of the economy in Latvia, generating more than one billion euros of revenue to the state budget or one eighth of the total state budget and employing up to 70 thousand people directly or indirectly.

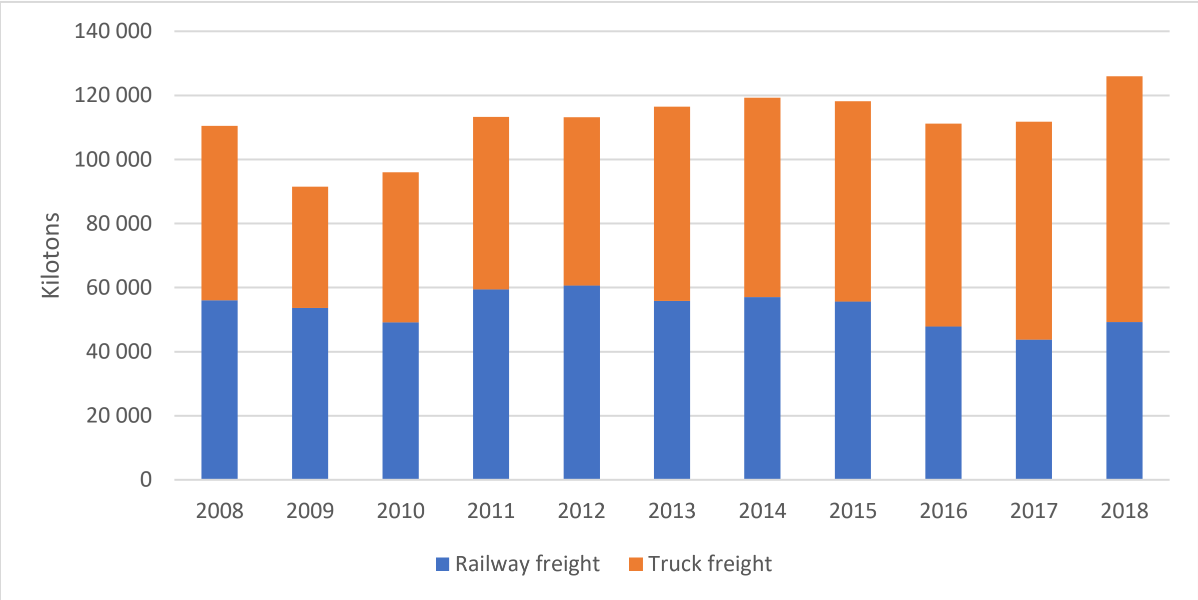


Fig. 1.2. Freight transportation by land in Latvia [25].

Railway transport is one of the most promising modes of land transport, both in safety and in environmental terms. Of the country's total land transport, the share of rail freight is approximately 39 % (as shown in Fig.1.2), while passenger transport is 7 %. In the structure of rail freight transport – 85 % is transit traffic, mainly from Russia and Belarus to ports in Latvia (East–West transit corridor), inland transport is about 11 % [26].

The total length of Latvia's rail network is about 1.860 km, of which only about 14 % is electrified (this is substantially lower than the EU average of 55 %). However, at present, electric trains can only be used for passenger transportation, while freight is only carried by diesel trains [27].

The European Commission has also noted that the transport sector has a negative impact on the environment and the quality of life of EU citizens. The transport sector accounts for about one third of energy consumption and total CO_2 emissions in the EU. Promoting efficient and sustainable transport modes such as rail and inland waterways could help in reducing Europe's dependence on imported oil and reduce pollution [28]. According to the European Environment Agency rail transport produces 3,5 times less CO_2 emissions per tonne-kilometre than road transport [29]. However, currently diesel is the main energy source both for truck and railway freight, which is also the main source of emissions (mostly CO_2) in the land transport sector.

Dependent on the available resources, every country in the regions of Scandinavia and the Baltics are aiming towards the same goal of the EU to decrease the outlet of greenhouse gases aiming at 20 % by 2020 [30] and to reduce CO_2 emissions by 80 % within 2050 [31], as well as to reach the goal of the Paris agreement [32]. The NECP goals in transport sector in Latvia include electrification of certain railway lines by 2023. However, NECP does not explain, what is the electrified percentage of the railway. Meanwhile, public information of JSC "Latvian Railway" sets out a plan to increase the railway electrification up to 30 % until 2023, thus we can assume that railway electrification technically has an electrification goal of 30 % by 2023, however there is not a specific 2030 goal. Paper 4 shows the impact on climate that railway electrification can provide.

1.4. Energy intensive manufacturing in Latvia

Manufacturing industry is sometimes considered to be the backbone of a country's economy. Some of the main benefits include such aspects as increased employment, country's gross domestic product (GDP) and technological advancement [33]. However, it is assumed that large manufacturing also comes together with high energy intensity and high greenhouse gas emissions.

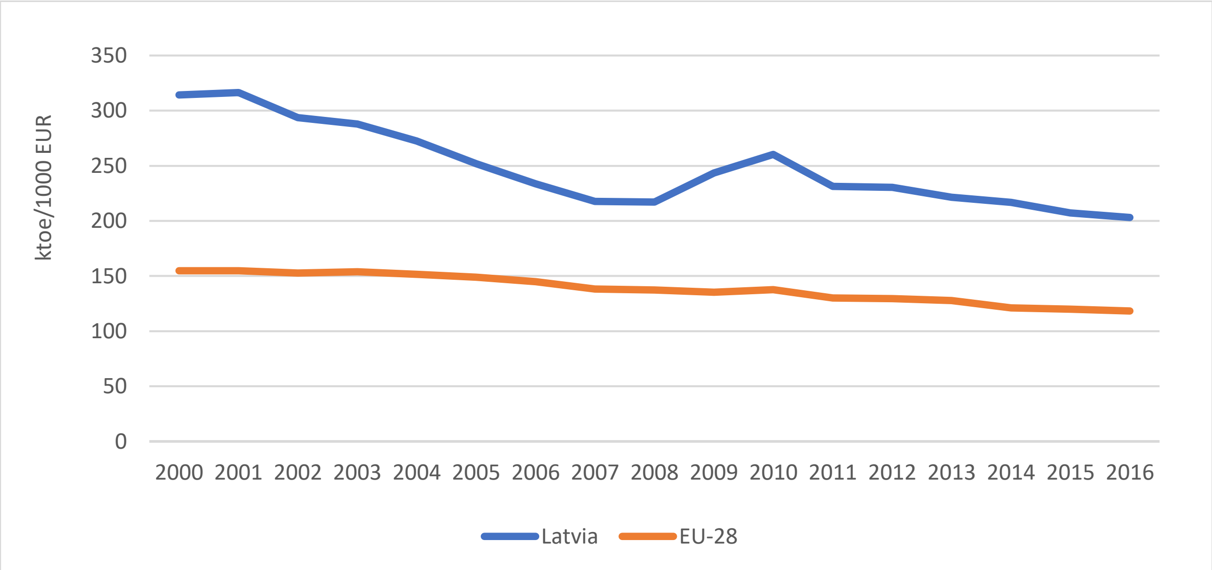


Fig. 1.3. Energy Intensity of the economy in Latvia and EU–28, ktoe/1000 EUR [34].

Fig. 1.3 indicates that the energy intensity in Latvia is quite above average in the EU, however, in the recent years the gap is narrowing down. Meanwhile, if energy intensity trends are compared with GDP, they are not always consistent. From 2001 to 2007 the GDP was growing, but the energy intensity was slowly decreasing. At the same time in 2008, when the crisis started to produce loss in GDP, the energy intensity reached the lowest mark in Latvia.

Data from the Central Statistical Bureau of Latvia shows that approximately 25 % of net electricity consumption is consumed in manufacturing industries, mainly in 4 particular industry sectors, which consume 85 % of the energy consumed in manufacturing. These are:

- Manufacturing of fabricated metal products;
- Manufacturing of wood;
- Manufacturing of food;
- Manufacturing of other non-metallic mineral products [35].

Currently (and during the last decade), the largest manufacturing companies in Latvia (based on their contribution to GDP) are energy intensive. About 15–25 % of costs for energy intensive manufacturers are composed of costs for energy consumption [36]. Such a large energy consumption is not only unsustainable and against the energy and climate goals of Latvia but is also very expensive for the manufacturer.

The issues coming from energy intensity in manufacturing in Latvia are further detailed in Paper 5. But what is important is that there is no specific NECP target defined in terms of reducing energy (electricity) intensity in the manufacturing sector in Latvia. The measures are descriptive and aimed at assessing whether entrepreneurs should be obliged to compare different alternatives (e.g. manufacturing facilities with higher and lower energy consumption) when making investment decisions. NECP also requires policy planners to amend legal acts that cover the EU funding rules to determine certain energy efficiency requirements, as well as requires additional studies to be made, e.g. regarding possible review of the scope of current energy efficiency obligations. Currently, energy intensive manufacturers must carry out an energy audit (once every 4 years) or implement a certified energy/environmental management system. Energy intensive manufacturers must implement at least 3 energy efficiency improvement measures that provide energy savings [37]. However, neither the pre-NECP legislation, nor NECP does not implement any specific measurable energy saving goals for energy intensive manufacturers.

1.5. Energy communities in Latvia

EU has provided a new legal framework for additional promotion of renewable energy – energy communities. With the increase of decentralized electricity production, creation of energy communities has become more and more topical considering the economic benefit that appears when a group of people engage in an activity that is considered to be more expensive if exercised individually [38]. The concept of energy communities has been developing for more than ten years and there are already operating pilot projects [39]. Energy communities provide the opportunity for consumers to be empowered at different community sizes and forms, produce their own electricity (or other type of energy) and consume it collectively with little or no involvement of an electricity supplier [40],[41].

There is already now an existing pilot project of an energy community in one of the municipalities (Marupe) in Latvia. The project involves a row house and an apartment building. The current pilot project is one of the reasons behind evolving the scope of jointly acting renewables self-consumers to cover a larger potential group of self-consumers. In both cases of the pilot project there are installed solar panels. The row houses, for example, have 6 solar systems (each consisting of 4 solar panels) with the total capacity of only 7.92 kW [42]. The lack of national legislation, technical challenges (rooftop repairments, network installations) and difficulties in communication with members of the energy community (not everyone is equally interested in the project) are some of the issues in developing an energy community.

The TSO of Latvia has modelled the possible electricity demand up to year 2030 in three scenarios, where the first one is the most conservative and the last one is the most optimistic and provides the highest increase in electricity consumption in Latvia [43]. Nevertheless, all three scenarios as can be seen in Fig.1.4 show that the electricity consumption in Latvia in the next years will only rise. The TSO has also compared this demand with the possibilities to provide the necessary capacity from the existing power plants and import. In the base scenario, Latvia would be capable to cover peak demand up to 2024, after that there would be electricity deficit in Latvia [43]. This means that additional electricity generation installations will be needed, and energy communities is a way to foster it.

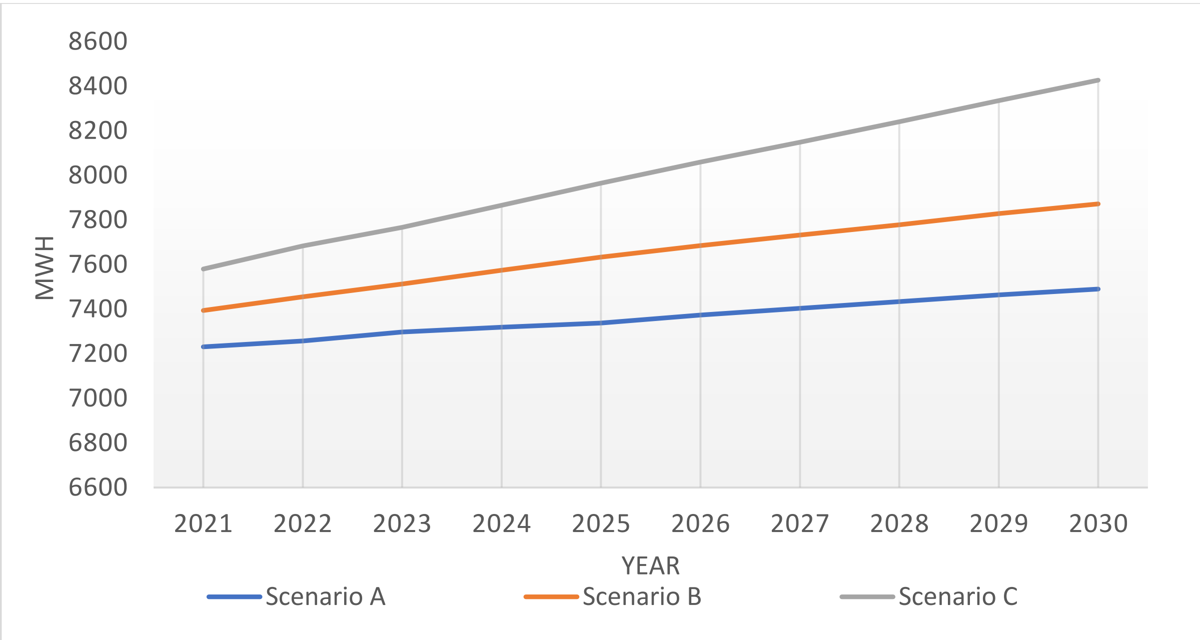


Fig.1.4. Electricity demand forecast 2021–2030 by electricity transmission system operator [43].

Latvia's NECP touches upon creation of energy communities in terms of creating the necessary regulation and possible funding, however there are no specific goals for creating a certain number of energy communities. Though it could be argued that electricity production goals for solar or wind energy could overlap with RES electricity production in energy communities, however it can also be argued that there is a certain amount of RES electricity generation capacity that will only be installed if there is an efficient regulation (incl. financing provisions) for energy communities allowing for a group of electricity self-consumers to combine their efforts in electricity generation, consumption and sharing and selling. The potential of energy communities has been reviewed in Paper 6.

1.6. Aggregators in Latvia

An aggregator is an electricity market player that has been defined at the European Union's level already for some time, but a player, who has been rather incomprehensible for the Latvian electricity market.

To understand the role of an aggregator, it is important to start with the concept of demand response. Demand-side response could be described as changes in the usual pattern of electricity consumption by the final consumer [44]. When a consumer decides on its own to use less electricity when it is more expensive (e.g. in the peak hours) and use it more when it is cheaper (e.g. at night) it becomes demand response, i.e., final consumers (demand-side) responds to the market incentives.

For the purpose of flexibility, demand response cannot be based on unpredictable actions of consumers, because these are not organized actions but based on personal interests of each individual. To make it organized (also known as explicit demand response), a new electricity market player has been introduced – an aggregator. As defined in the new Directive 2019/944 [45], an aggregator "combines multiple customer loads or generated electricity for sale, purchase or auction in any electricity market".

Fig.1.5. reflects all the flexibility mechanisms provided by the agreggators at different wholesale market segments, where aggregator can act as a facilitator for providing flexibility where needed – for electricity distribution or transmission systerm operators or for the balance responsible parties (electricity suppliers) [46]. They can ensure system stability while operating with the demand response proivided by their customers, i.e. the final consumers who adapt their consumption patterns as the aggregators requires. The final consumer gets paid for the demand response service as well as reveives benefit due to lower electricity bills (as their consumption was postponed to a time slot with lower tariffs). An open issue is whether the electricity supplier is in a disadvantage due to the aggregators. But Paper 7 and Paper 8 provides more insights on the concept of demand response and aggregators showing the possible input of an aggregator for a better performance of the electricity market.

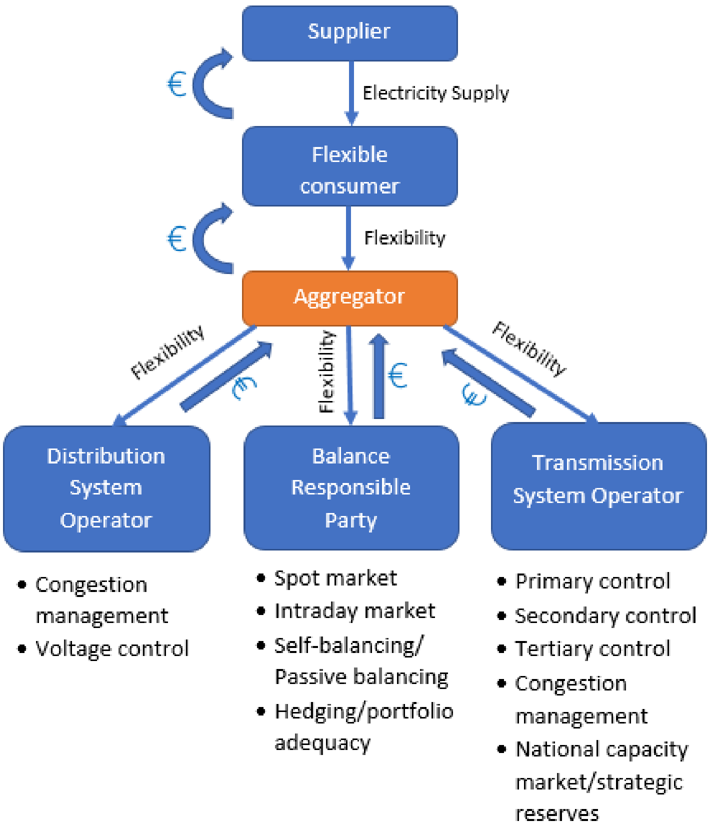


Fig.1.5. Flexibility services provided by aggregator [46].

Latvia's NECP does include vision of aggregators, prescribing the need for legislation that would set the rights and duties of the aggregators, however there are no specific goals for their actions, e.g. yearly electricity savings.

All the measures mentioned in Chapter 1 can have their own policy targets. But policymaking is a complex process, where it needs to be taken into account that the taken decisions may leave strong changes and socio-economic impact. In the context of climate change, the policy decisions are usually evaluated from the perspective of the decisions that it made for improving the climate. For example, whether the increase in carbon prices for promoting electrification would also increase the electricity price and thus would reduce the availability of energy for those, who cannot pay more. Which basically leads to energy poverty. Or, another example – can the support for biofuels lead to harsh land use change and eventually to water and food shortage [47]? Thus, before any decisions on implementing the policy, it is important evaluate the possible policy impact. The following chapter provides overview of the methodologies used in the research to evaluate the above-mentioned electricity policy measures.

2. RESEARCH METHODOLOGY

The Thesis utilizes seven different types of methodologies for evaluating the electricity policy measures that are not covered or at least not fully covered by the NECP of Latvia. As has been summarized in Figure 2.1., six of the methodologies are united by the final research using theory-based approach. Methodologies for researching the electricity policy measures were chosen based on the aim of each research – if the aim was to understand the financial side of the measure more mathematical approaches were used, while if the aim was to understand if and how the policy measure is being implemented in the national legislation – a qualitative analysis was used. At the same time, when using theory-based approach all previously explores policy measures received a quantifiable evaluation.

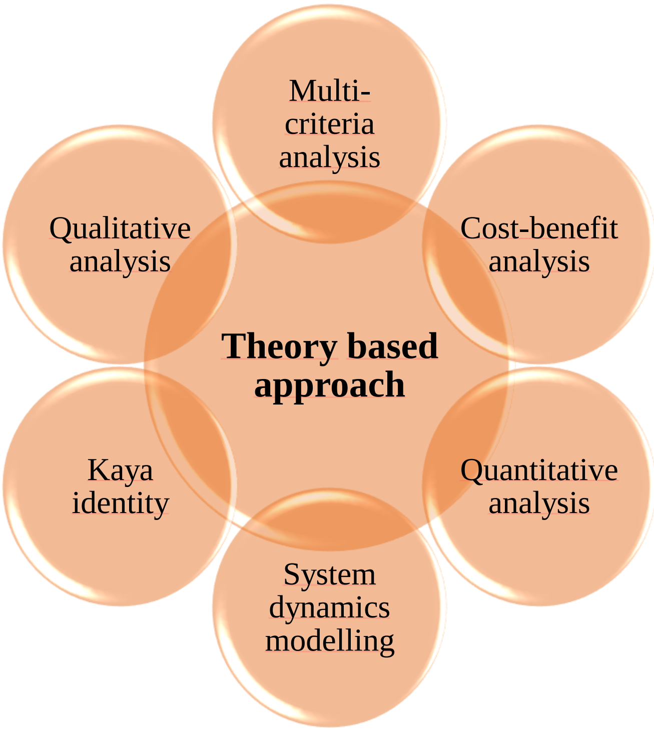


Fig. 2.1. Research framework uniting seven different methodologies.

The research topics are summarized in Figure 2.2., showing that the overarching theme is electricity policy from climate perspective that has been covered by the theory-based approach comprising the previous researches on different electricity policy measures. These measures can be divided into 3 categories:

- Electricity policy measures for producing more electricity (solar energy, wind energy and energy communities combing both);
- Electricity policy measures for reducing energy consumption (energy efficiency measures in manufacturing and demand response);
- Electricity policy measures fostering the consumption switch from using fossil fuels to electricity (railway electrification).

At the same time all the previously mentioned categories in some way overlap in their performance and the final goal of reducing CO_2 emissions.

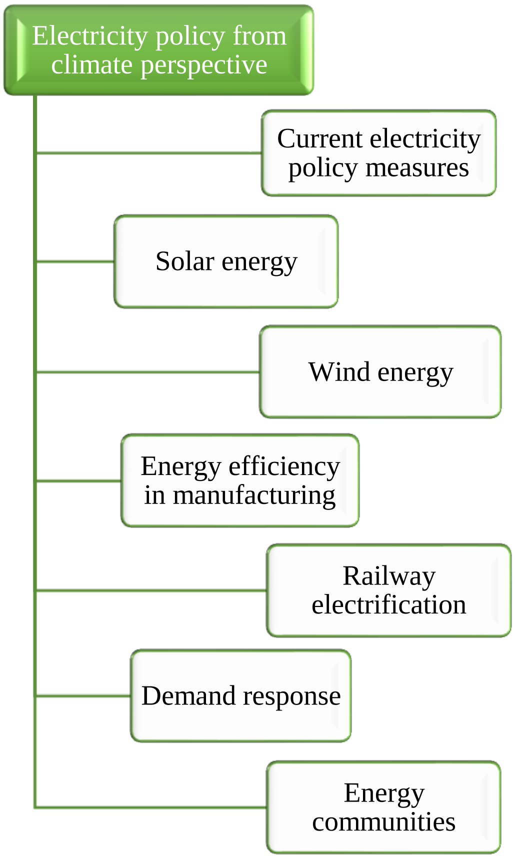


Fig. 2.2. Research topics covered by the study.

2.1. Multi-criteria analysis

At the beginning it is important to evaluate the existing electricity policy in Latvia and to assess its' focus and interrelation with climate aspects. To evaluate electricity policy, MCA can help to decide on the best choice by using multiple and sometimes even conflicting criteria in order to achieve the desired result [48]. MCA is also categorized as a sub-discipline of operations research, which is used in solving difficult problems with multiple points of view [49]. To aid the decision-making process, rather many objectives can be chosen – they can be related to economic, environmental, social, technical and other aspects. The criteria can be either monetized, non-monetized (albeit quantifiable) or qualitative based on information. MCA allows both quantitative and qualitative criteria of outputs/outcomes/impacts to be mixed together and provide the decision-making bodies the whole results of potential consequences in this specific field if the action (or policy) is completed [48]. By using MCA, there is less uncertainty regarding the monetary conversion, which is sometimes experienced. Moreover, this analysis also provides more transparency on the section process of projects [50]. MCA can be used for the whole policy-making sector. Besides, MCA methods are regularly used in energy policy and planning [51].

Table 1 shows the electricity policy aspects that were chose in the MCA. The criteria for evaluating these projects are different modes of benefits – benefits for electricity consumer, for electricity producer, for electricity seller, for transmission and distribution system operators, for the state and finally for the climate. These benefits have different weights (100 % in total for all criteria) – it is logically and at the same time subjectively assumed that benefit for consumer is the most important, followed by the benefit for producer, benefit for climate, benefit for state, benefit for seller and the benefit for the system operators in this case is the less valued criteria. It is important to stress that benefits for state can be both monetized (like a fee that is paid into budget) or it can be non-monetized, but have a different benefit, such as compliance with EU law, when it is necessary to apply EU law to national regulation. A state benefit could also be the reduction of bureaucracy in the government or a general increase of safety measures. It was decided that one criterion can have maximum 5 points (multiplied by weight). If the project does not give any benefit for the specific group (criterion), it gets 0 points. Thus, the most points one project can get is 5, meaning that is has 5 points under each criterion, which can be only in case if the project has maximum benefit under each criterion.

Table 2.1.

MCA analysis of Latvian electricity policy

	Current projects / **Criteria**	**Benefit for electricity consumer**	**Benefit for electricity producer**	**Benefit for electricity trader**	**Benefit for electricity distribution/transmission system operator**	**Benefit for the state**	**Benefit for the climate**	**MCA results**
1	Electricity market law providing amendments on:							
1.1	Data hub	1	3	5	5	1	0	1.62
1.2	Electricity production permit	1	5	0	5	4	4	2.98
1.3	Isolated island-mode test	0	0	0	5	4	0	1.13
1.4	Protected customer	5	0	2	0	4	0	2.54
1.5	Mandatory procurement payment	5	0	0	0	5	0	2.6
2	Law on buffer zones (protection zones)	0	0	0	5	2	0	0.69
3	National Energy and Climate Plan	3	4	3	2	4	5	3.72
4	Rules on Regulated public utilities	1	0	5	1	2	0	1.19
5	Synchronization	1	1	1	5	4	0	1.66

6	Tariff for trade with 3rd countries	0	3	5	5	3	1	1.96
7	Internal electricity market Directive & Regulation	5	5	3	4	3	2	3.75

MCA was also used as one of two methodologies to evaluate the potential of wind parks. In order to be able to compare wind parks of different sizes, the levelized costs per 1 MW are used. The chosen input data (criteria) for the wind park are defined in Table 2.2. As there has been a research showing that increased wind energy share does not necessarily mean that there will be decrease in electricity prices [52], impact on electricity price was not considered as a criterion for MCA. The capacity factor shows the energy output from a wind park per year as a share of wind parks maximum possible output that is influenced by the wind speed and the used technologies. By applying analytic hierarchy process method [53], the criteria received specific weight.

Table 2.2.

MCA analysis of an onshore and offshore wind park

Criteria	Weight	Wind park A	Wind park B
All investment costs, EUR/MW	15 %	1 229 000	3 171 000
Operation and maintenance costs, EUR/MW/year	13 %	37 000	80 000
Administrative burden, months	5 %	12	24
Job creations, number of workers	6 %	2	5
Capacity factor %	25 %	36	47
Import reduction, %	8 %		
LCOE, EUR/MWh	28 %	57.9	110.17

2.2. Cost-benefit analysis

Moving forward with wind park analysis, CBA is an instrument that provided the possibility to compare the costs of two case studies with the benefits that these projects provide in order to check if the benefits outweigh the costs [54]. CBA thus allows for the project promoters and all other interested parties to draw conclusions, whether the project is feasible. To do that, the costs and benefits must be monetized and expressed as the net present value (because the costs generally appear before the benefits, so the different points in time would actually impact the values) [55].

While wind has no fuel costs, there are several key parameters that define the costs of a wind park:

- Investment costs (also known as capital costs or CAPEX), which include the turbine costs, construction works, grid connection costs and other capital costs including administrative costs, designing costs etc.;
- Operation and maintenance costs (OPEX that can be fixed or variable);
- Capacity factor (the output of the turbine affects the rate of return);
- Economic lifetime;
- Cost of capital (i.e. the expected return) [56].

In case of wind parks, both MCA and CBA are applied to a case study in order to evaluate the potential of developing wind parks in Latvia from different perspectives. Both analysis complements each other.

Figure 2.3. shows the breakdown of costs for and onshore wind park. The costs of wind turbines include the costs of generator, transformer, power converters, gearbox, rotor blades, tower and other additional costs [56].

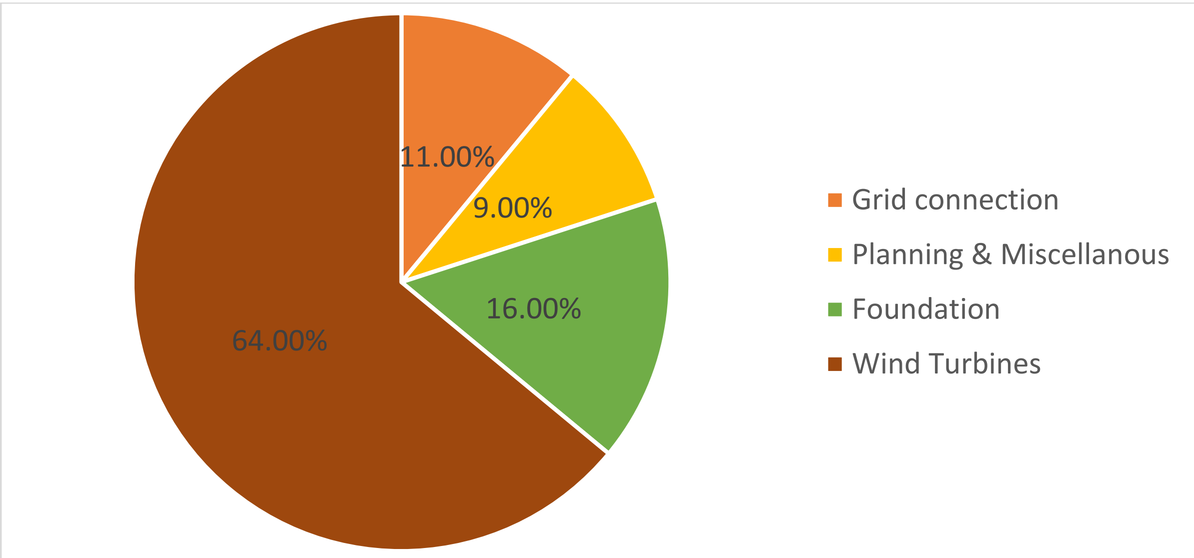


Fig. 2.3. Breakdown of costs for an onshore wind park.

Considering the above mentioned, for CBA analysis of wind parks, five criteria were taken into account:

1) The total costs of wind turbine;
2) Grid connection and other costs;
3) Operational and maintenance costs while assuming the average life span of a turbine is 20 years and that the operation costs increase every year by 2 %, discount rate is 8 %;
4) Revenues from electricity sales based on average Nordpool exchange price rate.

2.3. Quantitative analysis

The potential of solar energy was calculated by a quantitative analysis based on a model developed by the author. It was essential to develop a functional model, which would allow to determine the necessary actions to maximise the usage of solar panels in Latvia. The model first of all included data that forms the electricity bill of a household:

1) electricity tariff;
2) distribution tariff;
3) compulsory procurement component;
4) Value Added Tax.

To further develop the model, specific data summarized in Table 2.3. was collected from 15 households across the territory of Latvia. It was important to obtain data from different parts of Latvia to evaluate the amount of solar irradiation and also to make the research reliable, because it shows situation in the whole Latvia. In total respondents were asked to reply to 13 questions regarding their solar panel system.

Table 2.3.

Input data and calculation for the solar energy model

	Average
1) How many solar panels are installed (pieces)?	20.67
2) The size of one solar panel (m^2)	1.60
3) What is the size of the whole PV system (m^2)?	33.07
4) What is the efficiency rate of the PV system (%)?	16.92
5) What were the total costs for installing a PV system (EUR)?	4993.33
6) What is the total capacity of the PV system (kW)?	5.20
7) What is the output (kWh) of the PV system based on the location (solar irradiation) per month?	383.44
8) What is the monthly consumption of the household?	585.44
9) How much electricity is monthly received from the distribution system?	344.23
10) How much electricity is monthly fed in the distribution system?	142.22
11) How many phases the household has (1 or 3)?	1
12) How much amps connection does a household has (A)?	40
13) In what region of Latvia is the PV system installed?	n/a
Performance ratio, coefficient for losses (range between 0.9 and 0.5, default value = 0.75)	0.75
Solar irradiation kWh/m^2/year	1181
Government support EUR/kWh for the electricity fed in the system	0
Average monthly electricy bill before the PV system (EUR month w/o VAT)	56.99
Average monthly electricy bill before the PV system (EUR month incl. VAT)	68.96
Average monthly electricity bill with the PV system (EUR month w/o VAT)	29.48

Average monthly electricity bill with the PV system (EUR month incl. VAT)	35.67
Income from the electricity fed in the grid (EUR/month)	0.00
Average monthly saving from solar panels (EUR/month)	33.28
Average yearly saving from solar panels (EUR/month)	399.38
PV system's return of investments (years)	12.50

The electricity output of the solar panels was calculated. All the solar panels in case studies were optimally inclined, so they received the maximum possible solar radiation and based on the regional location of the solar panels, the irradiation was either 1150 kWh/m^2, 1167 kWh/m^2, 1183 kWh/m^2 or 1200 kWh/m^2.

2.4. System dynamics modelling

Further on, railway electrification was researched by using system dynamics modelling. Modelling is defined as an imitation of real-life situation with mathematical equations in order to forecast the future developments of a situation. It is an analytical instrument, which allows to quantify the aspects that may affect the environment. Computer models are often used to forecast the chemical or physical impact of an action on the environment. A model can aid in explaining the environment as a linked system and to research the impact of different environmental components as well as to give forecasts on their behaviour [57]. There are different approaches for modelling, but this particular research is focused on system dynamic modelling, which is an approach to figuring out the nonlinear behaviour of complex systems over time using stocks, flows, internal feedback loops, table functions and time delays [58].

To understand the impact electrification has on the environment as well as the energy supply and production, the model considers the current situation of the electrical supply system and the future development of the system. In the model there are four main factors that must be considered:

- emissions;
- power usage;
- transport opportunities;
- economic influence.

The model is developed from and explanatory model that highlights the problem model is going to show. The explanatory model in Figure 2.4. shows how the emissions affect the emissions over time, adding them to the stock “Pollution from railway”. This variable gives us an indicator of how many locomotives can be changed in order to reach the goal of the policy. With the change rate dependent on the sub-models it will be dynamic towards changes in these models and behave according to the changes done in the testing phase.

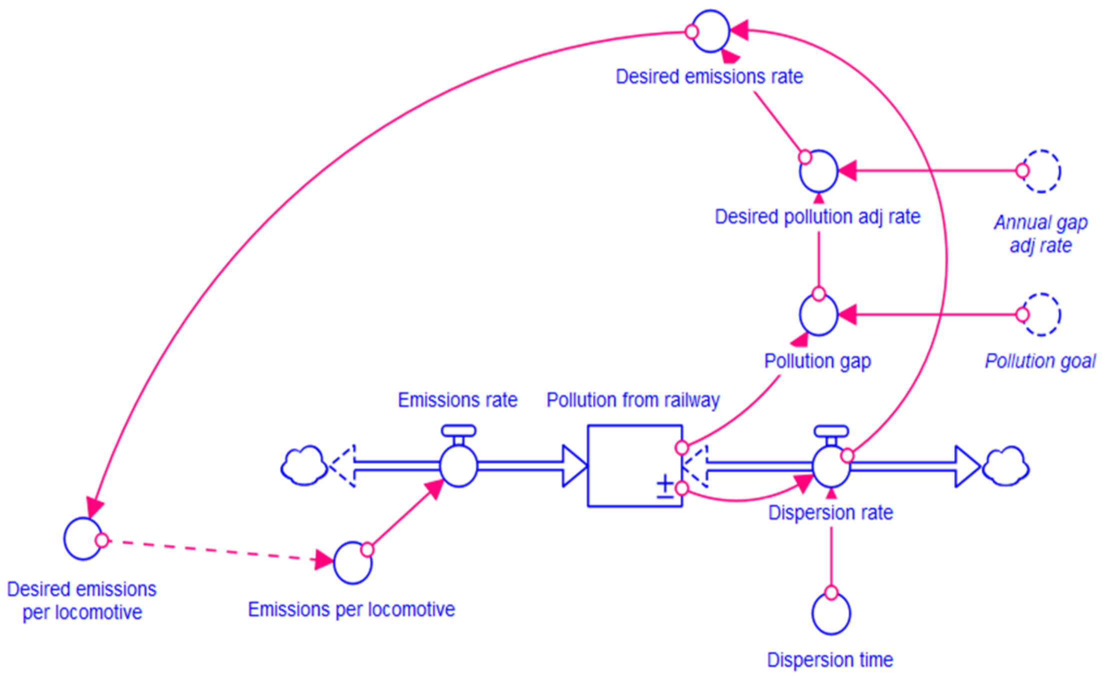


Fig. 2.4. Explanatory model.

2.5. Kaya identity

While the energy policy in Latvia on one hand stipulates the energy intensive manufacturers to introduce energy efficiency measures, on the other hand these manufacturers are still very energy intensive [59]. It is important to research not only the possibilities of increasing RES electricity generation but also to assess the energy efficiency measures that can be improved. The case study involves data on GDP, energy consumption and greenhouse gas emissions in Latvia (based on the data by the Statistical Bureau of Latvia), to evaluate the development tendencies of this data. Further on the Kaya identity is applied to analyse more thoroughly the allowed carbon intensity. The Kaya identity can be expressed as:

$$CO_2 = Pop \times \frac{CO_2}{E} \times \frac{E}{GDP} \times \frac{GDP}{Pop}, \qquad (2.1)$$

where

CO_2 – the total amount of carbon emissions;

E – the total energy consumption;

GDP – the gross domestic product;

Pop – the population [60].

The Kaya identity facilitates the understanding of the mechanism that determines the changes in emissions. While it cannot be assumed that an increase in population or GDP will mean that the carbon emissions will increase as well, the Kaya identity provides possibility to estimate quantitively, how different variables in this equation impact other variables such as emissions and energy consumption [60]. The Kaya identity also helps in understanding by how much it is necessary to reduce the carbon intensity to achieve the EU 2020 and EU 2030 goals in reduction of CO_2 emissions and it provides conclusions on how possible it is to achieve the goals and the perspective on the necessary actions [61].

The Kaya identity is applied for the case study in Latvia. The results are calculated for the years 2020 and 2030 based on the increase or decrease of the data (population, GDP per capita, energy intensity) relative to 1990. Thus, it is assumed that the base data in 1990 corresponds to 100 % and the respective changes in percentage are calculated for 2020 and 2030. Different growth patterns are assumed for the annual GDP based on the past, current and forecasted economic situation.

2.6. Qualitative analysis

Energy communities

The focus of qualitative analysis were two electricity policy concepts that are rather new – energy communities and aggregators that work with demand-response. As regards energy communities, the research focused on analysing and comparing the EU legal framework with the appropriate legislative proposals in Latvia to evaluate if the national legal framework is properly transposing the EU legislation without creating barriers for the introduction of energy communities in Latvia.

As can be seen in Figure 2.5., most of the small-scale renewable electricity (connected to the distribution grid) in Latvia is produced by biomass and biogas combined heat and power (CHP) plants. This is followed by wind parks, small hydroelectric plants and finally solar power plants [12]. Though the increase of small-scale renewable energy production has increased in the last decade, it is still only a little share of the total electricity demand in Latvia.

There are two EU's directives that were developed simultaneously and both set rules for energy communities – Directive 2019/944 of the European Parliament and of the Council on common rules for the internal market for electricity and amending Directive 2012/27/EU [45] (hereafter – Directive 2019/944) and Directive 2018/2001 of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (hereafter – Directive 2018/2001) [62]. Directive 2019/944 introduces the term "citizen energy community" (CEC), but Directive 2018/2001 introduces the term "renewable energy community" (REC). The main difference between CEC and REC is that CEC is specifically meant for electricity production (or storage, aggregation, sharing etc.) and this electricity can also be non-renewable, while REC concerns all types of renewable energy (these can be renewable electricity installings, but they can also be heat pumps, biomethane facilities etc.). Thus, if a group of people makes an energy community to collectively produce electricity from solar panels for their own needs, it will simultaneously be a REC (because of renewable energy) and CEC (because of electricity). Both CEC and REC are created as a legal voluntary entity. Energy communities are controlled by their members and their main aim has to be creation of benefits for the members of the energy community (instead of gaining financial profit) [63].

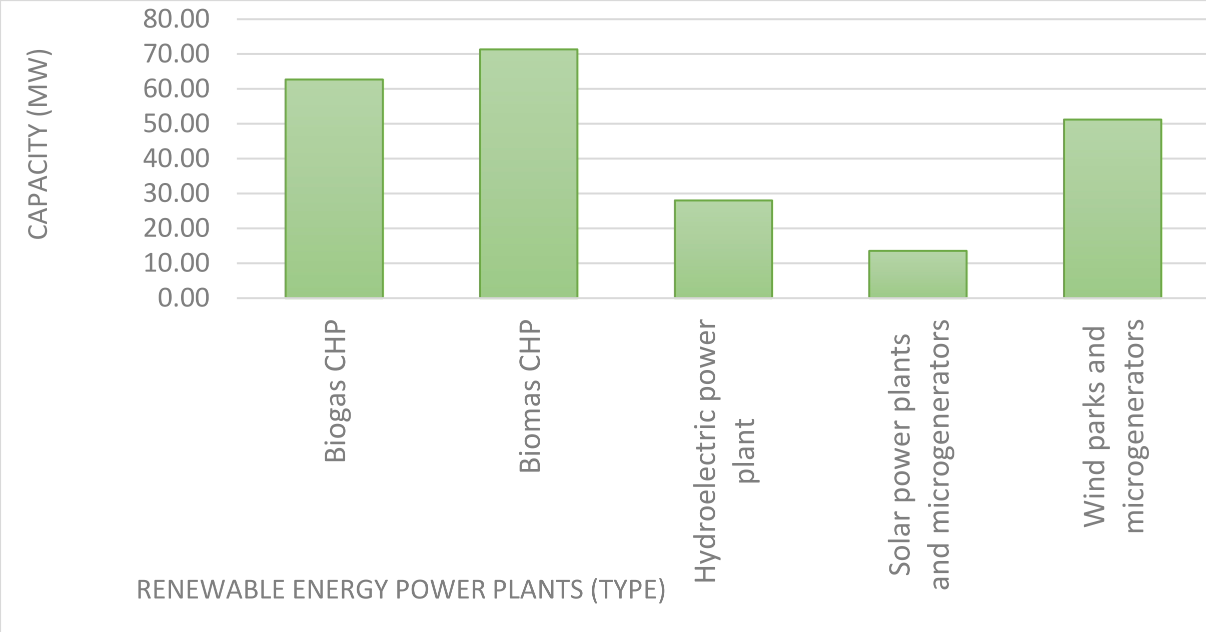


Fig. 2.5. Renewable electricity generation capacity in Latvia in the distribution grid, MW.

As per the data of distribution system operator [12], by the end of June 2021 the installed solar capacity for microgenerators (capacity up to 11.1 kW) was 9.12 MW, while the capacity of solar power plants (above 11.1 kW) was 4.44 MW, which adds up to 13.56 MW of solar capacity connected to the distribution grid in Latvia. The concept of energy communities can stimulate this tendency.

Aggregators

As regards aggregators, the study is based on researching the legal and economic aspects of demand response and aggregation, and applying them to the situation in Latvia. As has been noted in a research by J.K. Juffermans [64], it is hard to predict how much of the conventional generation will be able to aid in providing flexibility in the future, because it can be thoroughly based on political decisions on whether these conventional generation units will continue to operate (e.g. cogeneration plants from natural gas). Thus, a bigger role will be played by the demand side response.

There are 6 types of demand-side's electricity consumption management, which are shown in Fig.2. These different types of demand side management, which can be combined all together, allow us to very closely relate to generation [65].

There are two types of aggregators – independent and combined. Combined aggregator means that an electricity supplier or balance responsible party or distribution system operator is also an aggregator, so aggregation is an additional function of an already existing market player. An independent aggregator on the other hand is a separate undertaking working independently from the previously mentioned electricity suppliers, balance responsible parties or system operators. Currently, more common in the EU is the combined aggregator, because it is easier to involve it in the market. It's not only less complex from the legislative perspective, but also from the perspective of the electricity consumers in cases, where the aggregator is the consumer's electricity supplier [66],[67].

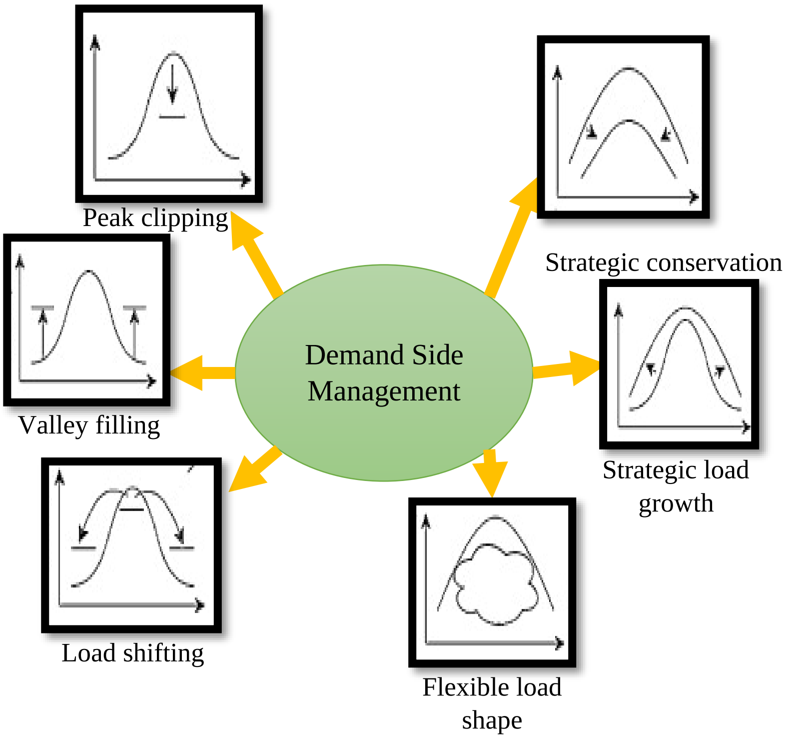


Fig. 2.6. Types of demand side management.

In growing demand of electricity, this can replace part of the generation that will be needed to fulfil this future demand. The demand side management types show us all the options an aggregator can use – it is not only load shifting to another period of time, but also decrease in electricity consumption in general by using the consumer's appliances more efficiently and thus providing benefits also for the EU's climate policy and climate targets [68].

2.7. Theory based approach

As was discussed before, the main idea of the research is to propose additional measures for the NECP of Latvia. In order to summarize the previously used methodologies, a theory-based approach is used for finalizing the study. As the author has summarized in Fig. 2.7., electricity policy is one of the gears in the NECP that plays an important role in the amount of GHG emissions in the energy sector.

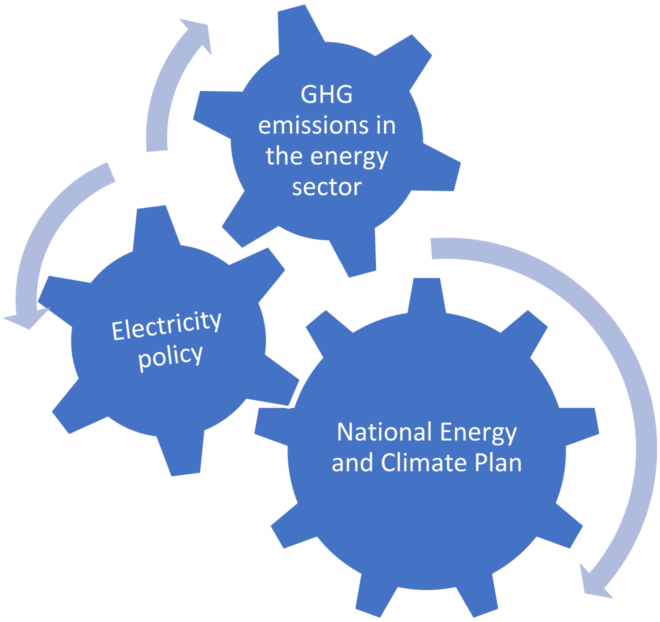


Fig. 2.7. Causal relationship between the GHG emissions and the NECP.

Theory-based analysis approach to evaluation is a method that allows to estimate the effects of a range of systemic activities, e.g. a policy program in one field to achieve certain results [69]. Theory-based evaluation aims to find out why and how a specific policy measure works [70]. Theory-based approach includes the theory of change, which allows to trace the changes over time and their causal relationships [71]. Theory of change creates a model that allows to test, which activities will bring the planned outcome [72]. Another possibility is to trace the process of policy implementation, where part of the process can be attributed to some part of the result instead of the overall results [73]. Thus, the policy activities can be measured in their intermediate results and in their final results [74].

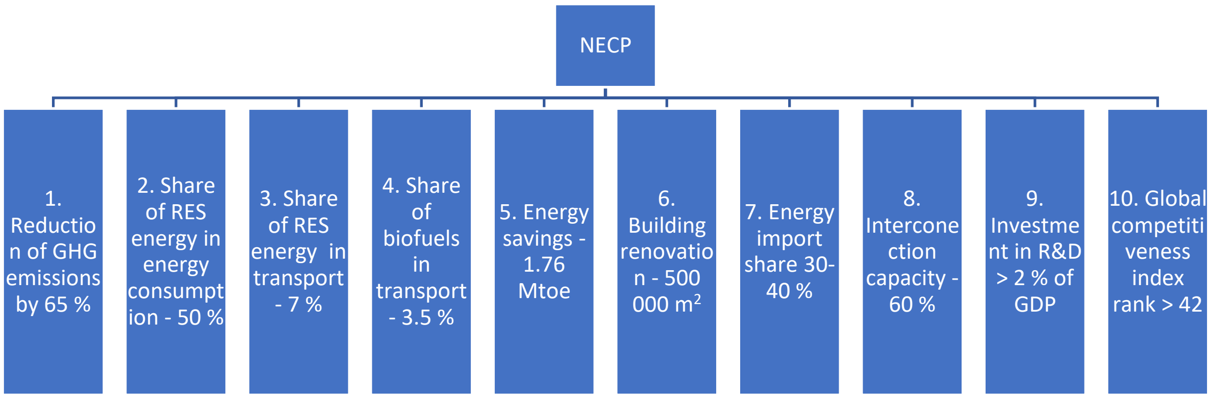


Fig. 2.8. Different dimensions and their targets in NECP of Latvia.

NECP has been devised in several dimensions with specific targets in each of the dimensions as can be seen in Fig. 2.8. There is a wide range of activities under each of the dimensions and they are closely interlinked.

Considering the fields of previous studies, the author paid attention to whether the NECP dimensions have specific electricity policy goals for 2030 in the following areas:

- ✓ electricity production from solar panels;
- ✓ electricity production from wind energy;
- ✓ electricity saving requirements for energy intensive manufacturers;
- ✓ railway electrification;
- ✓ electricity savings by aggregation (demand-response);
- ✓ RES electricity production in energy communities.

If such goals were not set or the goals were vague and only in relation to other activities, the author of the Thesis provided the possible goals based on the experience, knowledge and best practise in other EU member states arising from the previously researched topics.

3. RESULTS AND DISCUSSION

The results of the methodologies applied and reviewed in Chapter 2 are summarized in this chapter. The results are linked together as different electricity policy measures that should be part of the NECP of Latvia.

3.1. The focus of electricity policy measures

While developing a policy, the policymakers often think of amending obscure provisions, to implement clearer ruling and as the Figure 3.1. shows, the new projects can sometimes be beneficial for a rather small audience. Figure 3.1. shows more clearly the final results.

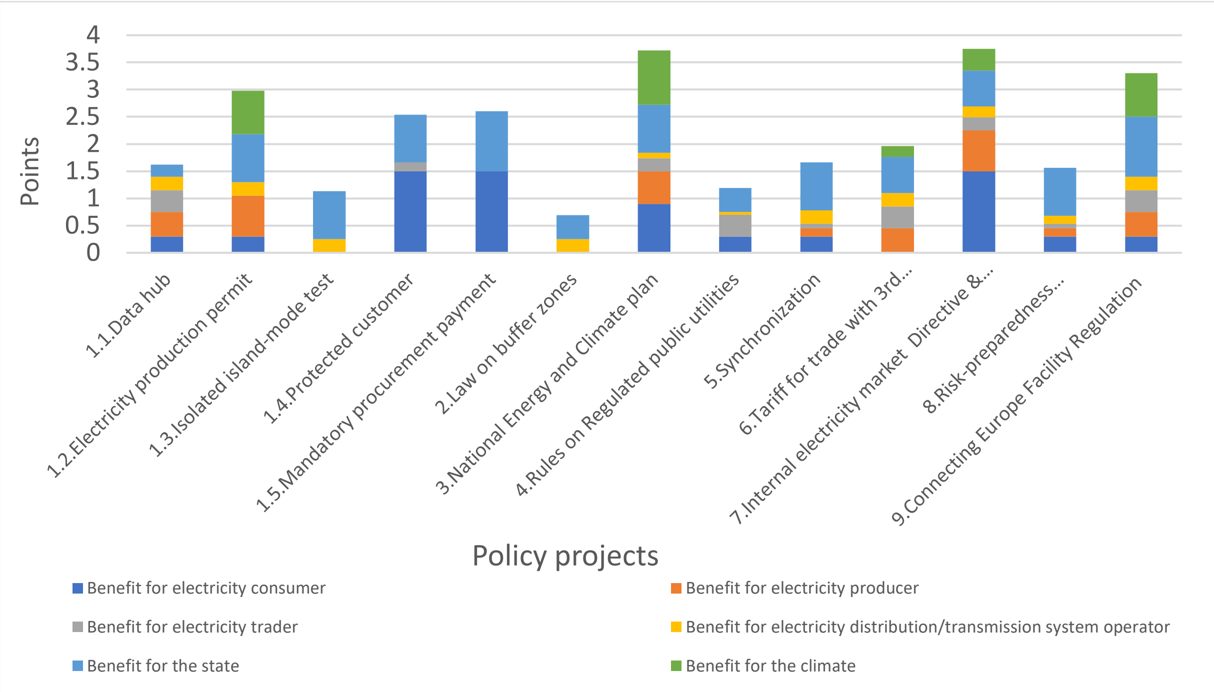


Fig. 3.1. Evaluation of the focus of electricity policy projects.

The EU level projects are mostly intended to improve the climate and moreover, they are intended for a large group of beneficiaries, so it is not surprising that Figure 3.1. shows that the project number 7 and 9 have one of the highest results in total. Moreover, one of the highest scored national projects (Number 3) is based on requirements from the EU, which also explains the versatile and relatable content for different involved sides. And there is a certain pattern – the climate benefits only in cases, where all other sides (consumer, producer, traders etc.) have benefits. So, it could be argued either it is a problem or a gain, but the system only works in a complex framework.

At the same time, it is important to stress, that, as can be seen from the light green parts in Figure 3.1., in most projects, the most gains go to consumers and it is essential that the policy planners concentrate their effort on consumers, which is the basis for society. There is also a tendency that consumer, state and climate are the criteria, which are thought of in almost all projects. Electricity producers and traders receive much less support, even though it could seem surprising considering that Latvia has an established system of mandatory procurement component that the consumers pay for the green energy and high efficiency cogeneration energy produced in Latvia. But this only means that, the policy makers are slowly moving away from this rather unsustainable support system and focus more on the electricity consumer, while developing new concepts for supporting renewable energy in Latvia without such high costs.

3.2. Potential of the wind parks in Latvia

The results of both MCA and CBA analysis are summarized in this subchapter. For MCA, criteria with the positive factor were added to the criteria with the negative factor (the positive or negative notion was set based on the best value indication column). The results of the MCA provide that in comparison between the two scenarios, some of the criteria have played a big role in determining that the best case study would be the onshore wind park. In general, the offshore wind park is not an optimal solution both due to the initial capital costs and the related LCOE value. The results of MCA are summarized in Table 3.1.

Table 3.1.

MCA Results for the Potential of Wind Parks

Criteria	Wind park A	Wind park B	Best values
C1 All investment costs, EUR/MW	+0.042	–0.108	Min
C2 Operation and maintenance costs, EUR/MW/year	+0.041	–0.089	Min
C3 Administrative burden, months	+0.017	–0.033	Min
C4 Job creations, number of workers	–0.017	+0.043	Max
C5 Capacity factor %	–0.108	+0.142	Max
C6 Import reduction, %	–0.027	+0.053	Max
C7 LCOE, EUR/MWh	+0.096	–0.184	Min
Total	–0.149	–0.176	

As regards CBA, if we calculate the costs and benefits from the project promoters point of view regarding the financial perspective, it can be seen that the onshore wind park can be beneficial if the produced electricity is sold by the current average electricity exchange price. These results were calculated by taking into account the possible OPEX growth (2 % annually) as well as the discount rate and the interlinked net present value of the costs and net present value of the electricity output. The results also provide that offshore wind park would not be rentable in normal market conditions as they were at the beginning of 2021. For clearer understanding of the circumstances, when the offshore wind park would be rentable, the authors calculated the levelized cost of electricity (LCOE), which is the selling price of electricity that is required so that the project’s revenues would at least equal the costs. LCOE was calculated by using the total project costs (over the 20-year lifetime, including OPEX with 2 % annual growth rate), capacity factor, 20-year lifetime, the respective electricity output in 20 years and the cost of capital (assumed discount rate 8 %). For onshore project the LCOE value was 57.9 EUR/MWh, which is close to actual market value of the electricity at the beginning of 2021. At the same time, the offshore project's LCOE was 110.17 EUR/MWh, which is close to the market value in 2022, but as the price spikes eventually drop, the project will become less rentable.

Table 3.2.

CBA Results for the Potential of Wind Parks

Costs and benefits		**Wind Park A**	**Wind Park B**
1	Wind turbine costs (total EUR)	–58 000 000	–792 970 000
2	Grid connection and other costs (total EUR)	–64 900 000	–792 970 000
3	Operation and maintenance costs (total EUR in 20 years, 2 % OPEX growth, 8 % discount rate)	–37 352 254	–403 634 155
5	Revenues from electricity sales (using average NordPool power exchange price for Latvian area in February 2021 – 59.15 EUR/MWh, 8 % discount rate for output)	+163 599 233	+1 067 939 438
	Total	+3 308 091	–921 634 717

3.3. Potential of solar energy development in Latvia

The average efficiency rate for solar panels from case studies was about 16.92 %. The average costs for installing the system were almost 5000 EUR. Based on the collected data (consumption, phases, amps), the average monthly electricity bill was calculated before installing the solar panels. Based on the electricity produced by panels and the amount of electricity fed into the grid and collected from grid, the average monthly electricity bill after installing solar panels was calculated. The difference between the electricity bill before and after installing the solar panels, are the savings per month. The total invested amount of money in the solar panel's system is divided by the yearly savings resulting in return of investments period, which on average was about 13 years.

A deeper research was done for the first case study – a household with a consumption of 293 kWh/month. Before the solar panels were installed, the household paid EU 35.87 per month for electricity (including distribution, MPC, VAT). The household installed solar panels for which they paid EUR 3100. The solar panel's system with the efficiency of 16.88 % and with the solar irradiation appearing in Liepāja region, was able to produce about 243 kWh/months. As the household did not have any battery for the storage of electricity, around 60 kWh/month were fed into the grid because the electricity was not used at that moment when it was produced. At the same time, the household needed more electricity for its' monthly consumption (for example, during night or cloudy days), so it took around 110 kWh/month from the grid. The distribution tariff and the MPC tariff has to be paid for the whole amount of electricity taken from the system (i.e. 110 kWh), however the electricity price has to be paid only for the NET amount of electricity taken from the system (110 kWh minus 60 kWh result in 50 kWh/month). Thus, in total, when the household installed the solar panels, the new electricity bill came down to EUR 12.63 per month. The reduction of the electricity bill, which is almost three times lower, can be better viewed in Fig. 3.2.

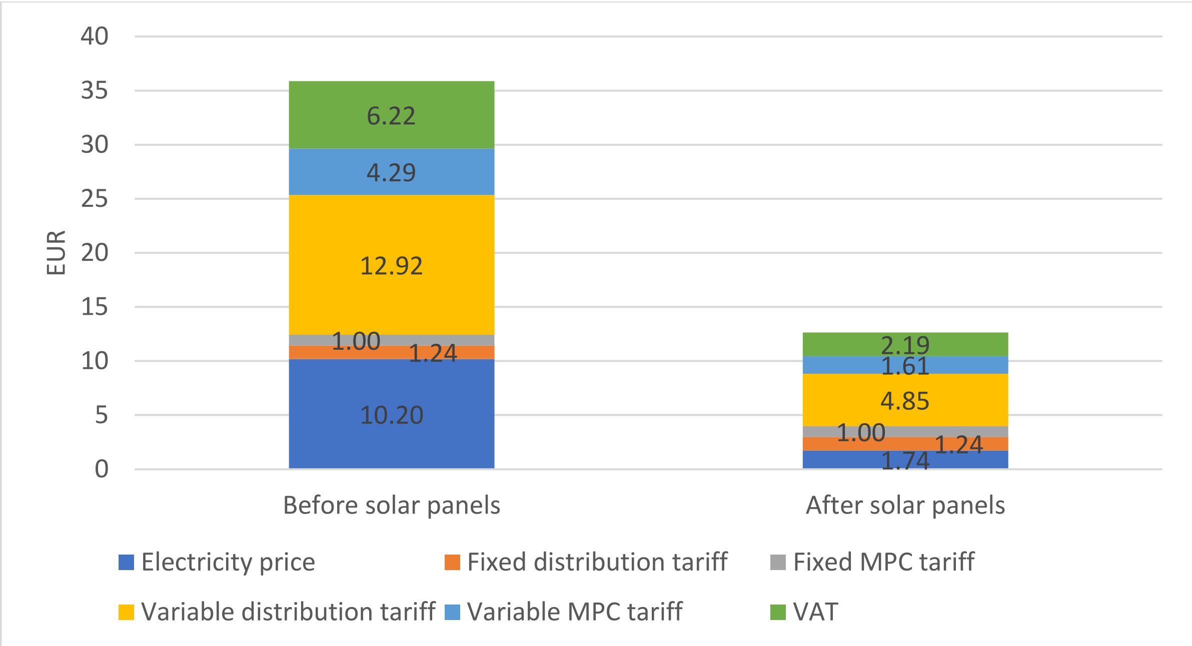


Fig. 3.2. Monthly electricity bill before and after installation of solar panels (293 kWh consumption).

3.4. Impact of railway electrification on climate

Railway electrification was reviewed in seven different scenarios depending on the level of electrification spanning from 0 % electrification to 100 % electrification from RES. In the scenarios where the only thing that is changed is emissions per tonne, the only results that change are the emissions, as seen in Fig. 3.3.

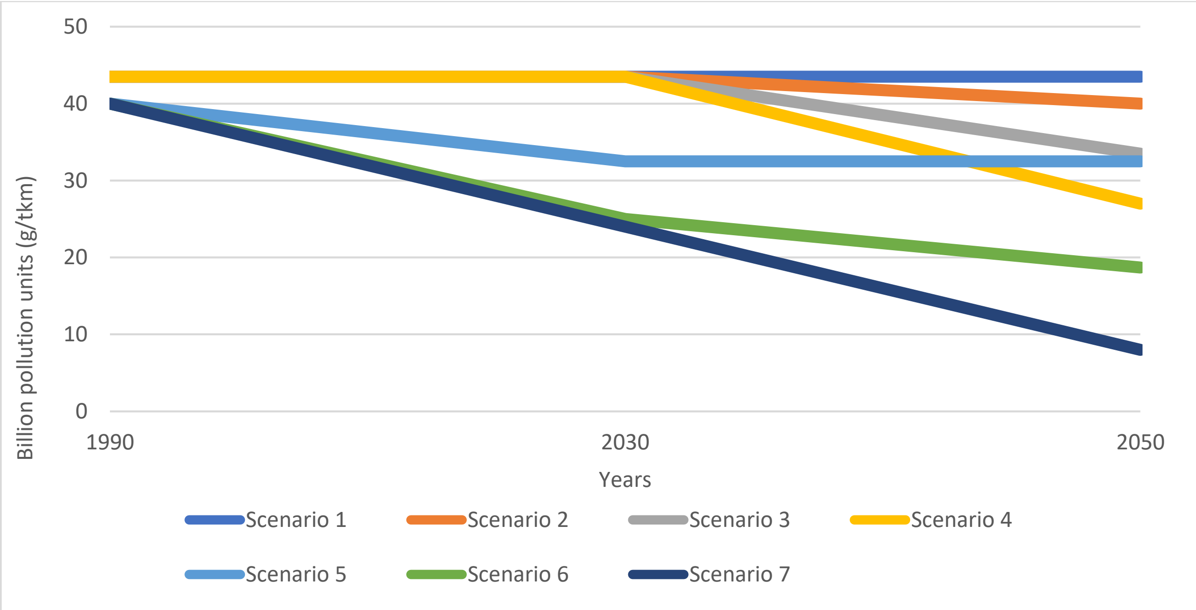


Fig. 3.3. Results of the system dynamics modelling.

In Scenario 2, the variables mimic the current Latvian railway electrification scenario. The pollution from the railway drops significantly – from 43.5 billion PU to 40 billion PU, this is a drop of 8.05 %. It is important to remember that in this scenario, the energy sector has not been incorporated into the model giving the electric locomotives a fuel source that is fossil. Meanwhile, in Scenario 7 the railway is 100 % electrified and energy supply is fully renewable. As could be expected, here the emissions have been reduced the most. The emissions drop according to the locomotive changes, the emissions start at 40 billion PU and drop under 10 billion PU in 2050. The emissions from the diesel locomotives also drop alongside the locomotive changes.

When looking from the perspective of climate change and the possibilities to reduce that, it would be enough to implement Scenario 2 in order to already decrease the PU by more than 8 % that can be reached already before 2050.

3.5. Carbon intensity of energy intensive manufacturers

Table 3.3. shows the results of the calculations for the optimal carbon intensity in 2020 and 2030 under the assumptions of forecasted GDP, population and energy intensity.

Table 3.3.

Results of Kaya Identity Calculations

	Years		
Criteria	1990	2020	2030
CO_2 emissions	100 %	43 %	45 %
Population	100 %	72 %	63 %
GDP per capita	100 %	168 %	215 %

Energy intensity	100 %	72 %	64 %
Carbon intensity	100 %	49 %	52 %

Table 3.3. shows that the carbon intensity in Latvia in 2020 should be 49 % (i.e., the reductions should be by 51 %) and 52 % in 2030 (i.e. the reduction should be by 48 %) in order to achieve the National Energy and Climate Plan's targets in reduction of CO_2 emissions. The Kaya identity allows to work with the data and understand, how much, for example, the reduction of energy intensity, would lower the carbon intensity. If the energy intensity is lowered by 5 % annually beginning from 2020, the carbon intensity reduction by 2030 would only need to be 20 %. Thus, the necessity to reduce carbon intensity would drop by half. This example proves the idea, that it is necessary to urgently develop manufacturing with much lower energy intensity than now.

About 15–25 % of costs for energy intensive manufacturers are composed of costs for energy consumption [75]. Such a large energy consumption is not only unsustainable and against the energy and climate goals of Latvia but is also very expensive for the manufacturer and may lead to bankruptcy. Such situation not only leaves negative impact on the GDP, but has other side effects such as increased energy tariffs for the rest of the energy consumers, because when a large energy user stops paying for the electricity or gas connection, the costs of maintaining electricity and gas transmission and distribution systems are redistributed to the remaining energy consumers.

When analysing the energy intensity (and CO_2) intensity, it is important to link it with the concept of decoupling. There are two types of decoupling – resource and impact decoupling, which can be further categorized as relative or absolute decoupling. Resource decoupling would be reduced usage of energy per unit of economic activity (GDP), so the production amount is the same, but with less energy resources, which can be labelled as increased resource productivity. Impact decoupling means that the economic output must be increased while reducing the negative environmental consequences such as CO_2 emissions, so the production volume is larger (not at the same level as in case of resource decoupling), but the energy resources are used at the same level as before or less, so it can be labelled as increased eco-efficiency [76]. In case of Latvia, both of the options would be acceptable from the point of view of country's economic growth.

3.6. Concept of energy communities

The EU member states are free to choose the best ways how to transpose rules set in the Directives in the national regulations. Each member state is trying to provide its own interpretation for a logical mechanism. The concept proposed in Latvia is summarized by the author in Fig. 3.4. The following interpretation of the Directives provides that there are three types of active customers: renewables self-consumers, jointly acting self-consumers and energy communities. Jointly acting renewables self-consumers and energy communities can use the electricity sharing option (sharing is not considered trade), while single renewables self-consumers (both households and legal entities) can use net-metering scheme. All three types are allowed to participate in peer-to-peer trade.

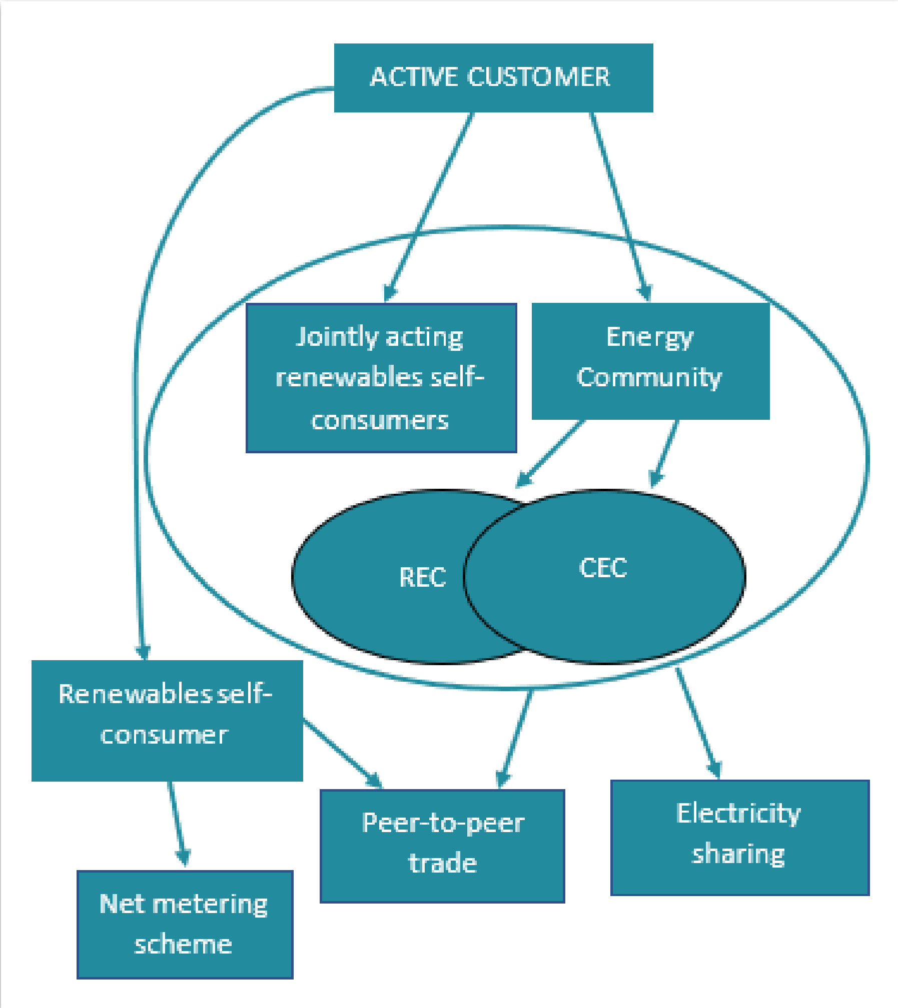


Fig. 3.4. Legislative framework for renewable self-consumption

Though according to the Directives, the primary target shall not be gaining financial benefit from energy community, the directives do not forbid energy communities to receive income, e.g., for the electricity that has been produced in the energy community and has been sold in peer-to-peer trade as the residual electricity that was not necessary for the consumption of the members in the energy community at that time. Thus, energy communities can have income that could be used to pay off the assets and to maintain electricity production installations, which has been stressed by the society as one of important aspects for the energy community to be cost-efficient.

3.1. Role of aggregators in the electricity market

If we are discussing the household sector, an aggregator needs to have about 10 000 consumers, who save 5 kWh a day to make it a profitable business. For instance, general review of online offers for electrical appliances provides that on average a central air conditioner/heat pump consumes around 5–15 kW per hour, so reduction of electricity consumption by 5 kWh a day is actually not so much considering that part of the amount of electricity would still be consumed but at different time of day, when the electricity prices are lower. Figure 3.5. shows the demand of electricity in Latvia on 3 August 2020. The red line is the actual demand, but the blue line has been drawn by the authors to show how an aggregator could level out the demand in peak hours by shifting it to a different time of the day.

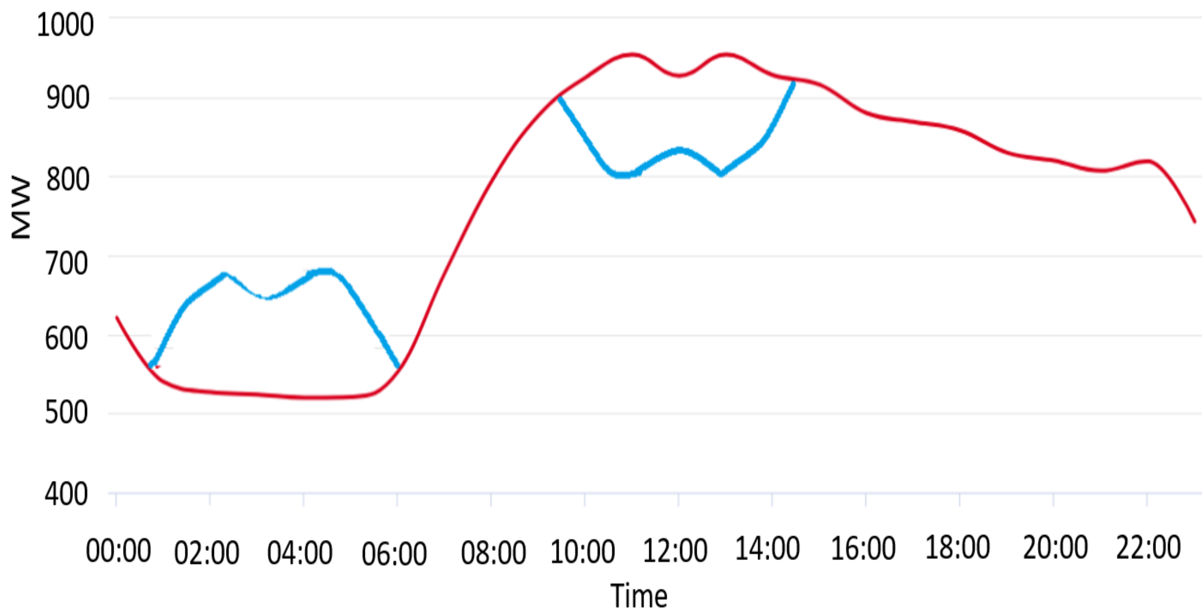


Fig. 3.5. Electricity consumption MWh/hour in Latvia on 3 August 2020.

If an aggregator has aggregation agreements with 10 000 consumers that reduce at least 1 kWh daily (not 5 kWh, because most of the aggregated amount is shifted to another timer period and not reduced), these are 10 MWh a day or 3650 MWh per year by rough calculations. Latvia's yearly consumption of electricity is around 7 TWh. This means that an aggregator could be capable of reducing the yearly electricity consumption in Latvia by at least 0.05 %. This may not seem much, but for one aggregator it is not a bad result and would also serve as means for achieving national energy and climate targets.

3.2. Electricity policy from climate perspective

All the outside-NECP activities that were researched and reviewed in the previous chapters have been assigned with a goal that is shown in Fig. 3.6. If the goals are reached, the activities will have different impacts. The installed new electricity generation capacities as well as aggregators and BESS will replace import or production of electricity from fossil fuels. Electrified railway will replace the diesel used in rail freight transportation. At the same time energy savings of energy intensive manufacturers will reduce energy consumption in total. Though all outside NECP electricity policy activities have different impacts, they can all be tied together with a common indicator, which is the guiding theme of this research, i.e., reduction of GHG emissions. In this case, GHG emissions have been narrowed down to CO_2

emissions that will be measured in kilotons per year. In case of new electricity generation installations, aggregators and BESS, the reduction of CO_2 emissions is calculated by considering that natural gas would instead create CO_2 in the amount of 185 kg/MWh. Diesel rail freight would create CO_2 in the amount of 18g/tk. As regards energy intensive manufacturers, weighted average CO_2 emission factor of 101.9 kg/MWh was used to estimate the reduction of CO_2 emissions per year if the electricity consumption is lowered.

The additional goals that are set for the NECP of Latvia are based on the national situation in combination with the experience of the neighbouring countries. For example, the goal for installed solar energy in 2030 is set as 629 MW based on the watts per capita set as goals in Estonia and Lithuania. As regards on-shore wind energy, the target is specified based on the current plan to have 800 MW off-shore wind energy by 2030 in Latvia as well by taking into account the grid capacities.

While the solar energy, wind energy, electrification, energy intensity and aggregation targets arise from previous studies on the capabilities of these measures, additional measure was added in the final step – introduction of BESS. This is due to the volatile nature of renewable energy that should be balanced by either some type of base generation load or storage. Considering that the currently available base generation loads in Latvia are provided by cogeneration plants powered by natural gas, it is important to find new alternative solutions for ensuring balancing and electricity system stability in a sustainable manner.

The results of the outside NECP activities are shown in Fig. 3.6, providing that the total CO_2 savings if the goals are achieved in 2030 would be additional 906.43 kt. For comparison, according to the NECP, total GHG emissions in 2018 were 11 800.2 kt CO_2-eq. It follows that outside NECP activities overviewed in this research could provide the reduction in GHG emissions by around 8 %.

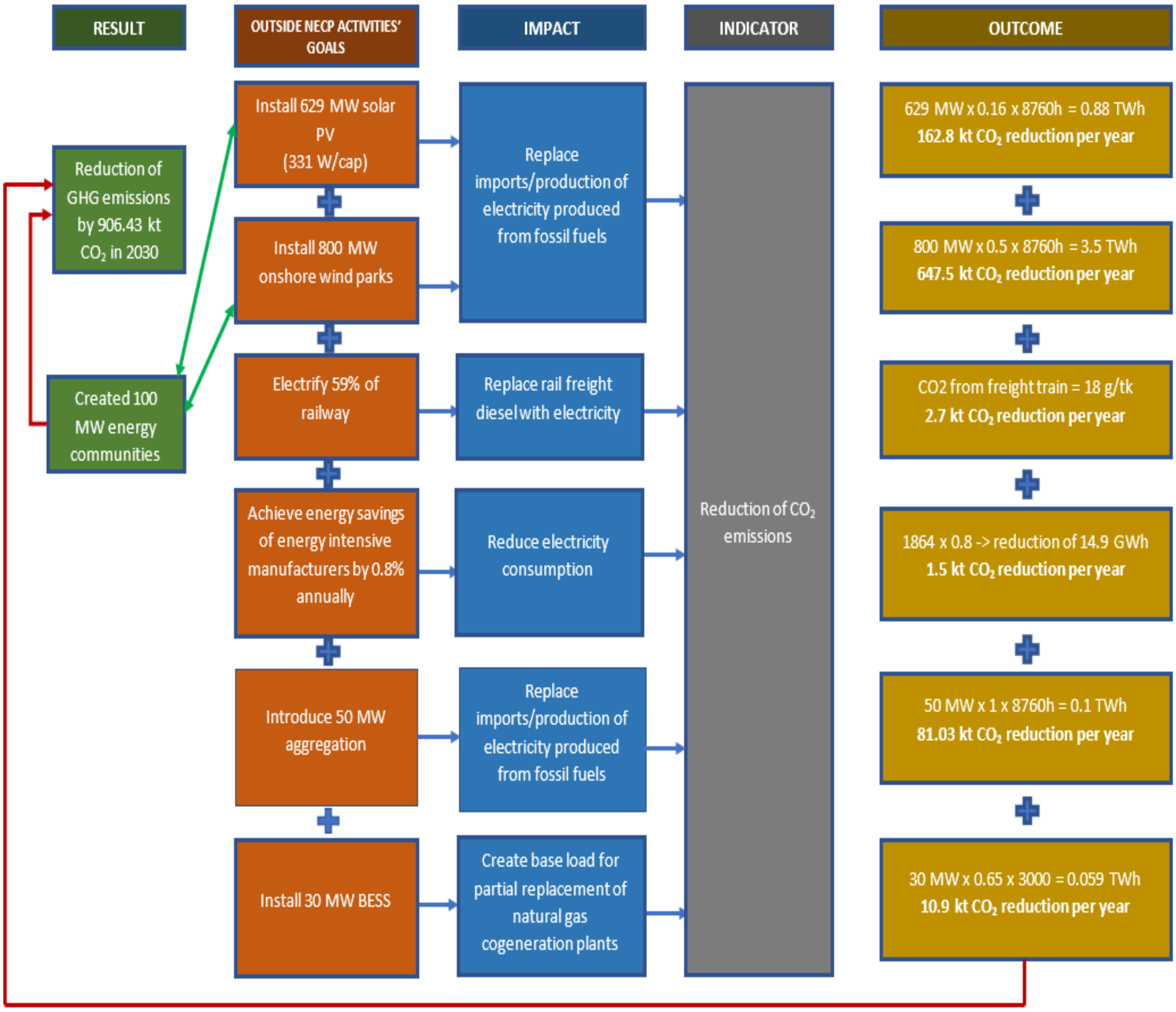


Fig. 3.6. Summary of the results of outside NECP activities and their contribution to the reduction of GHG emissions.

If we look at the input of each outside NECP activity, Fig. 3.7. provides a clear view on which measures have the most impact on the final CO_2 savings. Onshore wind energy provides the highest potential in reducing GHG emissions as a replacement for electricity generation from fossil fuels. This is followed by the benefits from installing solar energy capacities. Aggregators may also provide an effective amount of CO_2 reductions.

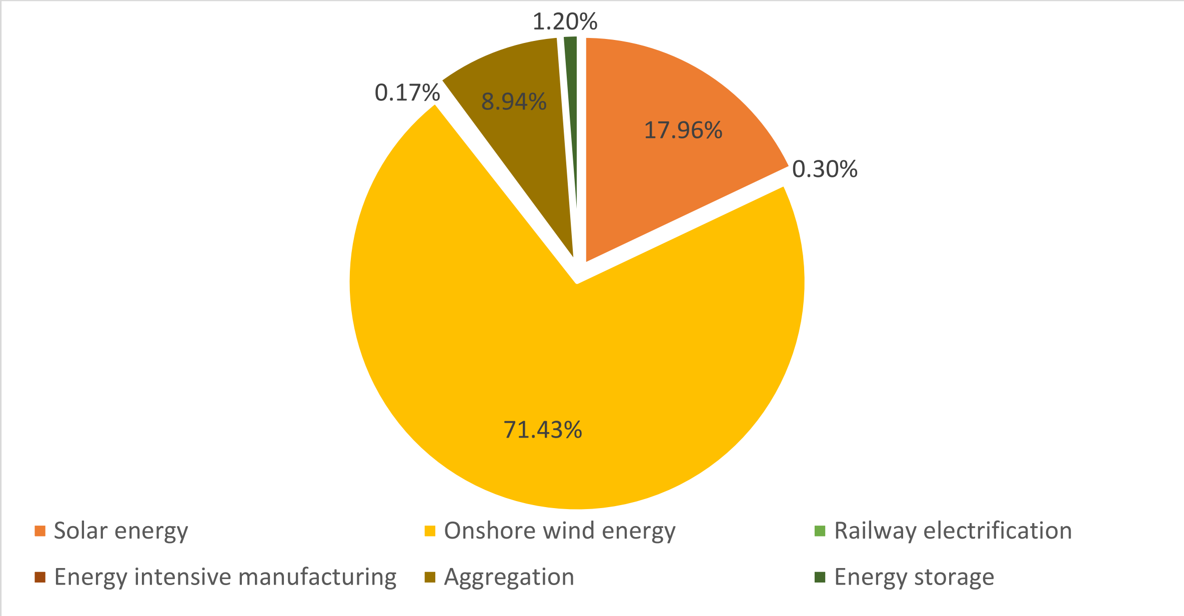


Fig. 3.7. Impact of each outside NECP activity on the reduction of GHG emissions.

At the same time energy storage, railway electrification and, finally, the reduction of electricity consumption in energy intensive manufacturing would actually play a very small role in the efforts of reducing GHG emissions. Nevertheless, these are still important aspects from other angles, i.e. energy storage would play a big role in ensuring the stability of the electricity system, railway electrification would ensure the reduction of energy (fuel) dependency from third countries and the reduction of electricity consumption in the manufacturing sector would benefit the manufacturer and increase cost-effectiveness and competitiveness.

CONCLUSIONS

While developing a policy in the electricity sector, the climate issues are only tackled in legislative initiatives, which cover a broad spectrum of questions, but not individually as such. Respectively, the outcome of the research provides that, at the national level, the most positive effect for climate comes from the National Energy and Climate Plan.

Both CBA and MCA analysis provided that an offshore wind park in the sea is currently not a good business case if there is no support in the form of financial grants or energy policy changes regarding a feed-in tariff for renewable energy. At the same time, the research clearly showed a good potential for onshore wind energy development that would not need state support and could operate on market-based principles with a competitive electricity price to provide.

Any large-scale wind park project would effectively contribute to the security of energy supply aspect if the wind energy was not exported but sold locally, which would reduce the imports significantly. At the same time, wind parks cannot provide specific base capacity due to its' volatile nature.2

It could be argued that the administrative procedure for introducing a wind park, especially an offshore wind park, is complicated, takes a lot of time and should be improved so that the new electricity producers would see support from the state at least in the terms of administrative procedures. Meanwhile, the administrative costs applied at state and municipal level are at acceptable level and should not be viewed as an obstacle for developing wind parks.

Economic situation and technological advancement level in the solar energy sector is adequate enough to achieve a situation in which the instalment of solar panels would pay back in 5 years or less. At the same time, political incentives and changes in current legal framework would be necessary to reduce the payback time for solar panels.

Based on the finding of the research, the price for solar panels in Latvia has been at least two times higher than in other European and non-European countries, which has been a huge barrier for the households to increasingly install the solar panels. Moreover, the prices for solar panels are not aligned with the efficiency, making the solar panels inadequately over-priced.

There are four factors that influence the return of investment period for solar panels – the solar panel system's efficiency rate, the price of the solar panel system, the government support and the components of the electricity bill. Separate actions, such as the reduction of the price of solar panels or an increased efficiency of solar panels gives only partial effect and would not bring the result of a five-year return of investment period. It should be solved by a complex action.

Different scenarios of the system dynamics modelling provided a rather wide range of results showing the real importance of two influential policies – electrification of the railway and switching over to usage of fully renewable energy.

It is important to understand that railway electrification not only provides climate benefits, but also impacts the economy from the side of investments, employment, and indirect economic benefits. Especially in these challenging times of international crisis it is very topical to discuss future investments for the benefit of economic recovery.

Energy intensity is an overarching problem in Latvia's manufacturing industry, while it is also the cornerstone of the country's economy, as it is strongly linked with the GDP.

As the manufacturing industry plays an important role in Latvia's GDP, the manufacturing should not be reduced, but it must be improved by introducing new energy efficient and low energy intensity manufacturing with high added value. To achieve the EU's goals for reduction of carbon emissions, it is important to put effort in restructuring the manufacturing industry. It is essential to minimize the carbon intensity, which is directly dependent on the energy intensity.

The research showed that currently the planned legislation in Latvia provides a solid basic mechanism for energy communities and electricity sharing as well as peer-to-peer trade without harsh restrictions. Considering the future electricity deficit in Latvia, energy communities have a good potential, but further detailed requirements (contracts, electricity data accounting, reporting, balancing) for creating them still must be developed in order to ensure the security of electricity grid.

For further development of the national legislation, it is important to involve society as much as possible to understand the current experiences and possibilities in order to create as efficient legal framework as possible. The research and development of the legislation is complicated also because of the lack of best practice in the EU. Though pilot projects have been launched in many EU countries, the EU legislation has not yet been transposed by the neighbouring countries that otherwise could provide advice.

Financing, such as providing grants, is one of the key measures that would allow energy communities to develop. Financing, appropriate legal framework, cost of technologies and the interlinked payback time, as well as responsiveness of the society will all impact the role energy communities will be able to play in order to avoid electricity deficit from 2024 onwards.

Aggregators and demand response can provide benefits not only for the electricity policy of Latvia, but also can serve for the good of climate policy, when reducing the electricity consumption in Latvia.

However, currently the existing electricity market players have not yet engaged in understanding and using the possibilities currently provided for the electricity suppliers who could combine their role of supplier with the role of aggregator. This model can be financially beneficial under the existing market conditions.

Meanwhile, independent aggregators are yet to develop in Latvia. Even if the technical barriers in the legislation are resolved, it will not be enough for independent aggregators to immediately enter the electricity market from the economic perspective, as an aggregator would need a rather big client portfolio.

The electricity market is constantly developing, providing new mechanisms, technical opportunities and solutions. The current NECP of Latvia is not using the full potential of these solutions and excludes solutions that could provide a substantial benefit in the work towards reduced GHG emissions. The NECP is not focusing on the electricity policy measures from climate perspective as much as needed or possible.

The research overviewed seven additional activities that are not part of the NECP and provided six new goals that could be added in the reviewed NECP of Latvia. If achieved, three of the goals would create significant input in the reduction of GHG emissions approving the hypothesis of the Thesis.

Though all of the activities could be included in the revised NECP, it is important to take into account the actual added value of each activity when deciding on funding opportunities.

Although the research focused on the reduction of GHG emissions, the discussed outside NECP activities create additional benefits in the energy sector, e.g. if the electricity production by solar or wind energy is increased nationally, Latvia becomes more self-sufficient and avoids electricity imports not only from the EU, but also from the third countries, which is also an issue of energy security. The outside NECP activities allow to create a complex solution for energy security issues considering not only the local electricity production increase but also by including the battery storage and aggregation solutions, which allow to shift the electricity demand.

Outside NECP activities may also provide additional socio-economic benefits considering the employment and investment opportunities, however, these aspects could be further studied in additional studies.

When the NECP is reviewed in 2023, it should focus not only on the improvements of the existing measures in the plan but on all the possible additional activities, i.e., not only the ones reviewed in this research, but also considering other trends and possibilities in the market in 2023. This would also include using the experience of neighbouring countries to avoid similar circumstances as in the solar energy field, where Latvia is the only EU member state without a solar energy capacity target.

REFERENCES

[1] European Commission. 2017. 2020 climate & energy package [Online]. Available at: https://ec.europa.eu/clima/policies/strategies/2020_en [Accessed: 15 December 2017]

[2] Vaughan, A. 2017. Renewable energy in Europe in 2016 [Online]. The Guardian. Available at: https://www.theguardian.com/environment/2017/feb/09/new-energy-europe-renewable-sources-2016 [Accessed: 9 February 2017]

[3] European Commission. Making the Internal Energy Market Work. Communication from The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions. 2012.

[4] Eurostat, Energy production and imports. 2022 [Online]. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_production_and_imports#The_EU_and_its_Member_States_are_all_net_importers_of_energy [Accessed: 3 March 2022]

[5] European Commission. 2030 climate & energy framework. [Online]. Available at: https://ec.europa.eu/clima/policies/strategies/2030_en [Accessed: 10 January 2019]

[6] Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action, amending Regulations (EC) No 663/2009 and (EC) No 715/2009 of the European Parliament and of the Council, Directives 94/22/EC, 98/70/EC, 2009/31/EC, 2009/73/EC, 2010/31/EU, 2012/27/EU and 2013/30/EU of the European Parliament and of the Council, Council Directives 2009/119/EC and (EU) 2015/652 and repealing Regulation (EU) No 525/2013 of the European Parliament and of the Council

[7] European Commission. National energy and climate plans. 2021. [Online]. Available at: https://ec.europa.eu/info/energy-climate-change-environment/implementation-eu-countries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en [Accessed: 1 March 2022]

[8] Schmela M et al, EU Market Outlook for Soalr Power 2021-2025, SolarPower Europe. [Online]. [Accessed 10 December 2021.] Available at: https://www.solarpowereurope.org/wp-content/uploads/2021/12/EU-Market-Outlook-for-Solar-Power-2021-2025_SolarPower-Europe.pdf?cf_id=48751

[9] Eurostat. Renewable energy 2020 inforgraphic. [Online]. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Renewable_energy_2020_infographic_18-01-2022.jpg [Accessed: 3 March 2022]

[10] Kudurs E., Tukulis A., Dzalbs A., Blumberga D., “Are Industries Open for Renewable Energy?”, *Environmental and Climate Technologies*, vol.24, no.3, pp.447-456, 2020

[11] Ministry of Economics of Latvia. Nacionālais Enerģētikas un Klimata Plāns (National Energy and Climate Plan) [Online]. [Accessed 04 April 2021]. Available: https://www.em.gov.lv/lv/nacionalais-energetikas-un-klimata-plans (in Latvian)

[12] Ministry of Economics of Latvia. Elektroenerģijas Ražošana (Electricity generation) [Online]. [Accessed 15 March 2021]. Available: https://www.em.gov.lv/lv/elektroenergijas-razosana

[13] CNBC. Europe installed a record amount of wind power last year. But industry says it'snot enough. 2022. [Online] Available at: https://www.cnbc.com/2022/02/24/europe-installed-a-record-amount-of-wind-power-in-2021.html [Accessed 15 March 2022]

[14] Wind Europe. Wind energy in Europe: 2021 Statistics and the outlook for 2022-2026 [Online]. Available at: https://windeurope.org/intelligence-platform/product/wind-energy-in-europe-2021-statistics-and-the-outlook-for-2022-2026/ [Accessed 5 March 2022]

[15] LVEA. Lithuanian statistics. 2022. [Online] Available at: https://lvea.lt/en/statistics/lithuanian-statistics/ [Accessed 2 March 2022]

[16] EREA. Renewable energy in Estonia. 2021 [Online] Available at: http://www.taastuvenergeetika.ee/en/renewable-energy-estonia/ [Accessed 8 February 2022]

[17] LSM. Vēja parku attīstīšanai plāno veidot «Latvenergo» un «Latvijas Valsts mežu» kopuzņēmumu. [Online]. Available at: https://www.lsm.lv/raksts/zinas/ekonomika/veja-parku-attistisanai-plano-veidotlatvenergo-un-latvijas-valsts-mezu-kopuznemumu.a444777/ [Accessed 3 March 2022]

[18] Kannan N., Vakeesan D. Solar energy for future world: - A review// Renewable and Sustainable Energy Reviews 62 (2016) 1092–1105

[19] Kabir E., Kumar P, Kumar S., Adelodun A. A., Kim K.H. Solar energy: Potential and future prospects//Renewable and Sustainable Energy Reviews, Volume 82, Part 1, February 2018, Pages 894-900

[20] Sun D, Wang L. Research on heat transfer performance of passive solar collectorstorage wall system with phase change materials. Energy Build 2016;119.[183–18].

[21] Herrando M, Markides CN. Hybrid PV and solar-thermal systems for domestic heat and power provision in the UK: techno-economic considerations. Appl Energy 2016;161:512–32.

[22] Mohanty P, Muneer T, Gago EJ, Yash Kotak Y. Solar radiation fundamentals and PV system components. Springe Int Publ 2015. http://dx.doi.org/10.1007/978-3-319-14663-8_2

[23] Sampaio P. G. V., González M. O. A. Photovoltaic solar energy: Conceptual framework// Renewable and Sustainable Energy Reviews 74 (2017) 590–601

[24] IRENA. Energy profile of Lithuania. 2018 [Online]. Available at: https://www.irena.org/IRENADocuments/Statistical_Profiles/Europe/Lithuania_Europe_RE_SP.pdf [Accessed 3 March 2022]

[25] Central Statistical Bureau of Latvia, Dzelceļa kravu pārvadājumi. [Online]. [Accessed 30 November 2019.]. Available: https://www.csb.gov.lv/lv/statistika/statistikas-temas/transports-turisms/transports/tabulas/tr200c/kravu-parvadajumi-dzelzcela-transporta

[26] European Commission, Dzelzceļu kravu pārvadājumi ES: pareizais ceļš vēl nav atrasts, 2016. [Online]. [Accessed 15 November 2019]. Available: https://www.eca.europa.eu/Lists/ECADocuments/SR16_08/SR_RAIL_FREIGHT_LV.pdf

[27] University of Latvia. Latvijas Dzelzceļš kravu pārvadājumu tarifa samazināšanas meklējumos, 2018. [Online]. [Accessed 23 November 2019]. Available: https://www.jf.lu.lv/en/par-mums/ul-media/news/detailed-view/t/43463/

[28] Porubova J., Bazbauers G. Analysis of Long-Term Plan for Energy Supply System for Latvia that is 100 % Based on the Use of Local Energy Resources. Environmental and Climate Technologies, pp. 82–90, 2010.

[29] European Commission, Dzelzceļu kravu pārvadājumi ES: pareizais ceļš vēl nav atrasts, 2016. [Online]. [Accessed 15 November 2019]. Available: https://www.eca.europa.eu/Lists/ECADocuments/SR16_08/SR_RAIL_FREIGHT_LV.pdf

[30] Genovaitė Liobikienė M. B., “The European Union possibilities to achieve targets of Europe 2020 and Paris agreement climate policy,” Renewable Energy, pp. 298-309, June 2017.

[31] Ruud Egging A. T., “Norway's role in the European energy transition,” Energy Strategy Reviews, pp. 99-101, April 2018.

[32] Genovaitė Liobikienė M. B., “The European Union possibilities to achieve targets of Europe 2020 and Paris agreement climate policy,” Renewable Energy, pp. 298-309, June 2017.

[33] Coad and A. Vezzanic, “Three cheers for industry: Is manufacturing linked to R&D, exports, and productivity growth?” Structural Change and Economic Dynamics, pp. 14-25, vol. 50, issue C, 2019.

[34] CSB, "ENVIRONMENT OF LATVIA IN FIGURES: climate change, natural resources and environmental quality 2017," [Online]. Available: https://www.csb.gov.lv/sites/default/files/publication [Accessed 15 November 2021]

[35] CSB, "Energy consumption by sectors (TJ),2008-2017," 2017. [Online]. Available: http://data1.csb.gov.lv/pxweb/lv/vide/vide__energetika__ikgad/?tablelist=true. [Accessed 15 July 2019].

[36] I.Kasjanovs, "Latvijas apstrādes rūpniecība šķērsgriezumā," [Online]. Available: https://www.macroeconomics.lv/node/280. [Accessed 8 September 2019].

[37] Blumberga A. et al, Project "Energoefektivitātes rīcībpolitikas novērtējums un analīze", 2021. [Online]. [Accessed 03 January 2022.] Available at: https://videszinatne.rtu.lv/wp-content/uploads/2021/01/2_Datu-v%C4%81k%C5%A1ana-un-anal%C4%ABze-par-eso%C5%A1ajiem-Latvijas-energoefektivit%C4%81tes-politikas-instrumentiem-ar-ex-post-metodi-un-eso%C5%A1%C4%81s-energoefektivit%C4%81tes-monitoringa-un-ietaup%C4%ABjumu-v.pdf

[38] De São José D., Faria P., Vale Z., Smart energy community: A systematic review with metanalysis, Energy Strategy Reviews, Volume 36, 2021

[39] Caramizaru A., Uihlein A. Energy Communities: an overview of energy and social innovation, JRC Science for policy report, 2020.

[40] Heleweg M A., Saintier S., Renewable energy communities as 'socio-legal institutions': A normative frame for energy decentralization? Elsevier. Renewable and Sustainable Energy Reviews, Volume 119, 2020

[41] Soeiro S., Dias M.F. Community renewable energy: Benefits and drivers. Elsevier. Energy Reports. Volume 6, Supplement 8, December 2020, Pages 134-140

[42] Riga planning region. Atjaunojamās enerģijas kopienu projekts Mārupē. 2020. [Online]. Available at: https://zrea.lv/upload/attach/4_Marupes_energo_kopiena_16dec2020.pdf [Accessed 8 July 2021]

[43] JSC "Augstsprieguma tīkls", Pārvades sistēmas operatora ikgadējais novērtējuma ziņojums par 2019.gadu. 2020. [Online] Available at: https://www.ast.lv/sites/default/files/editor/PSO_Zinojums_2019.pdf [Accessed 8 July 2021]

[44] A.A.Tellidou, Agent-based analysis of capacity withholding and tacit collusion in electricity markets, IEEE, Transactions on Power Systems, vol. 22, no. 4, pp. 1735-1742, 2007.

[45] Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU

[46] Ziegler H., Mennel T., Hulsen C. Eurelectric. Short study on Demand Response activation by independent aggregators as proposed in the draft Electricity directive, 2017. [Online] Available at: https://www.eurelectric.org/media/2155/eurelectric_dr_aggregation_final_report-2017-2521-0002-01-e.pdf [Accessed on 5 September 2020].

[47] Okpala et al. A review of modelling as a tool for environmental impact assessment. IREJEST. 10, 2013

[48] Ward E.J., Dimitriou H.T., Dean M. Theory and background of multi-criteria analysis: Toward a policy-led approach to mega transport infrastructure project appraisal. Research in Transportation Economics. Volume 58, Pages 21-45, 2016

[49] Doukas H., Nikas A. Decision support models in climate policy. European Journal of Operational Research. DOI: 10.1016/j.ejor.2019.01.017, 2019.

[50] Celli G., Chowdhury N., Pilo F., Soma G.G., Troncia M., Gianinoni I.M. Multi-Criteria Analysis for decision making applied to active distribution network planning. Electric Power Systems Research, Volume 164, Pages 103-111, 2018.

[51] Blanco G., Amarilla R., Martinez A., Lilamosas C., Oxilia V. Energy transitions and emerging economies: A multi-criteria analysis of policy options for hydropower surplus utilization in Paraguay. Energy Policy. Volume 108, Pages 312-321, 2017.

[52] Valdmanis G., Bazbauers G., "Influence of wind power production on electricity market price", *Environmental and Climate Technologies*, vol.24, no.1, pp.472-482, 2020

[53] Vamza I., Valters K., Blumberga D. "Multi-Criteria Analysis of Lignocellulose Substrate Pre-Treatment", *Environmental and Climate Technologies*, vol.24, no.3, pp.483-492, 2020

[54] Interreg. "Cost-Benefit Analysis of an integrated offshore grid in the Baltic sea. Comparison of different levels of grid integration based on case studies", 2019. [Online]. Available: https://projects.interreg-baltic.eu/fileadmin/user_upload/Library/Outputs/Baltic_InteGrid_HighLevelConcept.pdf [Accessed 30 March 2021].

[55] De Rus G., "Introduction to Cost-Benefit Analysis: Looking for Reasonable Shortcuts", *Edward Elgar*. Second edition, 2021

[56] IRENA. "Renewable Energy Technologies : Cost Analysis series. Wind Power", Volume 1 : Power Sector, Issue 5/5, 2012. [Online]. Available : https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2012/RE_Technologies_Cost_Analysis-WIND_POWER.pdf [Accessed 30 March 2021].

[57] Okpala et al. A review of modelling as a tool for environmental impact assessment. IREJEST, pp. 39-46, 2013.

[58] Forrester J. System Dynamics—The next fifty years. System Dynamics Review, 2007

[59] 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, pp.10-16, September 2017

[60] V.Bianco, F.Cascetta, A.Marino and S.Nardini, "Understanding energy consumption and carbon emissions in Europe: A focus on inequality issues," Energy, vol. 170, pp. 120-130, March 2019.

[61] J.A.Duro, "Weighting vector and international inequality changes in environmental indicators: An anallysis of CO_2 per capita emissions and Kaya factors," Energy Economics, vol. 39, pp. 122-127, September 2013. A.Tavakoli, "A journey among top ten emitter country, decomposition of “Kaya Identity”," Sustainable Cities and Society, vol. 38, pp. 122-127, April 2018.

[62] Directive 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources. 2018 [Online]. Available at: https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32018L2001 [Accesses 6 January 2022]

[63] Ceglia F., Esposito P., Marasso E., Sasso M, From smart energy community to smart energy munciplaties. Elsevier. Journal of Cleaner production, Volume 254, 2020

[64] Juffermans J.K., "Aggregators and flexibility in the Dutch electricity system" Industrial Engineering & Innovation Sciences; Eindhoven Univerity of Technology, 2018.

[65] K. A. Linas Gelazanskas, "Demand side management in smart grid: A review and proposals for future direction," Elsevier, Sustainable Cities and Society, vol. 11, pp. 22-30, 2014.

[66] De Clercq S., Schwabeneder D., Corinaldesi C., Bertetti O., "How to create value through aggregation: a business model review for multiple regulatory environments in Europe" 8th International Workshop on Integration of Solar Power into Power Systems, Stockholm, 2018.

[67] Ziegler H., Mennel T., Hulsen C. Eurelectric. Short study on Demand Response activation by independent aggregators as proposed in the draft Electricity directive, 2017. [Online] Available at: https://www.eurelectric.org/media/2155/eurelectric_dr_aggregation_final_report-2017-2521-0002-01-e.pdf [Accessed 5 September 2020].

[68] K. A. Linas Gelazanskas, "Demand side management in smart grid: A review and proposals for future direction," Elsevier, Sustainable Cities and Society, vol. 11, pp. 22-30, 2014.

[69] McConnell J., Adoption for adaptation: A theory-based approach for monitoring a complex policy initiative, Evaluation and Program Planning, Volume 73, 2019, Pages 214-223, ISSN 0149-7189, https://doi.org/10.1016/j.evalprogplan.2019.01.008.

[70] Chen H.T., Theory-driven evaluations. Thousand Oak, Sage, London, 1990

[71] Thusi J., Lucas B., Methodologies for measuring influence, GSDRC helpdesk research report 905, GSDRC, University of Birmingham, Birmingham, UK, 2013 [Online].

[Accessed 06.01.2022.], Available at: https://assets.publishing.service.gov.uk/media/57a08a0040f0b64974000384/hdq905.pdf

[72] Taplin D.H., Clark H., Collins E., Colby D.C. Theory of Change. 2013. ActKnowledge. [Online]. Available at: http://www.actknowledge.org/resources/documents/ToC-Tech-Papers.pdf [Accessed 15 December 2021]

[73] Mayne J. Making causal claims. Institutional Learning and Change (ILAC) Initiative, 2012. [Online]. Available at: https://cgspace.cgiar.org/bitstream/handle/10568/70211/ILAC_Brief26_Making%20causal%20claims.pdf?sequence=1&isAllowed=y [Accessed 16 December 2021]

[74] Funnell S.C., Rogers P.J., Purposeful Program Theory: Effective Use of Theories of Change and Logic Models, John Wiley & Sons, Hoboken, 2011

[75] I.Kasjanovs, "Latvijas apstrādes rūpniecība šķērsgriezumā," [Online]. Available: https://www.macroeconomics.lv/node/280. [Accessed 8 September 2019]

[76] J. Makijenko, J. Burlakovs, J. Brizga, M. Klavins, "Energy efficiency and behavioral patterns in Latvia," Management of Environmental Quality, vol. 27, no. 6, pp. 695-707, 2016.

PUBLICATIONS ARISING FROM THE THESIS

Paper 1: Rozentale L., Blumberga D. Methods to Evaluate Electricity Policy from Climate Perspective. // Environmental and Climate Technologies (ISSN 1691-5208) – 2019 - Vol. 23 - No. 2, pp. 131.-147. DOI: https://doi.org/10.2478/rtuect-2019-0060 *(Indexed in SCOPUS and ISI Web of Science)*

Paper 2: Rozentale L., Blumberga D. Cost-benefit and multi-criteria analysis of wind energy parks' development potential in Latvia // Environmental and Climate Technologies - vol.25 - no.1 – 2021 - pp.1229-1240. DOI: https://doi.org/10.2478/rtuect-2021-0093*(Indexed in SCOPUS)*

Paper 3: Rozentale L., Lauka D., Blumberga D. Accelerating Power Generation with Solar Panels. Case in Latvia. // Energy Procedia (ISSN 1876-6102) – 2018 - Vol. 147 - pp. 600-606. DOI: https://doi.org/10.1016/j.egypro.2018.07.077 *(Indexed in SCOPUS and ISI Web of Science)*

Paper 4: Rozentale L., Mo G., Gravelsins A., Rochas C,. Pubule J., Blumberga D. System Dynamics Modelling of Railway Electrification in Latvia. // Environmental and Climate Technologies – 2020 - Vol. 24 - No.2 - pp. 247-257. DOI: https://doi.org/10.2478/rtuect-2020-0070 *(Indexed in SCOPUS and ISI Web of Science)*

Paper 5: Rozentale L., Blumberga, D. Energy Intensive Manufacturers in State Economy: Case study of Latvia. // 60th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), Riga, Latvia, IEEE – 2019 - pp. 1-6. DOI: https://doi.org/10.1109/RTUCON48111.2019.8982318 *(Indexed in SCOPUS and ISI Web of Science)*

Paper 6: Rozentale L., Blumberga D. Potential role of energy communities in the way towards climate neutrality. Case study of Latvia // 62nd International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), IEEE - 2021, pp. 1-6. DOI: https://doi.org/10.1109/RTUCON53541.2021.9711724

Paper 7: Rozentale, L., Blumberga, D. Aggregator as a new electricity market player. Case study of Latvia. // 61th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), IEEE - 2020, pp. 1-6, DOI: 10.1109/RTUCON51174.2020.9316486 *(Indexed in SCOPUS and ISI Web of Science)*

Paper 8: Pakere I., Gravelsins A., Bohvalovs G., Rozentale L., Blumberga D. Will Aggregator Reduce Renewable Power Surpluses? A System Dynamics Approach for the Latvia Case Study // Energies (EISSN 1996-1073) – 2021. DOI: https://doi.org/10.3390/en14237900

Paper 9: Rozentale L., Blumberga D. Electricity policy solutions in Latvia from climate perspective // 2022 – Article submitted for review

Environmental and Climate Technologies
2019, vol. 23, no. 2, pp. 131–147
doi: 10.2478/rtuect-2019-0060
https://content.sciendo.com

Methods to Evaluate Electricity Policy from Climate Perspective

Liga ROZENTALE[1]*, Dagnija BLUMBERGA[2]

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

***Abstract* – Nowadays government policies to mitigate climate change are of a wide variety and they are evaluated before and after implementation. Much research has been conducted on how climate change policy will affect the climate. However, there is very little research on policies that are not intended to mitigate or reduce climate change and which, from the policy makers' point of view, have no relation to climate change. The goal of this study is to review the electricity policy in Latvia and the aspects that can be evaluated under this policy, and apply multiple-criteria analysis to determine on what spheres the electricity policy leaves the most positive impact – is it climate or are they consumers and other electricity market players? The outcome of the analysis shows that, at the national level, the most positive impact on climate is provided by the National Energy and Climate Plan, indicating that climate is taken into consideration mostly only under complex multi-sectoral legislation.**

***Keywords* – Climate change; electricity policy; multi-criteria analysis**

1. INTRODUCTION

A well-functioning internal energy market is crucial to provide Europe with secure, sustainable and affordable energy supply [1]. To ensure such an internal energy market, it is necessary to implement a sound national electricity policy, which may include the development of national legislation, regional cooperation, different political decisions (such as development of national and cross border infrastructure). All these actions are closely related to different monetary investments both from the national and EU financial resources. The EU internal energy market can be related to both the electricity and gas markets; however, to narrow down the research, this article will further focus on the internal electricity market. All the actions performed to ensure a well-functioning internal energy market can be viewed and evaluated from different perspectives – how much will it cost? will it be sustainable? what political or technical problems of the internal electricity market will it solve?, etc.

In this time of climate change and ever-increasing EU-level ambitions for mitigating climate change until 2030 by reducing greenhouse gas emissions, by increasing renewable energy use and by improving energy efficiency [2], it would be essential to evaluate both the political and technical actions in the electricity sector from the climate perspective, i.e., to measure the impact on climate. In a case study, this article will define the current draft legislation and concepts in electricity policy in Latvia, the criteria for their evaluation to evaluate the impact of this draft legislation and concepts on the determined criteria, including climate.

* Corresponding author.
E-mail address: liga.rozentale@em.gov.lv

2. METHODS AND PROCEDURES

Policy-making is a complex process, where it needs to be considered that decisions may lead to significant changes and socio-economic impact. In the context of climate change, the policy decisions are often evaluated only from the perspective of the actions they envisage for improving the climate. This can become a problem. For example, will the increase in carbon prices to promote the electrification also increase the electricity price and thus reduce the availability of energy for those, who cannot pay more? This would basically lead to energy poverty. Or, another example – can the support for biofuels lead to harsh land use change and eventually to water and food shortage? There are also specific policy examples in Latvia, which provide situations, where it is intended to be helpful on the one hand, but unfortunately the policy introduces negative side effects, such as the case of energy efficiency measures for manufacturers versus economic benefits for energy-intensive manufacturers under the mandatory procurement payment scheme, where the manufacturer may opt for keeping the economic benefit instead of introducing energy efficiency measures [3]. To evaluate the policy impact, it is necessary to have an impact assessment [4].

As it is further discussed, this research is focused on energy policy from two aspects – there is the actual draft legislation, which is one part of energy policy, and there are concepts and physical projects (such as infrastructure projects), which make the other part of energy policy.

When new physical infrastructure projects are implemented, the environmental impact assessment is used to evaluate the possible impact that this project can leave and the necessary actions to mitigate those impacts. Each project's impacts on environment are systematically compiled. The analysis of impacts begins with identification of the impacts and after that the impact assessment and forecasting take place. The impact assessments and forecasting phase of the analysis is very essential as it shows the risks for the environment [4], [5].

Modelling is the imitation of real-life situation with mathematical equations in order to forecast the future developments of a situation. It is an analytical instrument, which allows to quantify the aspects that may affect the environment. Often the models use IT technologies (computer models) to forecast the chemical and physical impact of an action in the environment. A model can help to explain the environment as a system and to research the impact of different environmental components as well as to give forecasts on their behaviour [4].

When showing a version of simple environmental system mathematically, it is possible to understand, examine and compare reasonable alternative scenarios. The development of a model includes derivation of mathematical equations. As per the research of Okpala et al., the development process of a model is the following:

1. Conduct monitoring of the system;
2. Gather existing data;
3. Make a link by using mathematical equations;
4. Calibrate the equation;
5. Validate the model;
6. Use the model for forecasting [4].

It is important to set the purpose of the model to explain the usage of a specific model. The purpose of the model will influence the necessary modelling works. Mathematical modelling and forecasting verify, how effectively a limited amount of data is used in decision making. Meanwhile, the conceptualization of a model is a process, where data, which reflects the circumstances are systematically compiled in order to describe the environment as the behaviour of the system and to research the impacts of different environmental components.

The tools of conceptualization of a model sets the approach for modelling and the model of the program [4].

The calibration of a model is a process, which sets the representative values of the model's parameters by using the available set of data. The calibration consists of changing the input data to match the environmental conditions with acceptable criteria. It is necessary that the environmental conditions of the project are correctly described. Lack of correct characterization can produce a model calibrated for a set of conditions which do not represent the real environmental conditions for the specific situation. Finally, there is the sensitivity analysis, which is a process, whereby different input data of the model are switched in a reasonable range and the relative changes are observed. Data for which the model is sensitive enough would need further research in comparison to data which is relatively insensitive. The calibrated model is verified before being used for effective forecasting [4].

Before using a specific model, it is necessary to identify the methodology, which allows to evaluate, what the essential aspects are and how they are dealt with in the energy policy. From the authors' point of view, it would first be important to separate actions based on their geographical scope – EU-level actions, regional actions (in case of Latvia, this mostly means actions taken together with Lithuania and Estonia) and national actions. The EU-level actions driven by the European Commission are already now focused on climate change. Meanwhile, the regional actions are understandably based on national interests, which often are considered only from the economic and specific narrow political point of view (e.g. national security), without considering the climate perspective. Thus, regional actions are often consistent with the national actions and it is important to evaluate the climate perspective for both national and regional decisions.

Secondly, from the policy perspective, all actions could be divided into three fields:

1. Legislative or non-legislative actions that affect the consumer such as opening of the electricity market, protection of vulnerable consumers, tariff policies, etc.;
2. Legislative or non-legislative actions that affect electricity market participants which provide services for consumers. This may include trade in general (such as trade with third countries), tariff policies, development of new services (such as demand response), etc.;
3. Legislative or non-legislative actions concerning energy security such as development of infrastructure, synchronization of the Baltic electricity grid with the European grid, trade with third countries, etc.

As it can be seen, different national actions may affect more than one of the fields set out above. From the political point of view, in most situations, the more fields the action improves, the more desirable and effective the action. Based on author's vast experience in the public administration, if the action is regional, it is an excellent opportunity for great results as the regional cooperation provides a common position on the issue and it is a more effective way to achieve goals that are similar or equal in the region.

At the same time, it is *a priori* understandable that some policy decisions do not leave any impact on the environment or it is so indirect that this impact is practically impossible to evaluate. However, with traditional modelling tools it is possible to evaluate regional infrastructure projects that are developed for energy supply security reasons and can be included in the above-mentioned third field.

There are several questions to be answered despite the geographical scope of the action:

- Will the action increase the usage of fossil fuels?
- Will this action require extensive deforestation?
- Will the action involve land use change?

– Is there or will there be an environmental impact assessment made for this action?

Several other characteristic questions can be developed. The more the answers "yes", the worse is the project.

Meanwhile, as described above, there are several existing models, which quantify the impact of a project on the environment. One of the tools, which can analyse the impact on the environment is ECO-it, which uses eco-indicators in order to determine a product's/process's environmental impact by one numerical value. It is a rather simple tool to use. The higher the result, the higher the impact. There are 5 steps needed to be followed (Fig. 1) to ensure correct use of the model [6].

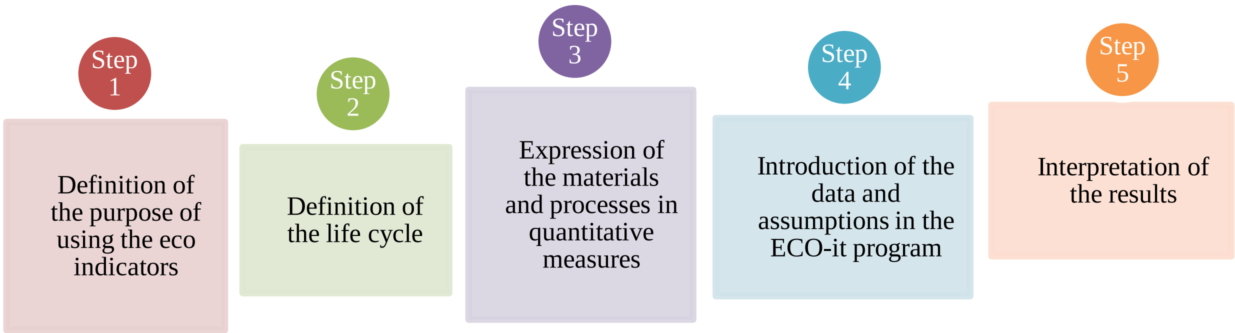


Fig. 1. Step-by-step principle implemented in the model.

In the first step, it is necessary to clearly describe the product and the product components (or in case of infrastructure projects, it can be the planned infrastructure and its' materials), which are analysed. It should be defined, whether the analysis is made as a project analysis or a comparison between different projects. At the end of the first step, the level of accuracy should be defined. If the purpose of the calculations is to define the overall impact of the product (project) on the environment, it is enough to use only the main parameters. It will result in the initial estimate results [6].

The second step includes a schematic overview of the project life cycle during its' whole live time. In the third step it is important to set the functional unit, as well as to quantify all the relevant processes from the process tree. In the fourth step, the specific components and processes are defined and included in the model with specific quantities. Finally, in the fifth step the initial conclusions need to be aligned with the results. It is essential to define the effects rising from uncertainty and assumptions and to define, whether the purpose is achieved [6].

Besides such models as ECO-it, there is a special type of environmental impact assessment that is used in strategic decision making. It is called Strategic Environmental Assessment or SEA. Therivel (2010) describes SEA as "a process that aims to integrate environmental and sustainability into strategic decision-making" [7]. It is a specific instrument that helps to avoid impacts of proposed projects [8]. SEA means that the environmental aspects are required to be integrated, when preparing any plans and programs and it needs to be used before the adoption of the actions proposed within the plans and programs [9]. As reported by the International Association for Impact Assessment, the SEA can be used for such topics as natural resources, social, cultural and economic conditions [10]. While Environmental Impact Assessment is used for projects, the SEA can also evaluate policies, decisions etc., thus it is more appropriate for government-level decisions.

SEA has three main characteristics:

1. It is used to prepare a document that needs government approval. It can be both a plan

or a program;

2. The main aim of it is to show what are the environmental effects or consequences for the proposed documents;
3. The standard methodology is very similar to EIA, with such steps as screening, scoping, assessment, mitigation, decision and monitoring [11].

For example, in Latvia, the strategic environmental assessment is compulsory since 2004 for several types of documents such as national level development plans, sectoral policy plans, national level territory planning documents, etc. However, it is not compulsory for regional-level energy infrastructure, because it is not a plan, these are projects promoted mostly by transmission system operators and the government just gives the approval and special conditions if the project receives status of a project of national interest.

To evaluate policies, it is also possible to use multiple-criteria analysis (further on – MCA), which can help to decide on the best choice by using multiple and sometimes even conflicting criteria in order to achieve the desired result [12]. MCA is also categorized as a sub-discipline of operations research, which is used in solving difficult problems with multiple points of view [13]. To aid the decision-making process, many objectives can be chosen – they can be related to economic, environmental, social, technical and other aspects. The criteria can be either monetized, non-monetized (albeit quantifiable) or qualitative, based on information. MCA allows both quantitative and qualitative criteria of outputs/outcomes/impacts to be mixed together and provide the decision-making bodies the overall results of potential consequences in the specific field of the action (or in this case policy) where the evaluation is to be completed [12]. By using MCA, there is less uncertainty regarding the monetary conversion, which is sometimes experienced. Moreover, this analysis also provides more transparency [14]. While the previously described methodologies in the case of energy policy could be used more for real technical actions, such as decisions on building infrastructure, the MCA can be used for the whole policy-making sector. Besides, it is noted that MCA methods are regularly used in energy policy and planning [15].

Under the concept of MCA, different policy scenarios can be compared by using TOPSIS method – a Technique for Order of Preference by Similarity to Ideal Solution. This concept was introduced by Hwang and Yoon already in 1981 and it is a classic MCA method. The method suggests that the best alternative is the one, which is closest to the best desired solution and farthest from the worst solution [16]. The best desired solution is the one, which has the highest benefits and lowest costs, while the opposite is true for the worst solution. Thus, the best values under the criteria are the ones that compose the best desired solution. There is also the so called Fuzzy TOPSIS, which was introduced in 2000 by Chen C.T., which is used for solving multiple-criteria decision-making problems in fuzzy environment, which means uncertainty or subjectivity of evaluations and judgements [17]. The original version of TOPSIS is usually used in MCA problems where the criteria for a decision are independent. The steps for dealing with this approach are described in Eq. (1) to Eq. (6) [18]. The input is decision data *V* and set of weights *w*, but the output is closeness measure *r* [19]. The first step is normalization. For each evaluation $v_{m,k}$, it is necessary to perform the following normalization:

$$u_{m,k} = \frac{v_{m,k}}{\sqrt{\sum_{k=1}^{K} v_{m,k}^2}}, \quad m = 1,...,M, \quad k = 1,...,K \,. \tag{1}$$

The second step is weighted normalization. For each normalized evaluation $u_{m,k}$, it is necessary to perform this weighted normalization:

$$p_{m,k} = w_m u_{m,k},\ m = 1,...,M,\ k = 1,...,K. \tag{2}$$

The third step is the determination of positive and negative ideal alternative by this equation:

$$\text{PIA} = p^+ = \{p_1^+, p_2^+, ..., p_M^+\} \text{ and } \text{NIA} = p^- = \{p_1^-, p_2^-, ..., p_M^-\}, \tag{3}$$

where p_m^+ = max $\{p_{m,k}|1 \le k \le K\}$ and p_m^- = min $\{p_{m,k}|1 \le k \le K\}$, m = 1, …, M.

The fourth step is the calculation of Euclidean distances from each alternative and both PIA and NIA:

$$D_k^+ = \sqrt{(p_k - p^+)^T + (p_k - p^+)}, k = 1,...,K, \tag{4}$$

and

$$D_k^- = \sqrt{(p_k - p^-)^T + (p_k - p^-)},\ k = 1,...,K, \tag{5}$$

where $p_k = [p_{1,k}, p_{2,k}, \dots p_{M,k}]$.

The fifth step is the calculation of closeness measure for each alternative:

$$r_k = \frac{D_k^-}{D_k^+ + D_k^-},\ k = 1,...,K. \tag{6}$$

As has been stressed by other authors [20], one of the motivators for using MCA and particularly TOPSIS analysis is its simplicity and the fact that is does not need any specialized programs to use it and it gives the opportunity to compare the results, which would be hard to do by using other non-quantitative analysis. This and the previously mentioned reasons are why MCA is the chosen methodology for the case study in the next chapter. It is combined with the above-mentioned division into EU-level, regional and national level.

3. CASE STUDY

In this study, the author has chosen to evaluate the current drafts of legal acts, action plans and concepts that are available to the public for discussion in the electricity sector in the Republic of Latvia. This includes the proposed amendments to the Electricity Market Law and to the Law of Buffer Zones, amendments in regulations of the Cabinet of Ministers, as well as the newly drafted National Climate and Action Plan, the project for synchronizing the electricity grid of the Baltic States with the continental Europe's electricity grid, the idea of introducing a cross border electricity transmission infrastructure tariff and, finally, three EU-level proposals. Thus, different types of possible decisions are described as follows (summarized in Table 2 in the next section):

1. Electricity Market Law amendments are proposed as a package; however, these proposals are not related to each other:
   1.1. Data hub – According to the best practices of European countries, the regulation and operation of a single electricity market data storage and exchange platform has already been implemented in several European countries (incl. Estonia) and in several implementation has started (incl. Lithuania). In addition, on 30 November 2016, the European Commission issued a so-called "Winter Package" for energy, which includes proposals for the internal market for electricity and provides for the establishment of transparent internal electricity market mechanisms that enable system users to actively participate in electricity market activities [21]. The creation of a unified, centralized data storage and exchange platform is a prerequisite for further development of the Latvian electricity market. Centralized data exchange enables to minimize the handling of manual information requests, reducing the overall cost of data processing and exchange. The proposal suggests that the biggest distribution system operator in Latvia JSC “Sadales tīkls” is the holder of the data exchange platform. JSC “Sadales tīkls” already operates an existing data exchange platform, however it is not centralized, and it is not considered a national data hub. The use of an existing data exchange platform will not lead to additional costs for market participants,
   1.2. Electricity production permit – The Ministry of Economics of Latvia has issued permits for increasing electricity generation capacity or introducing new electricity equipment since 2006, as a result the Ministry has currently issued more than 1000 permits. Legislation provides that authorization from the Ministry is the first step in increasing the capacity of electricity or introducing new electricity installations. As the practice shows, only a small proportion of the individuals who have received the permit are involved in further implementation of the permit. Thus, the permits issued do not allow for the accumulation of reliable statistics on the installed electricity generation capacities or for forecasting the development of capacity deployment, which were the original objectives of these permits. It is also concluded that, after receiving the Ministry's permission, a person will apply for new electricity connection to the system operator by re-submitting the documents already checked by the Ministry. Thus, the Ministry has decided to simplify this administrative process by stipulating that in the future only large power plants that shall be connected to the transmission system and can potentially affect the achievement of the targets set in the policy planning documents and may have a negative impact on the electrical system, are required to receive permits. The distribution system operator, on the other hand, will provide the Ministry with regular statistics on new connections to the distribution system,
   1.3. Isolated island-mode test – Conducting an isolated performance test of the Baltic States is necessary for the expected synchronization of the Baltic States with continental Europe and for desynchronization from the Russian-Belarussian power system (BRELL). During an isolated operation test, it is planned to separate from BRELL, verify the system's ability to work in isolated mode and perform the necessary system checks. During this test, the power systems of all three Baltic States will operate outside the normal operating mode under reduced

operational safety conditions and will cease the operation of the existing 12 power transmission lines with Russia and Belarus. Also, during the test, the Baltic transmission system operators will take all necessary measures, including ensuring the readiness of generators, readiness of personnel and other measures to ensure a stable and secure operation of the Baltic transmission system. However, complete disconnection from BRELL will increase the risk of system failure and system shutdown. In view of the above, it is necessary to clearly define the set of rights and obligations of the transmission system operator during the test of the transmission system,

1.4. Protected customer – according to the current wording of the Electricity Market Law, the electricity trade service for a protected customer may be provided only by one tendered electricity trader, who is also responsible for the assessment of the customer to check its compliance with the protected customer's status. Considering the current framework of the Electricity Market Law, it is difficult to receive a protected customer service for those users or sub-users who have not signed an electricity trade contract with the specific protected customer trade service provider. Therefore, the protected customer support mechanism as a social tool does not reach all the eligible electricity users, as well as contradicts the consumer's right to choose the electricity trader under the conditions of a free electricity market. The Ministry of Economics encourages the creation of a new, simpler system for providing support to the protected user, which will be managed and maintained by the Construction State Control Office. Namely, the Data Protection System, which is under the control of the State Construction Control Office, will collect data on the status of the protected customer, and will calculate the amount of support that they will be able to receive from any electricity trader wishing to provide a protected user trade service,

1.5. Mandatory procurement payment – the amendments under this concept have several components:

- The proposal ensures that the gross capital internal rate of return is calculated by also taking into account the support provided before the Electricity Market Law came into force. Thus, the internal rate of return on the total capital investment of individual power plants is expected to be higher than before and will be subject to a reduction in financial support,
- Additional proposal which defines that for a producer, which produces electricity in a cogeneration unit with an installed electrical capacity of more than 100 megawatts, the transmission system operator shall pay the guaranteed fee for the installed electrical capacity of the cogeneration unit,
- The purpose of the amendments is to exempt net system users (e.g. households with solar panels) from payments for the variable part of the mandatory procurement component in respect of the share of electricity received by the net system user from the network to the extent that it is transferred to the network,
- The proposal requires the supervising body to monitor and control electricity producers receiving state aid, including by introducing a condition for recovering the aid paid out in accordance with the procedures established by the Cabinet of Ministers,
- The EM proposal provides for the introduction of a general condition for the provision of energy-efficient and cost-effective heat production. The current regulations of the Cabinet of Ministers do not provide for the obligation of the

electricity producer receiving state support to ensure that the heat produced in the cogeneration process, which is transferred to a third party, is used in an energy efficient and cost-effective way. Thus, there may be situations where the supervising authority has limited possibilities to control the use of heat,

- The proposal envisages to ensure that from 1st January 2022 the support for the production of electricity from renewable energy sources is provided as a supplement to the electricity market price, not as before, i.e., by calculating the total purchase price of electricity in accordance with the procedures specified by the Cabinet of Ministers. This will facilitate the adaptation of electricity generators that receive state aid to the electricity market processes, as well as the possibility to reduce the total amount of paid state aid;

2. Law on Buffer Zones (or protection zones) has several proposals for amendments, but the most important amendment is the establishment of operational protection zones and their restrictions on oil and oil product pipelines, their equipment and structures. In addition, there are amendments to determine the width of operational protection zones for individual gas supply installations;
3. Meanwhile, the National Energy and Climate Plan for 2021–2030 is a policy planning document that will set Latvia's goals and their implementation measures in such sectors or activities as – reduction of greenhouse gas emissions and increase of CO_2 capture, increase of the share of renewable energy resources, improvement of energy efficiency, energy security provision, maintenance and improvement of energy market infrastructure, and innovation, research and competitiveness. In each EU Member State including Latvia, the Plan is being developed to meet EU targets and international commitments:
   - The commitment made by the United Nations Framework Convention on Climate Change in Paris to reduce climate change by 2030 – to reduce total greenhouse gas emissions from all EU Member States by at least 40 % by 2030 in a cost-effective way compared to 1990 [22],
   - The EU's Roadmap for moving to a competitive low carbon economy in 2050 – the EU is ready in 2050 to reduce its total Member States' emissions by 80–95 % compared to 1990 levels to move to a competitive low carbon economy [23],
   - The conclusions of the European Council of 24 October 2014 entitled "Climate and Energy Policy Framework for 2030" set targets for climate change mitigation and energy in increasing renewable energy, improving energy efficiency and establishing interconnections [24];
4. Smaller, yet valuable amendments to regulations on regulated public utilities have the purpose to ensure consistent regulation of electricity trade service and heat supply services, providing that it is necessary to regulate electricity trade for any electricity sellers (and not only the ones who trade more than 4000 MWh/year as it is now) and that the state regulates the heat supply services provided in the district heating system that meet the specified criteria;
5. One of the main priorities in the Baltic States in the last years is the so-called Synchronization project, which is the first one in this list that is actually not a legal act, but a technical project. Unlike other European Union countries, the Baltic power systems operate in parallel, synchronous mode with IPS / UPS (Unified Power System – Russia, Ukraine, Belarus, Kazakhstan, Kyrgyzstan, Azerbaijan, Georgia, Tajikistan, Moldova and Mongolia) instead of European electricity systems. The cross-border operation of the electricity markets of the Baltic States, Russia and Belarus is defined

by the BRELL agreement (Belarus, Russia, Estonia, Latvia, Lithuania) concluded by the transmission system operators of Belarus, Russia, Estonia, Lithuania and Latvia. As a result, the Baltic power system is currently managed by third countries that increase energy dependence on third countries and impact on system security issues, make it difficult to exchange information with European transmission system operators, and there is no way to ensure coordinated action (e.g. in case of power line disconnections) between the Baltic States and the rest of Europe. The integration of the Baltic States' electricity networks into the EU electricity system is one of the strategic priorities of the EU energy policy. The Prime Ministers of the Baltic States put forward the idea of desynchronization already in 2007 and the importance of the synchronization project in recent years has been highlighted in several policy documents;

6. On the same regional level as synchronization, another discussion takes place on a tariff with third countries. The issue related to energy import from third countries is open for discussion among the Baltic States for some time. In 2017, during the Baltic Council of Minister's Senior Officials Meeting, the Baltic States jointly touched upon this challenge of unequal electricity trade conditions for competition with third countries. Since then a legal and economic analysis was developed to identify possibilities to implement such a tariff. The outcome of studies foresees that it is possible to develop a common cross border infrastructure tariff for all Baltic States, which would take into account the costs of all three transmission system operators. That would be a regional solution related to energy import from third countries. Currently, the legislation of the Baltic States does not allow to introduce such a common tariff and therefore legislation amendments are necessary. The Cabinet of Ministers of Latvia has already approved the possibility to implement such a tariff regarding electricity import from third countries. Thus, the next step is for the Baltic States to agree on an approach of a common cross border infrastructure tariff and after that to appropriately change the respective legislation. Latvia is committed to work on developing the necessary amendments to the national legislation by 1st January 2020.

Finally, there are 3 EU level proposals, which will soon be adopted:

1. Proposal for a Regulation of the European Parliament and of the Council on the internal electricity market (recast) and Proposal for a Directive of the European Parliament and of the Council on common rules for the internal market in electricity (recast) – the two new proposals are closely linked. Their primary objective is to adapt current market rules to new market conditions by increasing flexibility, allowing electricity to move freely to where and when it is most needed, using undistorted price signals and at the same time giving the consumer greater opportunities for maximum benefit from cross-border competition, providing the right signals and incentives to drive investment and make Europe's energy system more competitive and low-carbon [25], [26];
2. Proposal for a Regulation of the European Parliament and of the Council on risk-preparedness in the electricity sector and repealing Directive 2005/89/EC – proposal for the Regulation replaces Directive 2005/89 / EC, which provided for a very broad framework of objectives to be achieved by Member States in the field of security of supply, but with little practical value. This directive will therefore be repealed as well as some of the provisions of the current Third Energy Package relating to security of supply, in particular Article 4 of Directive 2009/72/EC (requiring Member States to monitor security of supply through national reports) and Article 42 (allowing Member

States to take "safeguard measures" in the event of a sudden crisis in the electricity sector). The proposal for a regulation is based on the System Operational Guidelines and the Network Code electricity emergency and restoration, which provide technical rules for transmission system operators on how to ensure system security, including in emergency situations [27];

3. Proposal for a Regulation of the European Parliament and of the Council establishing the Connecting Europe Facility and repealing Regulations (EU) No. 1316/2013 and (EU) No. 283/2014. The proposal defines the objectives of the Connecting Europe Facility (CEF), the types of funding and rules for funding, as well as the budget for the period 2021–2027. The objectives of the CEF in the energy sector are to promote the development of projects of common interest related to the further integration of the internal energy market, cross-border and cross-sector interoperability of networks, promotion of decarbonization and security of supply, and to promote cross-border cooperation on renewable energy [28].

The criteria for evaluating all the above described draft legislation, infrastructure projects and concepts (all together further on - projects) are different modes of benefits – benefits for electricity consumer, for electricity producer, for electricity seller, for transmission and distribution system operators, for the state and finally for the climate. These criteria have different weights (100 % in total for all criteria) – it is logically and at the same time subjectively assumed that the benefit for the consumer is the most important, followed by the benefit for the producer, benefit for climate, benefit for state, benefit for seller and the benefit for the system operators in this case is the less valued criteria. It is important to stress that benefits for state can be both monetized (like a fee that is paid into budget) or it can be non-monetized, but have a different benefit, such as compliance with EU law, when it is necessary to apply EU law to national regulation (under presumption that EU penalty should not be an option). A state benefit could also be the reduction of bureaucracy in the government (it can be a time-saving, but not always a cost-saving action) or a general increase of safety measures. It was decided that one criterion can have maximum 5 points (multiplied by weight). If the project does not give any benefit for the specific group (criterion), it gets 0 points. Thus, the most points one project can get is 5, meaning that is has 5 points under each criterion, which can be only in case if the project has maximum benefit under each criterion. In the table below, the final results are shown.

4. RESULTS

The criteria were chosen based on the concept, what are the most important aspects when developing a policy at the government level. The overarching idea is always to improve the situation for the consumer, so the effect on the consumer is considered as the basis. From the expert's point of view, this is true in developing all the energy policies. If a policy does not benefit a consumer or even brings some negative effects for the consumer, it should be reconsidered. Thus, in this case study, the consumer has a 30 % weight and it has the highest rank compared to other criteria. The benefit for the consumer in this case is narrowed down to the most essential aspects – available and affordable electricity. When implementing a policy, the next important criteria is the state. If it can improve, for example, the state budget while positively affecting the consumer, this is something we would want to implement, because it is not a common situation – usually when a consumer gains by, for example, reduced taxes, the state loses. Thus, this criterion is mostly considered not from the perspective of gains, but from the perspective of costs – if it does not cost anything for the state, it is more likely to be approved. That is why benefit for the state has a 22 % weight in the criteria. In this case study we look at the state in a narrow definition, the benefit for the state is the benefit for the public administration, for the budget and for the national security. Thirdly, at this point in time, we are looking rather carefully for the climate benefits – in this case the benefits that would allow to achieve the EU 2020 and EU 3030 climate targets. It is not the first aspect to consider, but in recent years it becomes more and more valuable due to reasons described before, so in this case study this criterion has a 20 % weight. Fourthly, we are looking at the electricity producers – this is a sector specific criterion, because we cannot have electricity policy without electricity producers. And the Baltic States are in a situation, where national electricity generation is very important to avoid excessive electricity import from third countries and thus to avoid import dependency. This criterion is important not only from the security point of view, but also considering the necessity to support national renewable energy generation. Thus, the overall value for this criterion was granted 15 %. Finally, there are two criteria, which go below 10 % each. These are electricity market participants, without which it is impossible to use the electricity market – electricity traders and distribution/transmission system operators. Any regulation or project should be acceptable to them, because they ensure the operations of the market. The granted weights are 8 % and 5 % respectively. The weights of criteria are summarized in Table 1.

TABLE 1. WEIGHTS OF CRITERIA

	Criteria	**Weight**
1.	Benefit for electricity consumer	0.30
2.	Benefit for the state	0.22
3.	Benefit for the climate	0.20
4.	Benefit for electricity producer	0.15
5.	Benefit for electricity trader	0.08
6.	Benefit for electricity distribution/transmission system operator	0.05

Multicriteria analysis (MCA) results are presented in Table 2. MCA shows evaluation of the projects, which touch upon or are closely related to electricity policy, as well as their evaluation from the expert's point of view. In total there are 13, which were described in the previous chapter. These are not all energy-related, but are all somehow related to electricity (as opposed to gas and oil) and they are from different geographical scopes – EU level, regional level and national level.

TABLE 2. MULTIPLE-CRITERIA ANALYSIS ON THE CURRENT ELECTRICITY POLICY PROJECTS IN LATVIA

	Current projects / ***Criteria***	Benefit for electricity consumer	Benefit for electricity producer	Benefit for electricity trader	Benefit for electricity distribution/transmission system operator	Benefit for the state	Benefit for the climate	MCA results
1	**Electricity market law providing amendments on:**							
1.1	*Data hub*	1	3	5	5	1	0	**1.62**
1.2	*Electricity production permit*	1	5	0	5	4	4	**2.98**
1.3	*Isolated island-mode test*	0	0	0	5	4	0	**1.13**
1.4	*Protected customer*	5	0	2	0	4	0	**2.54**
1.5	*Mandatory procurement payment*	5	0	0	0	5	0	**2.6**
2	**Law on buffer zones (protection zones)**	0	0	0	5	2	0	**0.69**
3	**National Energy and Climate plan**	3	4	3	2	4	5	**3.72**
4	**Rules on Regulated public utilities**	1	0	5	1	2	0	**1.19**
5	**Synchronization**	1	1	1	5	4	0	**1.66**
6	**Tariff for trade with 3rd countries**	0	3	5	5	3	1	**1.96**
7	**Internal electricity market Directive & Regulation**	5	5	3	4	3	2	**3.75**
8	**Risk-preparedness Regulation**	1	1	1	3	4	0	**1.56**
9	**Connecting Europe Facility Regulation**	1	3	5	5	5	4	**3.3**

While developing a policy, policy-makers often think of amending obscure provisions, to implement clearer rulings and as the table above shows, if we look from the point of these five criteria, sometimes the new electricity policy can be beneficial for only some of the beneficiary groups, e.g., for consumer and state, but not for the climate and producer. Fig. 1 below shows more clearly the final results.

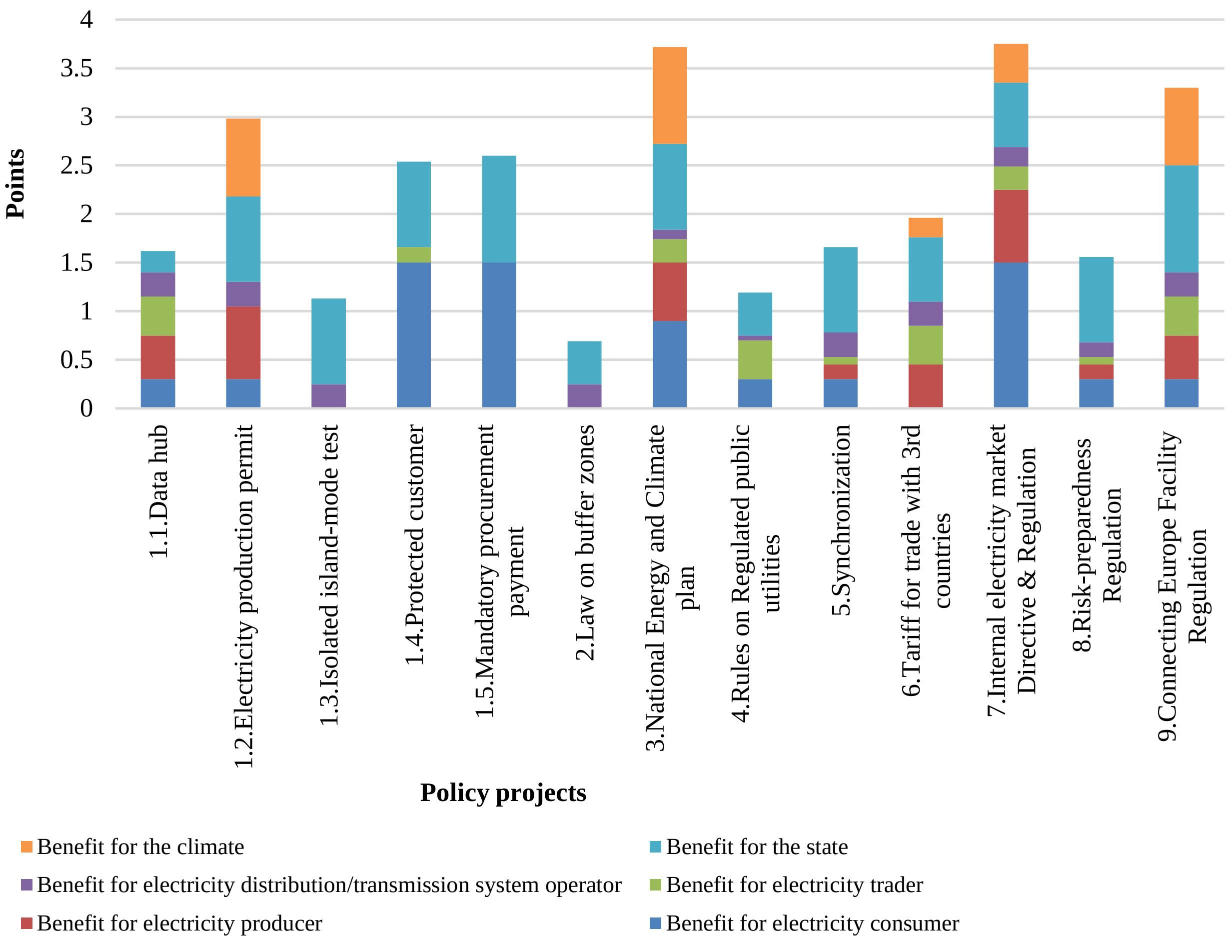


Fig. 2. Evaluation of current electricity policy projects.

As was mentioned earlier, the EU-level projects are mostly intended to improve the climate and, moreover, intended for a large group of beneficiaries, so it is not surprising that the matrix above shows that the project number 7 and 9 have one of the highest results in total.

Moreover, the highest scored national-level project (Number 3, National Energy and Climate Plan) is based on requirements from the EU, which also explains the versatile and relatable content for different affected parties. While the EU-level projects are harder to influence from the national perspective, Latvia's National Energy and Climate Plan (NECP) is based on the national views on how to develop a sustainable and efficient energy system that has benefits for all related participants. For example, according to the forecasts for 2030, with the policies and measures currently implemented, the share of Latvian renewable energy in final energy consumption in 2030 would be about 41.2 %. The NECP foresees that Latvia should have at least 45 % of renewable energy in the final energy consumption by 2030. It will therefore be necessary to implement additional measures to increase the share of renewable energy. To achieve this goal, NECP proposes several measures. For example, to apply a reduced rate for value added tax of 12 % to households for the purchase and installation of solar panels and services to households for the supply and installation of solar technology. It also encourages long-term lease contracts for basic wind farms with a total capacity of up to 500 megawatts in the country's forests and adjacent areas, to support wind and solar energy technology deployment, and to promote collaboration between scientists and entrepreneurs in the field of renewable energy sources. The plan also encourages increased natural resource tax for all fossil fuels and other important measures [18]. As can be seen from this small example, NECP would thus have a significant impact on all market participants.

In Table 1, a certain pattern is evident– the climate benefits only in cases, where all other sides (consumer, producer, traders, etc.) reap benefits. Thus, it could be argued either it is a problem or a gain, but the system only works in a complex framework.

At the same time, it is important to stress, that, as can be seen from the light green parts in Fig. 2, in most cases reviewed in this study, the most gains go to consumers and it is essential that the policy planners concentrate their effort on consumers, which is the basis of society. There is also a tendency that the consumer, state and climate (by their narrow definitions as described earlier) are the criteria, which are thought of in almost all of the researched cases. Electricity producers and traders receive much less support, even though it could seem surprising considering that Latvia has an established system of mandatory procurement component that the consumers pay for the green energy and high efficiency cogeneration energy produced in Latvia. But this only means that, the policy makers are slowly moving away from this rather unsustainable support system and focusing more on the electricity consumer, while developing new concepts for supporting renewable energy in Latvia without such high costs.

5. CONCLUSIONS

There are many methods and options that can be used to estimate the impact of a legislative initiative. Most of them, however, are of complex nature and could not really be used by the policy makers at the government level but would include the necessity to use outside sources to introduce these more complex methods.

However, based on the research, it can be concluded that there are a few not so complex methods that could be used by policy makers at the expert level in the government. The research helped to understand that if we want to look at policy making in a more sophisticated way by including all aspects of policy making, both physical infrastructure projects concepts, laws and regulations, the optimal way for that is to use multiple-criteria analysis. A case study for such a concept in electricity policy in Latvia was developed. It showed that most of the cases that were reviewed focused on finding solutions for rather specific aspects that are not connected to the climate – mostly the policy measures are intended for solving issues that are relevant for the consumers.

As regards the problem of climate, the research showed that while developing a policy in the electricity sector, the climate issues are only tackled in legislative initiatives, which cover a broad spectrum of questions, but not individually as such. Respectively, the outcome of the research provides that, at the national level, the most positive effect for climate comes from the National Energy and Climate Plan. Thus, it can be concluded that more consideration should be given to the climate perspective when developing electricity policy that focuses on specific narrow aspects, because these narrow aspects may as well actually influence the climate by, for example, indirectly promoting usage of specific energy sources.

It would be appropriate to continue the study by expanding the evaluation scheme also in terms of examining the negative impacts, because certain initiatives would may leave a negative impact on the consumers, producers, climate, etc. and not neutral or zero impact as was assumed in this case.

ACKNOWLEDGEMENT

This 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. Making the Internal Energy Market Work. Communication from The Commission to The European Parliament, The Council, The European Economic and Social Committee and The Committee of The Regions. 2012.
[2] European Commission. 2030 climate & energy framework [Online]. [Accessed 10.01.2019]. Available: https://ec.europa.eu/clima/policies/strategies/2030_en
[3] 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* 2017:128:10–16. doi:10.1016/j.egypro.2017.09.005
[4] Okpala et al. A review of modelling as a tool for environmental impact assessment. *IREJEST* 2013:10(1):39–46.
[5] Dagiliute R., Juozapaitiene G. Stakeholders in the EIA Process: What is Important for them? The Case of Road Construction. *Environmental and Climate Technologies* 2018:22(1):69–82. doi: doi:10.2478/rtuect-2018-0005
[6] Pre-consultants. Guide to using ECO-it 1.3., 2004.
[7] Therivel R. *Strategic environmental assessment in action*, 2nd ed. London: Earthscan, 2010.
[8] Bidstrup M., Hansen A. M. The paradox of strategic environmental assessment. *Environmental Impact Assessment Review* 2014:47:29–35. doi:10.1016/j.eiar.2014.03.005
[9] European Commission. Strategic Environmental Assessment. [Online]. [Accessed 10.01.2019]. Available: http://ec.europa.eu/environment/eia/sea-legalcontext.htm
[10] International Association for Impact Assessment. Strategic Environmental assessment. [Online]. [Accessed 11.01.2019]. Available: http://www.iaia.org/wiki-details.php?ID=24
[11] Carew J., Strategic Environmental Assessment, Process and Methods. Strategic Environmental Assessment Workshop, 24–27 May 2016.
[12] Ward E. J., Dimitriou H. T., Dean M. Theory and background of multi-criteria analysis: Toward a policy-led approach to mega transport infrastructure project appraisal. *Research in Transportation Economics* 2016:58:21–45. doi:10.1016/j.retrec.2016.08.003
[13] Doukas H., Nikas A. Decision support models in climate policy. *European Journal of Operational Research* 2019:280(1):1–24. doi:10.1016/j.ejor.2019.01.017
[14] Celli G., et al. Multi-Criteria Analysis for decision making applied to active distribution network planning. *Electric Power Systems Research* 2018:164:103–111. doi:10.1016/j.epsr.2018.07.017
[15] Blanco G., Amarilla R., Martinez A., Lilamosas C., Oxilia V. Energy transitions and emerging economies: A multi-criteria analysis of policy options for hydropower surplus utilization in Paraguay. *Energy Policy* 2017:108:312–321. doi:10.1016/j.enpol.2017.06.003
[16] Ertugrul I., Karakasoglu N. Performance evaluation of Turkish cement firms with fuzzy analytic hierarchy process and TOPSIS methods. *Expert Systems with Applications* 2009:36(1):702–715. doi:10.1016/j.eswa.2007.10.014
[17] Seyedmohammadi J., Sarmadian F., Jafarzadeh A. A., Mohammad A. Application of SAW, TOPSIS and fuzzy TOPSIS models in cultivation priority planning for maize, rapeseed and soybean crops. *Geoderma* 2018:310:178–190. doi:10.1016/j.geoderma.2017.09.012
[18] Pelegrina G. D., Duarte L. T., Romano J. M. T. Application of independent component analysis and TOPSIS to deal with dependent criteria in multicriteria decision problems. *Expert Systems with Applications* 2019:122:262–280. doi:10.1016/j.eswa.2019.01.008
[19] Ervural B. C., et al. An ANP and fuzzy TOPSIS-based SWOT analysis for Turkey's energy planning. *Renewable and Sustainable Energy Reviewed* 2018:82(1):1538–1550. doi:10.1016/j.rser.2017.06.095
[20] Zihare L., Splavins K., Blumberga D. Multi criteria analysis for products derived from agro-industrial by-products. *Energy Procedia* 2018:147:452–457. doi:10.1016/j.egypro.2018.07.045
[21] European Commission. Clean energy for all European. [Online]. [Accessed 10.01.2019]. Available: https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans
[22] United Nations. Framework Convention on Climate Change. FCCC/INFORMAL/84 GE.05-62220 (E) 200705. 1992.
[23] European Commission. Communication from The Commission to The European Parliament, The Council, The European Economic and Social Committee and The Committee of The Regions A Roadmap for moving to a competitive low carbon economy in 2050. COM/2011/0112.
[24] European Council. Conclusions on 2030 climate and energy policy framework. Brussels: European Commission, 2014.
[25] European Commission. Proposal for a Regulation of The European Parliament and of the Council on the internal market for electricity (recast). COM/2016/0861. Brussels: European Commission, 2016.

[26] European Commission. Proposal for a Directive of The European Parliament and Of the Council on Common Rules for The Internal Market in Electricity (Recast) COM/2016/0864. Brussels: European Commission, 2017.
[27] European Commission. Proposal for A Regulation of The European Parliament and of the Council on Risk-Preparedness in The Electricity Sector and repealing Directive 2005/89/EC. COM/2016/0862. Brussels: European Commission, 2016.
[28] European Commission. Proposal for A Regulation of The European Parliament and of the Council Establishing the Connecting Europe Facility and repealing Regulations (EU) No 1316/2013 and (EU) No 283/2014. COM/2018/438. Brussels: European Commission, 2018.

Environmental and Climate Technologies
2021, vol. 25, no. 1, pp. 1229–1240
https://doi.org/10.2478/rtuect-2021-0093
https://content.sciendo.com

Cost-Benefit and Multi-Criteria Analysis of Wind Energy Parks Development Potential in Latvia

Liga ROZENTALE[1*], Dagnija BLUMBERGA[2]

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

Abstract – **In the last decade the European Union (EU) has been steadily increasing its' ambition regarding the climate policy. Considering the linkage between the climate targets and energy sector's greenhouse gas emissions, the EU's member states are respectively adjusting their energy policies. One of the current trends in the EU is to increase the renewable electricity generation by roll-out of onshore and offshore wind parks. This research aims at evaluating the potential of large-scale wind parks in Latvia by using the cost-benefit and multi-criteria analysis from financial, technical, climate and administrative perspectives as well as considering the impact on security of energy supply. The results of the research show a good potential for onshore wind park development in Latvia without any state aid, while offshore wind parks are in a much worse position and would not be beneficial for the project promoters without any kind of EU or state aid.**

Keywords – **Cost-benefit analysis; energy policy; multi-criteria analysis; offshore wind; wind energy; wind parks**

1. INTRODUCTION

As has been stated by the EU's statistical office Eurostat, all the EU's member states in 2019 generated 3.8 billion tonnes of carbon dioxide (CO_2) equivalents, which is the most emitted greenhouse gas (GHG) in the EU [1]. The EU's energy sector is the area of economic activity with the highest share of GHG emissions. There is a continuous increase in demand of electricity due to the growth of population and the interlinked growth of economy [2]. The EU's ambition towards climate neutrality is a major driving force for the EU's member states to adjust their energy policies and provide other means of electricity production.

Considering both the costs and the necessity to ensure security of energy supply, the transition from fossil fuels to renewable energy sources is neither easy nor quick. The EU's member states have different approaches to moving towards increased usage of renewable energy, however one of the major common trends is to stimulate the development of wind energy – onshore as well as offshore for the member states which have access to the sea.

This research firstly looks at two different methods of analysis – cost-benefit and multi-criteria analysis, which have been widely used for evaluating wide range of projects. Then these methods are applied for evaluating two theoretical case studies for potential offshore and onshore wind parks in Latvia. The aim of the research is not only to evaluate the financial feasibility of different types of wind parks but also to understand their impact on climate, both the administrative and technical prerequisites for developing a wind park in

* Corresponding author.
E-mail address: liga.rozentale@em.gov.lv

Latvia as well as the impact of such wind parks on the security of energy supply considering the possible reduction of electricity imports.

2. METHODS AND PROCEDURES

2.1. Cost-Benefit Analysis

Cost-benefit analysis (CBA) is an instrument that provides the possibility to compare the costs of a certain project with the benefits that this project provides in order to check if the benefits outweigh the costs [3]. CBA thus allows for the project promoters and all other interested parties to draw conclusions, whether the project is feasible. To do that, the costs and benefits must be monetized and expressed as the net present value (because the costs generally appear before the benefits, so the different points in time would actually impact the values) [4].

Though the costs and benefits should be monetized to make the financial analysis in the CBA, setting value can only be one of the tools to express the social costs and benefits of the project to evaluate the impact on the social welfare [5]. In the case of a wind park, the success of the project cannot only be defined by the amount of electricity that has been sold into the electricity grid, because it could be possible to set a feed-in subsidy tariff that would foster the wind park project without increasing social welfare if the feed-in tariff costs had to be compensated by the electricity end-users.

The social welfare impact is not easy to evaluate as it is a rather subjective criterion, but many researchers use the concept of Pareto efficiency entailing that social welfare for a project can be defined as positive if someone benefits without making it worse for others [6]. However, this criterion can easily undermine the results of a CBA if, for example, only one person complains about the visual degradation of the environment due to a wind park project. Another criteria for measuring social welfare is the Kaldor-Hicks compensation test, which entitles that social welfare of a project is positive in case the benefits of a project are so big that the project promoters would be able to compensate the costs for those who have loses due to the project. It is important to stress that the compensation would not actually have to be paid, it is just a way to measure the social welfare benefits [6].

While wind has no fuel costs, there are several key parameters that define the costs of a wind park:

- Investment costs (also known as capital costs or CAPEX), which include the turbine costs, construction works, grid connection costs and other capital costs including administrative costs, designing costs etc.;
- Operation and maintenance costs (OPEX that can be fixed or variable);
- Capacity factor (the output of the turbine affects the rate of return);
- Economic lifetime;
- Cost of capital (i.e. the expected return) [7].

For the CBA of an electricity infrastructure project European Network of Transmission System Operators for Electricity (ENTSO-E) identifies three categories for assessment that are reflected in Table 1 [8].

Costs and benefits in this research will be analyzed by a linear cost model (LCM) that allows to calculate CAPEX and OPEX [4]. For a wind park, the basic CAPEX would be defined by number of cables, substations and turbines. This would include also the costs of materials and construction. The costs would vary depending on the length of cables and the capacity of the wind turbines, which would create a linear function.

TABLE 1. ENTSO-E DEFINED ASSESSMENT CATEGORIES

Benefits	**Residual impact**	**Costs**
Socio-economic welfare (including impact on RES integration and avoided CO_2 emissions)	Environmental	Total project expenditures
Reduction in grid electricity losses	Social	
Security of Supply	Other	

OPEX for a wind park are relatively low compared to fossil energy sources, for which around 40–70 % of costs are related to fuel as well as operation and maintenance during the whole life cycle [9].

2.2. Multi-Criteria Analysis

Multi-criteria analysis (MCA) is a widely known research method, which has various techniques and ways of application, but in general it uses several objectives and criteria to solve decision-making problems [10]. MCA is a well appreciated instrument in the decision-making process regarding transition of energy policy. MCA is continuously chosen as a good tool for energy policy as it can cover different relevant actors and criteria [11].

In order to apply MCA analysis, it is necessary to develop criteria and set their corresponding importance. The criteria in this study will be ranked by Analytic hierarchy process (AHP) providing specific score for each criteria, showing the importance of the criteria in comparison to other criteria (1 – equally important, 9 – much more important than other criteria) [12]. After that, the evaluation of the case study projects will be made by using Technique for Oder Preference by Similarity to Ideal Solutions (TOPSIS) method. The concept of TOPSIS is that the best alternative is the one which is closer to the ideal solution and the farthest away from the worst solution. Thus, when the best and worst values for criteria are defined, alternative with the highest value will be the best one [13], [14].

Both CBA and MCA are applied to the case study in order to evaluate the potential of developing wind parks in Latvia from different perspectives. Both analysis complements each other.

3. CASE STUDY

3.1. Energy and Climate Policy of Latvia

The share of renewable energy sources (RES) utilized in Latvia is rather high, in accordance with the data of 2017, when RES in final consumption was 39.01 %. This is mostly due to the hydroelectric power plants, which produce most of the electricity produced in Latvia, as well as the high usage of biomass for the fuel considering Latvia's advantage of highly afforested lands [15]. Meanwhile, the National Energy and Climate Plan (NECP) provides a target that the RES share should be 50 % by 2030. Moreover, NECP also stipulate that by 2030, there should be installed 800 MW capacity wind parks offshore and 800 MW capacity wind parks onshore [16]. It's important to mention that currently there are no offshore wind parks in Latvia and rather few onshore wind parks, mostly small scale that are connected to the distribution grid (70 wind parks with the total generation capacity of 51 MW are connected to the distribution grid, showing that the average capacity of a wind park is far below 1 MW) [17]. The current total wind energy capacity in Latvia is 78 MW, which include the above mentioned small wind parks, wind micro-generators (i.e. generators that have capacity of up to 11.1 kW) and wind parks that are connected to the transmission system operator's grid. Thus, large scale wind parks have a very underdeveloped sector in Latvia. The reasoning for that is partly because there are no state grants or feed-in tariff possibilities as the state's position is that the electricity producers have to compete on market-based rules.

At the same time, taking into account the RES targets, Latvian and Estonian government in collaboration are working on a common offshore wind park 'ELWIND' with the total capacity of about 1000 MW (to be determined during the feasibility studies). In September 2020 both governments signed a memorandum of understanding and have begun active work on the project that could be ready by 2030 [18].

3.2. Administrative Procedures for Developing Wind Park in Latvia

The Law on Environmental Impact Assessment prescribes in which cases an environmental impact assessment is necessary. In case of wind parks, an environmental impact assessment is necessary for the construction of the wind parks if there are 15 turbines or more, or if the total generation capacity of the wind park is 15 MW. The initial environmental impact assessment is necessary for the construction of a wind park if there are 5 turbines or more, or if the total generation capacity is 5 MW or more. If the initial assessment ends with a decision that the full impact assessment is not necessary, the electricity producer receives just the technical rules for implementing the powerplant. If the initial assessment prescribes the full environmental assessment, it must be done by the project promoter and the final document is evaluated by the government institution, which will issue an approval decision. While the initial assessment is made by the government institution and takes only 20 days, the full impact assessment is a much longer procedure with specific program and public consultations that will take at least 10 months [19].

For any electricity generation plant (above 11.1 kW) to be allowed to operator in Latvia, the potential electricity producer has to receive a permit from the Ministry of Economics of Latvia in accordance with Rules of the Cabinet of Ministers No.559 (adopted 2 September 2020) 'Regulations Regarding Permits for Increasing Electricity Production Capacities or the Introduction of New Electricity Production Equipment'. If the electricity generation installation is above 1 MW, the potential electricity producer has to provide:

- Fulfilled application indicating the legal information of the entrepreneur and the basic data of the power plant – type of power plans, generation capacity, location and point of connection to grid;
- Detailed description with technical data of the power plant;
- Blueprint of the power plant;
- Ownership documentation for the property;
- Technical rules for implementation of the power plant in accordance with environmental guidelines (if the technical rules in the specific case have been deemed necessary according to the legal acts in the field of environment);
- Approval decision after the environmental impact assessment (if the assessment in the specific case has been deemed necessary according to the legal acts in the field of environment);
- Caution money (178 EUR for a power plant up to 1.99 MW capacity, 267 EUR for a power plant up to 2.99 MW capacity, 356 EUR for a power plant up to 3.99 MW capacity and 50 EUR more for each MW above 4 MW capacity).

The Ministry of Economics of Latvia provides a permit within one months and defines several rules for the power plant – it has to begin construction of the power plant within 6 months (submission of the construction permit is enough, actual construction works are not a prerequisite) and it has to finish the construction works within 5 years. Otherwise the permit will be cancelled [20].

It is important to stress that there is a very different additional procedure for construction in the sea, where a license from the government is necessary in accordance with the Rules of Cabinet of Ministers No. 631 (adopted 14 October 2014) 'Construction Regulations for Structures in the Internal Waters, Territorial Waters and Exclusive Economic Zone of the Republic of Latvia'. This procedure may take at least 6 months [21].

After receiving the permit from the Ministry of Economics, the potential electricity producer must turn to the system operator to receive technical rules for building the electricity connection between the power plant and the system operator's grid. The distribution system operator can connect to the grid power plants with the generation capacity of up to 10 MW. Above this threshold, it is usually a connection to the transmission system operator's grid [22]. For a wind park to receive an authorization from the transmission system operator for a grid connection, the potential electricity producers have to comply with the Commission's Regulation (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators [23]. Decision No. 1/6 (adopted 22 February 2012) of the Board of the Public Utilities Commission 'Regulation Regarding System Connection for Electricity Producers' define prerequisites for a system connection and the methodology for the calculation of a connection fee for electricity producers. The system operator will provide technical rules within 60 days. The electricity producer is then responsible for designing the connection in accordance with those rules, but the system operator is responsible for the construction of the connection (the electricity producer pays for that) [22].

As defined in Rules of Cabinet of Ministers No. 500 (adopted 19 August 2014), 'General Construction Rules', a power plant with generation capacity above 20 kW is considered a third group engineering construction [24]. Meanwhile, the Rules of Cabinet of Ministers No.573 (adopted 30 September 2014) 'Construction Rules for electricity generation, transmission and distribution facilities' defines the documentation that has to be submitted for obtaining the building permit. The building permit is issued within one month [25]. The cost of a construction permit for engineering construction for legal entities is 51.22 euro. The construction permit is valid for five years for construction that had qualified for environmental impact assessment and 8 years if the environmental impact assessment was not needed. The cost of prolonging a construction permit for legal entities is 21.32 euro.

It can be summarized that the administrative state fees do not put any dramatic burden on the potential electricity producer, but all the administrative procedures take time and depending on the location of the wind park (onshore/offshore), all the process staring from the environmental impact assessment and ending with the construction permit can take from about 1 year up to 2.5 years.

3.3. Scenarios for Case Study

In order to evaluate a wind park's real potential, it is important to look at specific wind park projects, which could provide both estimate financial costs as well as the feasibility of the project from the technical, administrative and environmental perspectives. To have a broader view it is important to evaluate projects of different scope. Thus, this research focuses on wind parks of two different sizes and different locations (onshore and offshore):

- Wind park with the generation capacity of 100 MW, located onshore in the western part of Latvia (in the region of Kurzeme);
- Wind park with the generation capacity of 500 MW, located offshore in the territorial sea of Latvia (in the Gulf of Riga).

In both case scenarios the life span of the wind park technologies is 20 years. Though different generation capacities make the comparison between the scenarios impossible, it is important to stress that the aim of the research is not to choose one of the two scenarios as the best option, but to evaluate these 2 scenarios as different possibilities for Latvia. The generation capacities assumed by the authors are based on the practical experience on the real-life wind park projects that have been developed or are in planning stage in Latvia.

3.4. Wind and Electricity Grid Potential in Latvia

The wind speed not only differs depending on the region, but also depending on the height. Latvian researchers have gathered average wind speed statistics for the height of 10 meters, 50 meters and 100 meters [26]. European Commissions Joint Research Center has distinguished between small wind turbines with the height of 35 m (250 kW generation capacity) and larger wind turbines with the height of 80 m (3 MW generation capacity) [27]. Considering that in both case studies the generation capacities are 100 MW or more, they would use large wind turbines. In the last years the technologies become more and more advanced and the average height of the turbines is increasing above 100 meters. In this research we would assume that the wind turbine would be about 100 meters high, thus the relevant wind speed would also be for the height of 100 meters, which has been showed in Fig. 1.

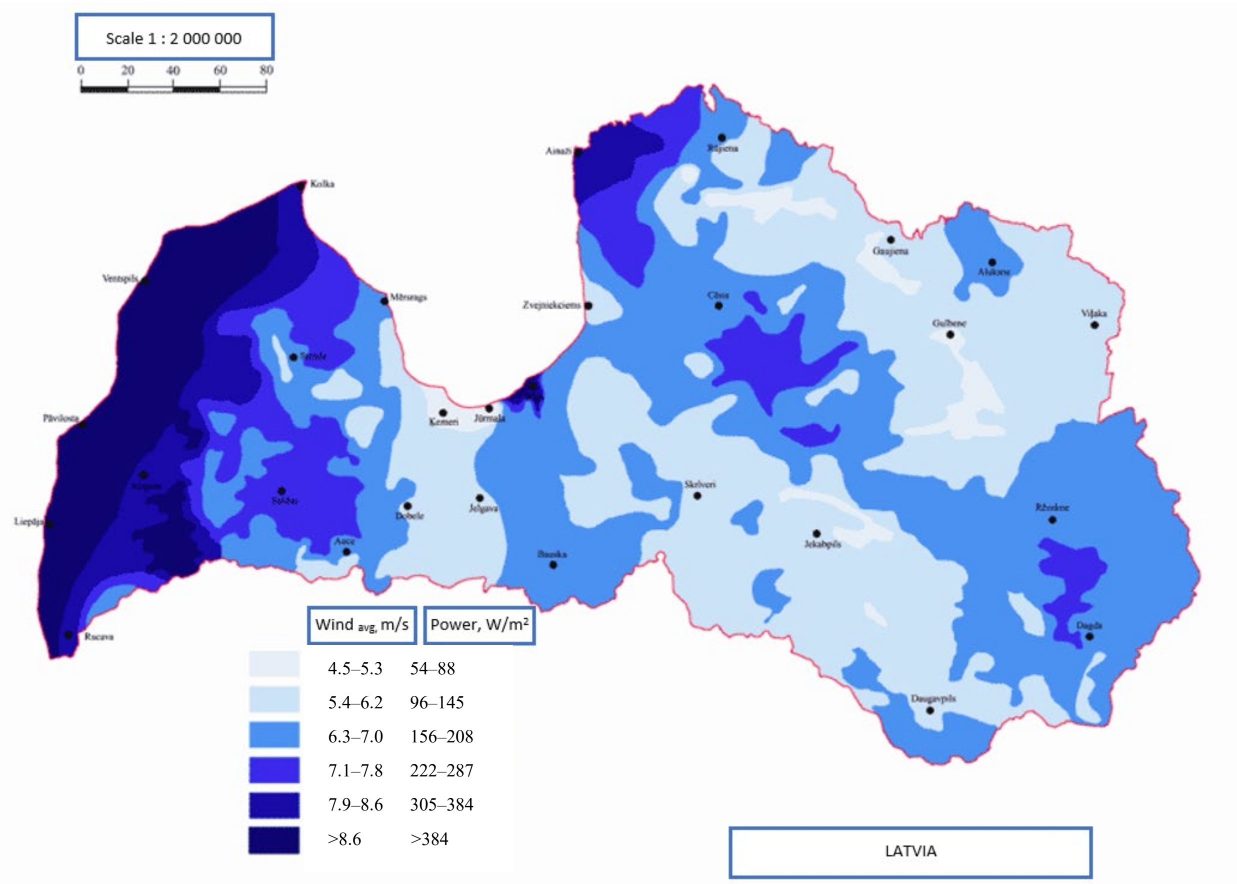


Fig. 1. Average wind speed in Latvia at the height of 100 meters [26].

It is important to stress that not only the wind power is different in different regions of Latvia, but also the electricity grid capacity and the possibilities of the electricity system operator to connect new wind parks to the grid. Considering the generation capacity in both case study scenarios, it can be assumed that both wind parks would be connected to the transmission system operator's grid. As was mentioned in subchapter 3.2., the potential energy producer shall receive technical rules from the system operator, which will define what are the technical solutions that shall be implemented in order for the system operator to be able to connect the new wind park to the grid. Thus, depending on the location of the new wind park, the grid requirements will differ.

As can be seen in Fig. 2, the grid is most developed in the region Kurzeme with the recently finished 'Kurzeme ring' project providing 800 MW grid capacity, however, here the capacity is also the most demanded, thus the grid capability is not unlimited and for large new generation capacities, the grid would have to be improved. Meanwhile, the grid is rather flexible in the Latgale region, where there is less demand for new generation capacities to be connected to the grid [28].

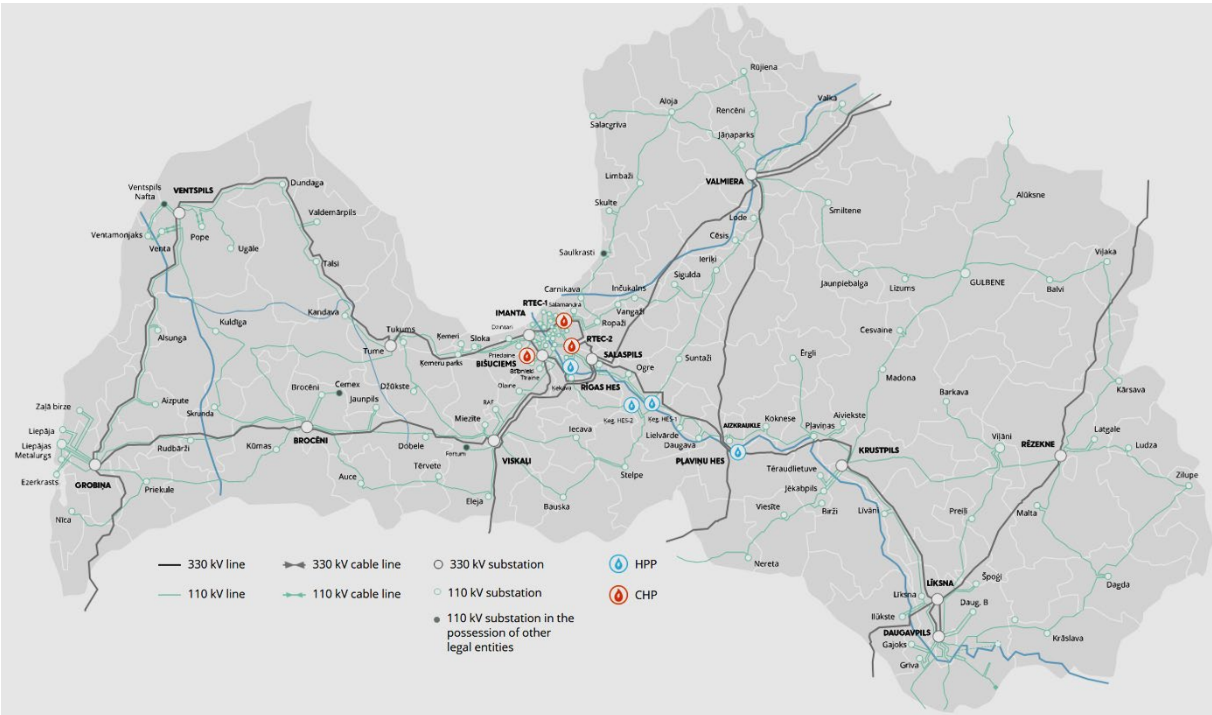


Fig. 2. Latvian transmission network [28].

As regards the sea, it has been researched that the Baltic seas common wind energy capacity could be more than 93 and the Baltic Sea has a potential to locate 187 wind parks with each capacity of 500 MW (which is also the capacity that was assumed for the offshore wind park case scenario). Furthermore, if narrowed down to the potential of Latvia in the Baltic sea – Latvian territorial sea could contain 29 wind parks with the total capacity of 15.5 GW, that could produce 49.2 TWh per year [16].

4. Results

4.1. Cost-Benefit Analysis of the Case Study

As has been calculated by the International Renewable Energy Agency (IRENA), the breakdown of the share of costs for a typical onshore wind park can be seen in Fig. 3.

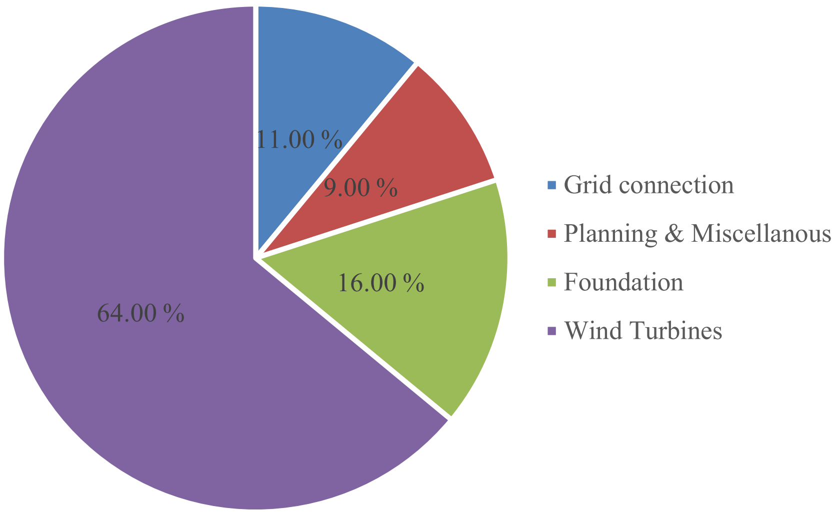


Fig. 3. Breakdown of costs for an onshore wind park in 2012 [7].

The costs of wind turbines include the costs of generator, transformer, power converters, gearbox, rotor blades, tower and other additional costs. However, in the last decade the costs of the wind turbine have largely decreased. The tables have changed now and according to the newest IRENA report on renewable power generation costs in 2019, average onshore wind turbine costs would be 580 000 EUR/MW. The rest of the costs (grid connection, planning, foundation construction) on average comprise around 649 000 EUR/MW [29], so the additional costs now are higher than the wind turbine costs. Operational and maintenance costs for onshore projects on average in Europe are 37 000 EUR/MW/year, which also includes the labour force.

Offshore wind projects cost more. The average total costs of wind park are 3 171 000 EUR/MW, where offshore turbines take about 50 % of these total costs and the other 50 % are for the grid connection and other additional costs would make around 80 000 EUR/MW/year.

TABLE 2. COSTS AND BENEFITS OF THE WIND PARK CASE STUDIES

Costs and benefits		**Wind park A**	**Wind park B**
1	Wind turbine costs (total EUR)	−58 000 000	−792 970 000
2	Grid connection and other costs (total EUR)	−64 900 000	−792 970 000
3	Operation and maintenance costs (total EUR in 20 years, 2 % OPEX growth, 8 % discount rate)	−37 352 254	−403 634 155
5	Revenues from electricity sales (using average NordPool power exchange price for Latvian area in February 2021–59.15 EUR/MWh, 8 % discount rate for output)	+163 599 233	+1 067 939 438
	Total	+3 308 091	−921 634 717

If we calculate the costs and benefits from the project promoters point of view regarding the financial perspective, it can be seen that the onshore wind park can be beneficial if the produced electricity is sold by the current average electricity exchange price. These results were calculated by taking into account the possible OPEX growth (2 % annually) as well as the discount rate and the interlinked net present value of the costs and net present value of the electricity output. The results also provide that offshore wind park is currently not rentable. For clearer understanding of the circumstances, when the offshore wind park would be rentable, the authors calculated the levelized cost of electricity (LCOE), which is the selling price of electricity that is required so that the projects revenues would at least equal the costs. LCOE was calculated by using the total project costs (over the 20-year lifetime, including OPEX with 2 % annual growth rate), capacity factor, 20-year lifetime, the respective electricity output in 20 years and the cost of capital (assumed discount rate 8 %). For onshore project the LCOE value was 57.9 EUR/MWh, which is rather close to the current actual market value of the electricity. At the same time, the offshore project's LCOE was 110.17 EUR/MWh, almost double the market price. Thus, without project grants or feed-in tariffs, the authors of the research don't see, how such a project could be introduced.

If we look as social welfare part of cost-benefit analysis, it could be argued that the benefits outweigh the costs. For both of the case studies, we can see several benefits:

- Increased security of supply due to the decrease of imports. In February 2021, Latvia had a net import of 40 831 MWh. The onshore wind park could produce for Latvian market 25 920 MWh/month, so it could reduce this net import by more than a half (if the electricity is sold for the national market). The offshore wind park could produce 169 200 MWh/month fully covering the deficit of electricity in Latvia.
- Reduction in CO_2 emissions – introduction of wind parks reduces the carbon footprint on average be 600 g/kWh [30]. Thus, the onshore wind park could reduce the CO_2 emissions by 15 552 tons/month, while the offshore wind park could even reduce the CO_2 emissions by 101 520 tons/month.
- A step towards achieving the targets set in NECP of 800 MW onshore and offshore. The offshore target would easily achievable by 2 large scale wind parks.
- Increased employment – different research studies suggest that on average around 5 jobs per wind energy MW are created in the world [31]. Of course, this does not mean so many employees in Latvia on the specific wind park, but that is the number of workers, who would be employed to develop designs, come up with engineering solutions, produce wind park's turbines and all other parts, as well as this includes the workers that are necessary to maintain the wind park. So, the onshore project could provide work for 100 people around Europe (or around the world, depending on the country that produces parts for the wind park) and the offshore park could provide even 500 jobs. If we look locally, the onshore park would provide around 2 work places, while the offshore park would need around 5 employees.

The costs of the social welfare are harder to express in numbers. These costs are mostly comprised of the complaints about the aesthetic view in the environment, threat to health. Different researches show that there is not threat to human health (besides there is a security protection zone set by the law defining the necessary construction distance from houses and other objects). Thus, from the social welfare point of view, if we consider the previously explained Kaldor-Hicks method, the benefits outweigh the costs.

4.2. Multi-Criteria Analysis of the Case Study

In this case study, the MCA is done to compare an offshore and onshore wind park. In order to be able to compare wind parks of different sizes, the levelized costs per 1 MW are used.

The chosen input data (criteria) for the wind park are defined in Table 1.As there has been a research showing that increased wind energy share does not necessarily mean that there will be decrease in electricity prices [32], impact on electricity price was not considered as a criteria for MCA. Meanwhile, the previously calculated LCOE is included between the criteria. The capacity factor shows the energy output from a wind park per year as a share of wind parks maximum possible output that is influenced by the wind speed and the used technologies. By applying AHP method, the criteria received specific weight.

TABLE 3. MCA INPUT DATA

Criteria		Weight	Wind park A	Wind park B
C1	All investment costs, EUR/MW	15 %	1 229 000	3 171 000
C2	Operation and maintenance costs, EUR/MW/year	13 %	37 000	80 000
C3	Administrative burden, months	5 %	12	24
C4	Job creations, number of workers	6 %	2	5
C5	Capacity factor %	25 %	36	47
C6	Import reduction, %	8 %		
C7	LCOE, EUR/MWh	28 %	57.9	110.17

The input data was normalized by dividing criteria value by the sum of criteria value. Table 4 shows the results of the MCA.

TABLE 4. MCA RESULTS

Criteria	Wind park A	Wind park B	Best values
C1 All investment costs, EUR/MW	+0.042	−0.108	Min
C2 Operation and maintenance costs, EUR/MW/year	+0.041	−0.089	Min
C3 Administrative burden, months	+0.017	−0.033	Min
C4 Job creations, number of workers	−0.017	+0.043	Max
C5 Capacity factor %	−0.108	+0.142	Max
C6 Import reduction, %	−0.027	+0.053	Max
C7 LCOE, EUR/MWh	+0.096	−0.184	Min
Total	−0.149	−0.176	

Criteria with the positive factor were added to the criteria with the negative factor (the positive or negative notion was set based on the best value indication column). The results of the MCA provide that in comparison between the two scenarios, some of the criteria have played a big role in determining that the best case study would be the onshore wind park. In general, the offshore wind park is not an optimal solution both due to the initial capital costs and the related LCOE value.

5. Conclusions

While cost benefit analysis on its own serves as a tool to understand if any of the wind park case study scenarios are feasible from financial and other perspectives, the multi criteria analysis provide a comparison between the two suggested case study projects.

Both of the analysis provided rather similar results, showing that an offshore wind park in the sea is currently not a good business case if there is no state (or EU) support in the form of financial grants or energy policy changes regarding a feed-in tariff for renewable energy. For current situation it is understandable that the only project under real consideration for offshore is the common Estonian-Latvian wind park project that will be able to qualify for the EU grant from Connecting Europe Facility. Other support mechanisms should be further researched that could be applied to private project promoters. At the same time, the research clearly showed a good potential for onshore wind energy development that would not need state support and could operate on market-based principles with a competitive electricity price to provide.

Any large-scale wind park project would effectively contribute to the security of energy supply aspect if the wind energy was not exported but sold locally, which would reduce the imports significantly. At the same time, wind parks cannot provide specific base capacity due to its' volatile nature.

It could be argued that the administrative procedure for introducing a wind park, especially an offshore wind park, is complicated, takes a lot of time and should be improved so that the new electricity producers would see support from the state at least in the terms of administrative procedures. Meanwhile, the administrative costs in comparison are minimal considering the project costs that circle around several million euros, thus there is no real need to lower the fees and levies from the state side.

In order to fulfil the targets of NECP, it is planned to introduce additional 800 MW of onshore and offshore wind capacity. To be able to do that, it's also important to develop the electricity grid. Both onshore and offshore project promoters are interested in connecting their wind parks to the transmission grid and mostly in the western part of Latvia (due to the wind speed), the respective electricity grid has to have enough capacity to do that. The necessary grid improvement works should be done as soon as possible.

References

[1] Eurostat. Grenhouse gas emission statistics – air emissions accounts, 2021. [Online]. [Accessed 01.04.2021]. Available: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Greenhouse_gas_emission_statistics_-_air_emissions_accounts&oldid=549000

[2] 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* 2017:15(4)133–142. https://doi.org/10.1016/j.jsm.2017.02.001

[3] Intrac. *Cost-benefit analysis*. Oxford: Intrac, 2017.

[4] Avdic Belltheus D.m Stahl P. Cost-Benefit Analysis of an integrated offshore grid in the Baltic sea. Berlin: Baltic InteGrid, 2019.

[5] De Rus G. Introduction to Cost-Benefit Analysis: Looking for Reasonable Shortcuts. Cheltenham: Edward Elgar, 2021.

[6] Mouter N. Cost-Benefit Analysis in Practice. Thesis. Delft: Delft University of Technology, 2014.

[7] IRENA. Renewable Energy Technologies: Cost Analysis series. Wind Power. Abu Dhabi: IRENA, 2012:1(5/5).

[8] ENTSO-E. Guideline for Cost Benefit Analysis of Grid Development Projects. Brussels: ENTSO-E, 2016.

[9] Wind Europe. Wind energy is the cheapest source of electricity generation, 2019 [Online]. [Accessed 20.03.2021]. Available: https://windeurope.org/policy/topics/economics/

[10] Dean M. Chapter Six – Multi-criteria analysis. *Advances in Transport Policy and Planning* 2020:6:165–224. https://doi.org/10.1016/bs.atpp.2020.07.001

[11] Uroševic B. G., Marinovič B. Ranking construction of small hydro power plants using multi-criteria decision analysis. *Renewable Energy* 2021:172:1174–1183. https://doi.org/10.1016/j.renene.2021.03.115
[12] Vamza I., Valters K., Blumberga D. Multi-Criteria Analysis of Lignocellulose Substrate Pre-Treatment. *Environmental and Climate Technologies* 2020:24(3):483–492. https://doi.org/10.2478/rtuect-2020-0118
[13] Zlaugotne B., *et al.* GHG Performance Evaluation in Green Deal Context. *Environmental and Climate Technologies* 2020:24(1):431–441. https://doi.org/10.2478/rtuect-2020-0026
[14] Zlaugotne B., *et al.* Multi-Criteria Decision Analysis Methods Comparison. *Environmental and Climate Technologies* 2020:24(1):454–471. https://doi.org/10.2478/rtuect-2020-0028
[15] Kudurs E., *et al.* Are Industries Open for Renewable Energy? *Environmental and Climate Technologies* 2020:24(3):447–456. https://doi.org/10.2478/rtuect-2020-0115
[16] Ministry of Economics of Latvia. Nacionālais Enerģētikas un Klimata Plāns (National Energy and Climate Plan) [Online]. [Accessed 04.04.2021]. Available: https://www.em.gov.lv/lv/nacionalais-energetikas-un-klimata-plans (in Latvian)
[17] Ministry of Economics of Latvia. Elektroenerģijas Ražošana (Electricity generation) [Online]. [Accessed 15.03.2021]. Available: https://www.em.gov.lv/lv/elektroenergijas-razosana (in Latvian)
[18] Latvijas Vestnesis. Parakstīts Saprašanās memorands par Igaunijas un Latvijas vēja parka projektu (A Memorandum of Understanding has been signed on the Estonian and Latvian offshore wind farm project) [Online]. [Accessed 15.03.2021]. Available : https://lvportals.lv/dienaskartiba/320014-parakstits-saprasanas-memorands-par-igaunijas-un-latvijas-atkrastes-veja-parka-projektu-2020 (in Latvian)
[19] Vides eksperti. Ietekmes uz vidi novērtējums (Environmental Impact Assessment) [Online]. [Accessed 10.04.2021]. Available: https://videseksperti.lv/ietekmes-uz-vidi-novertejums-2 (in Latvian)
[20] Cabinet of Ministers Republic of Latvia. Regulations Regarding Permits for Increasing Electricity Production Capacities or the Introduction of New Production Equipment. *Latvijas Vestnesis* 2020:175.
[21] Cabinet of Ministers Republic of Latvia. Construction Regulations for Structures in the Internal Waters, Territorial Waters and Exclusive Economic Zone of the Republic of Latvia. *Latvijas Vestnesis* 2014:211.
[22] Sadales tīkls. Elektrostacijas pieslēgums (Power plant connection) [Online]. [Accessed 30.03.2021]. Available: https://sadalestikls.lv/lv/elektrostacijas-pieslegsana (in Latvian)
[23] Augstsprieguma tīkls. Connections to the transmission grid [Online]. [Accessed 01.04.2021]. Available: https://www.ast.lv/en/content/connections-transmission-grid
[24] Cabinet of Ministers Republic of Latvia. General Construction Regulations. *Latvijas Vestnesis* 2014:191.
[25] Cabinet of Ministers Republic of Latvia. Elektroenerģijas ražošanas, pārvades un sadales būvju būvnoteikumi (Building regulations for electricity generation, transmission and distribution facilities.). *Latvijas Vestnesis* 2014:194. (in Latvian)
[26] WindEnergy. Vēja ātrums 100 metru augstumā (The Speed of Wind at a Height of 100 Metres) [Online]. [Accessed 01.04.2021]. Available: http://www.windenergy.lv/map/en/veja-atrums-100-metru-augstuma/
[27] Dalla Longa F., *et al.* Wind potentials for EU and neighbouring countries. Luxembourg: Publications Office of the European Union, 2018. https://doi.org/10.2760/041705
[28] Augstsprieguma tīkls. Transmission network and substations [Online]. [Accessed 18.03.2021]. Available: https://www.ast.lv/en/transmission-network-info/transmission-network-and-substations
[29] IRENA. Renewable power generation costs in 2019. Abu Dhabi: IRENA, 2020.
[30] Hernandez C. V., Gonzalez J. S., Fernandez-Blanco R. New mothod to assess the long-term role of wind energy in reduction of CO_2 emissions – Case study of the European Union. *Journal of Cleaner Production* 2019:207:1099–1111. https://doi.org/10.1016/j.jclepro.2018.09.249
[31] Aldieri L., *et al.* Wind Power and Job Creation. *Sustainability* 2019:12(1):45. https://doi.org/10.3390/su12010045
[32] Valdmanis G., Bazbauers G. Influence of wind power production on electricity market price. *Environmental and Climate Technologies* 2020:24(1):472–482. Https://doi.org/10.2478/rtuect-2020-0029

Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 147 (2018) 600–606

Energy Procedia

www.elsevier.com/locate/procedia

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

Accelerating power generation with solar panels. Case in Latvia

Liga Rozentale*, Dace Lauka, Dagnija Blumberga

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

Abstract

The main aim of the research is to determine the conditions under which it would be possible to increasingly cover as much electricity demand of Latvia as possible by the electricity generated by solar panels. A *Microsoft Excel* model was developed with an assumption that it would be efficient to install solar panels if the investments returned in a five-year period or sooner. A restriction was set that only household users with solar panels would be taken into account. The model included data from 15 case studies. Based on the collected data, the average monthly electricity bill was calculated before and after installing the solar panels and subsequently the return of investments period in years was calculated. Several model's positions were variated – the solar panels' efficiency rate, the price of the solar panels, etc. – to find out which combination of changes would result in a five-year return of investments period.

Selection and peer-review under responsibility of the scientific committee of the International Scientific Conference 'Environmental and Climate Technologies', CONECT 2018.

Keywords: photovoltaics; solar panels; electricity generation; return of investments; support schemes

1. Introduction

With increasing exhaustion of natural resources, one of the main priorities in the world and in the European Union has become increased usage of renewable energy. In 2007 the EU's leaders agreed on three EU climate and energy targets for 2020, which meant to cut greenhouse gas emission by 20 % (in comparison to 1990), to produce 20 % of energy from renewable energy sources and to improve energy efficiency by 20 % [1]. The first

* Corresponding author.
E-mail address: liga.rozentale@em.gov.lv

Selection and peer-review under responsibility of the scientific committee of the International Scientific Conference 'Environmental and Climate Technologies', CONECT 2018.
10.1016/j.egypro.2018.07.077

two targets have vastly promoted the industry for renewable energy technologies. Europe is constantly moving towards the target and in 2016 about 90 % of all new power added to the Europe's electricity grid came from renewable energy sources [2]. At the same time, most of energy in Europe is still produced by non-renewable energy sources, thus any solutions to minimize that are a priority.

Solar energy, among other forms of renewable energy sources, is promising and freely available, which in the long term period could manage the energy crisis. The solar industry is constantly evolving around the world as there is a high demand for energy, but the main source of energy – fossil fuels – is limited and other sources are expensive [3].

The range for annual effective solar irradiance is between 60 and 250 Wm^{-2}, which depends from the location in the world, but there are several factors that influence the amount of solar irradiance that arrives through the atmosphere of Earth. As regards solar technologies, there are two types of solar energy technologies – passive and active. Passive technology means that the solar energy, which is accumulated, is not transformed from thermal or light energy in to a different form. For example, the collection of solar energy, the storage of it and then distribution as the heat for houses during winter is a passive solar technology form. Meanwhile, active technologies accumulate the solar radiation and by using such mechanical and electrical equipment as pumps or fans, converts the solar energy into heat or electric power. The active solar energy technologies are also distinguished into two categories – photovoltaic (PV) technologies and solar thermal technologies. In the renewable energy sector PV technologies with semiconductors that convert the solar energy in to electrical energy have become very well recognized over time and have a high potential in the market. Considering the above mentioned, as well as the large investments that are now involved in the PV sector, the PV market is very competitive, especially in such regions as Europe, China and the Unites states [3–8].

While in general the renewable energy sector in Latvia is currently rather advanced, the usage of solar energy in Latvia could be described as underdeveloped. The Central Statistical Bureau of Latvia does not include solar energy in the statistics of national energy mix, because it is less than 0.1 %. The possibilities of the development of solar panel usage and the necessary steps for that have not been thoroughly researched. Considering the above mentioned, the aim of the research is to determine the conditions under which it would be possible to increasingly cover as much electricity demand of Latvia as possible by the electricity generated by solar panels. By understanding the major factors currently restricting the usage of solar panels in Latvia for producing electricity, it will become clear, what should be the necessary actions to resolve that.

2. Methodology of research

It was essential to develop a functional model, which would allow to determine the necessary actions to maximise the usage of solar panels in Latvia. The model first of all included data that forms the electricity bill of a household:

- The electricity tariff. The price for a household user is determined by the electricity seller. As the market is liberalised, the tariffs are not approved by the Public Utilities Commission anymore. The market price is based on the NordPool energy exchange, which is currently the exchange spot for electricity in Europe. The electricity is sold through Nord Pool exchange in the Nordic and Baltic countries, as well as in Germany and the United Kingdom. For the purpose of the research, the average NordPool electricity price in 2017 will be used in the case studies – 0.0348 EUR/kWh. However, it is important to keep in mind that the actual tariffs are higher, based on the different types of tariffs proposed by the electricity seller. At the same time, it is not necessary to use the hourly price of the solar energy, because the research does not look at selling the electricity on the wholesale market by NordPool tariff, but at the gains from feeding the electricity produced from the solar panels, into the grid;
- The distribution tariff. This is the tariff for the service of electricity distribution. Since August 2016, this tariff has been split into two parts:
  - Capacity component – consumer pays a fixed monthly charge for the voltage and technical parameters of the connection,
  - Electricity supply fee – variable cost based on the consumed amount of electricity – 0.04408 EUR/kWh [9];

- The compulsory procurement component (MPC) – support mechanism set by the government for electricity producers that generate electricity at cogeneration plants or from renewable energy sources. The size of the MPC is approved by PUC. Since January 2018, MPC consists of two components:
    - Capacity component – as in the case of distribution tariff, this is the fixed tariff depending from the voltage and technical parameters of the connection,
    - MPC – depends on consumed electricity. The following approved sizes of the MPC are in force now:
        - the component from producers generating electricity in cogeneration: 0.01185 EUR/kWh,
        - the component from producers generating electricity with the use of renewable energy sources: 0.01494 EUR/kWh [10];
- Value-added tax – 21 % tax applied to the final electricity bill.

Table 1 shows the distribution tariff's and MPC tariff's capacity components for the most common types of connections. The difference is based on the connection phases (single-phase or three-phase) and the current of the input protection device (16, 20, 25, 32, 40 A). The values from the table were used in the case studies.

Table 1. Distribution and MPC tariff's capacity (fixed) component.

	1 phase; up to 40 A	3 phases; up to 16 A	3 phases; 20 A	3 phases; 25 A	3 phases; 32 A	3 phases; 40 A
Distribution tariff's capacity component EUR/month	1.24	3.20	4.00	5.00	6.40	8.00
MPC tariff's capacity components EUR/month	1.00	2.59	3.23	4.04	5.17	6.47

To further develop the model, specific data was collected from 15 households across the territory of Latvia. It was important to obtain data from different parts of Latvia to evaluate the amount of solar irradiation and also to make the research reliable, because it shows situation in the whole Latvia. In total respondents were asked to reply to 13 questions regarding their solar panel's system. The electricity output of the solar panels was calculated by Eq. (1):

$$E = A \cdot r \cdot H \cdot PR \tag{1}$$

where

E energy, kWh;
A area of solar panels, m^2;
r efficiency of the solar panels, %;
H hours of annual average solar radiation on tilted panels in the specific geographical location;
PR coefficient for losses (the default value is 0.75) [11].

All the solar panels in case studies were optimally-inclined, so they received the maximum possible solar radiation and based on the regional location of the solar panels, the irradiation was either 1150 kWh/m^2, 1167 kWh/m^2, 1183 kWh/m^2 or 1200 kWh/m^2 [12].

There are currently no government subsidies for households producing electricity from solar energy in Latvia. Households can feed produced electricity in the grid and in return they don't have to pay for that amount of electricity, when taken back from the distribution system (NET payment scheme), however the households do not get any extra bonuses for generating electricity. The model reflects the possibility to add government support (EUR/kWh) for electricity that is fed into the grid.

3. Results

The average efficiency rate for solar panels from case studies was about 16.92 %. The average costs for installing the system were almost 5000 EUR. Based on the collected data (consumption, phases, amps), the average monthly electricity bill was calculated before installing the solar panels. Based on the electricity produced by panels and the amount of electricity fed into the grid and collected from grid, the average monthly electricity bill after installing solar panels was calculated. The difference between the electricity bill before and after installing the solar panels, are the savings per month. The total invested amount of money in the solar panel's system is divided by the yearly savings resulting in return of investments period, which on average was about 13 years.

A deeper research was done for the first case study – a household with a consumption of 293 kWh/month. Before the solar panels were installed, the household paid 35.87 euro per month for electricity (including distribution, MPC, VAT). The household installed solar panels for which they paid 3100 EUR. The solar panel's system with the efficiency of 16.88 % and with the solar irradiation appearing in Liepaja region, was able to produce about 243 kWh/months. As the household did not have any battery for the storage of electricity, around 60 kWh/month were fed into the grid because the electricity was not used at that moment when it was produced. At the same time, the household needed more electricity for its' monthly consumption (for example, during night or cloudy days), so it took around 110 kWh/month from the grid. The distribution tariff and the MPC tariff has to be paid for the whole amount of electricity taken from the system (i.e. 110 kWh), however the electricity price has to be paid only for the NET amount of electricity taken from the system (110 kWh minus 60 kWh result in 50 kWh/month). Thus, in total, when the household installed the solar panels, the new electricity bill came down to 12.63 euro per month. The reduction of the electricity bill, which is almost three times lower, can be better reviewed in Fig. 1.

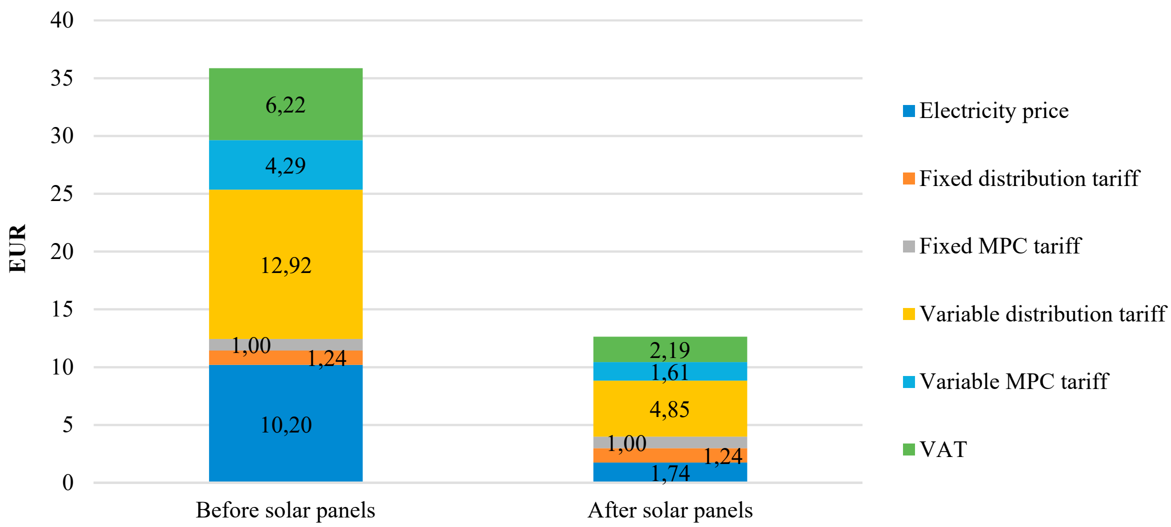


Fig. 1. Monthly electricity bill before and after installation of solar panels (293 kWh consumption).

This could be assumed to be a rather significant reduction in monthly electricity bills. However, the investment of 2850 EUR is not proportionate with the reduction of the bill, because the return of investment period is more than 11 years. As was discussed above, an affordable and proportionate return of investment period should be 5 years, so in this particular case, the return of investment period is more than 2 times higher than it should be.

There are potentially four positions that could be changed that would impact the return of investment period for solar panels:

- Solar panel systems' efficiency (and respectively the output of the solar panel system in kWh);
- The price of the solar panel system;
- The government support;
- The components of the electricity bill – the price of electricity, distribution and MPC tariff, VAT.

The above-mentioned positions were varied in the model to evaluate the changes in average return of investments period for the case studies.

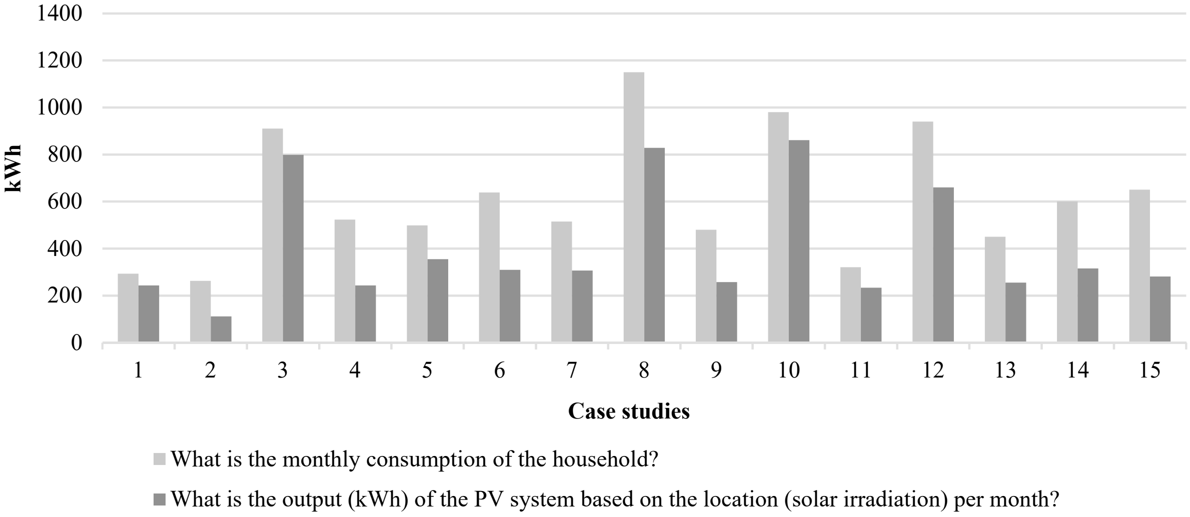


Fig. 2. PV system's monthly output versus household's monthly consumption, kWh.

In Fig. 2 it can be observed that in all 15 cases the monthly consumption of the household is higher than the solar panel's system can produce per month. At the same time, in all 15 cases, the households still feed into the grid some amount of electricity. This is due to the uneven consumption of electricity during different time periods. As those households do not have any electricity storage technologies, the electricity that is produced in day, while the household members are not at home, are fed into the grid.

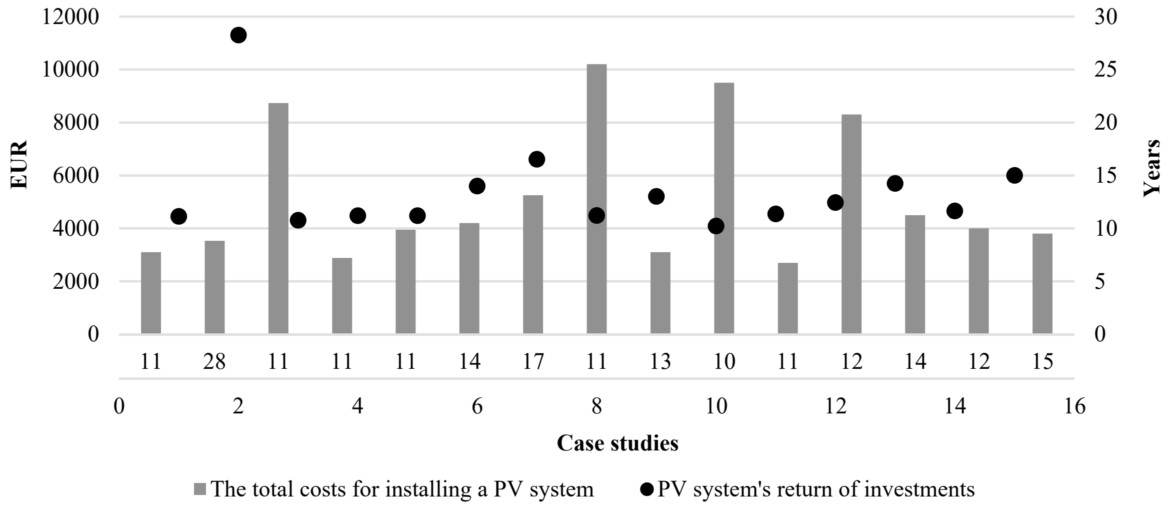


Fig. 3. Total costs for PV system versus the pay-back time.

The left vertical axis in Fig. 3 shows the total investments in solar panels in euro (shown by columns), while the right vertical axis shows the corresponding payback time (shown by dots). It can be observed that the period for return of investment is from 10 to 16 years (except for one extreme case study with a payback time of 28 years) and the cases with the highest investments may have a shorter return of investment period than other cases with lower initial investments, because more expensive solar panels normally are more efficient and thus produce more electricity.

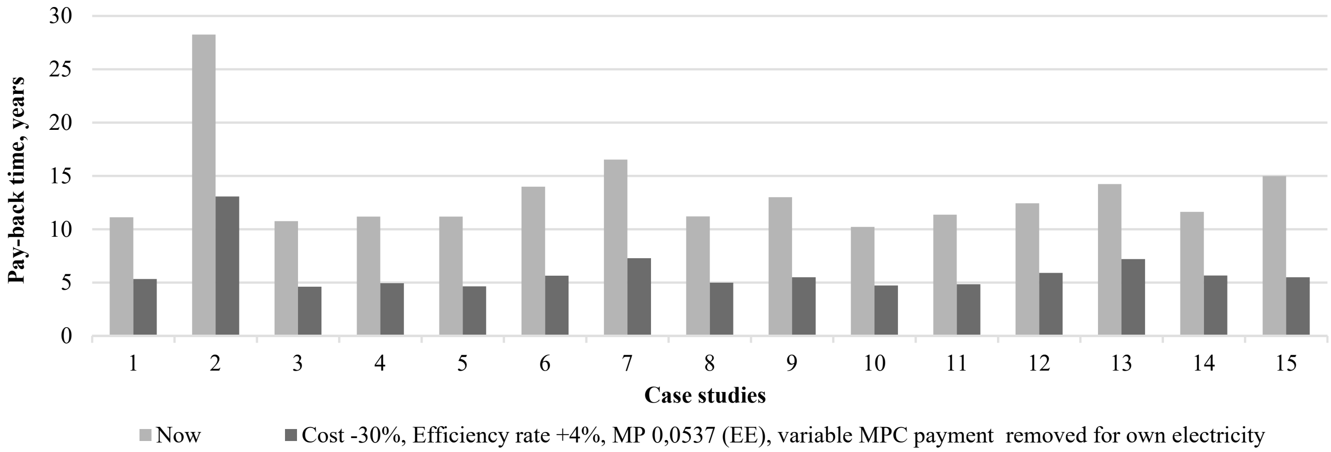


Fig. 4. Return of investment period before and after introducing changes in the costs, efficiency rate and government support for solar panels.

Fig. 4 shows that with several policy incentives, it would technically be possible to achieve a situation, were the solar panels pay back in 5 years. It would be necessary to introduce a combined scheme of lowered solar panel system's costs by 30 %, increased solar panel system's efficiency by 4 % and government's support for introducing a mandatory procurement for solar energy and to remove the mandatory procurement payment for the amount of electricity produced by the household on its own.

The cost reduction and efficiency rate's increase would be a plausible scenario in case of political incentives. More efficient technologies are in the market, but they are not imported in Latvia. It is more profitable for the entrepreneurs to buy cheaper and thus less efficient solar panels from outside Latvia and sell them as expensive solar panels in Latvia. While there should not be product restrictions in a free market, there might be other types of political incentives. For example, there could be introduced a mandatory procurement for electricity produced from solar panels, but only in case if the efficiency of the installed solar panels is over 17 %. This would increase the demand for more efficient solar panels, which would in turn reduce the amount of inefficient solar panels in the market. If the demand for efficient panels would be high enough, it would also bring down the price of the solar panels.

It is essential to stress, that introduction of a mandatory procurement does not mean that it should then become a new mandatory procurement payment from the individual consumers. This payment could be obtained from other government sources, such as from the profit of a state-owned company or from other sources that would need to be further researched.

4. Conclusions

It can be concluded that the economic situation and technological advancement level in the solar energy sector is adequate enough to achieve a situation in which the instalment of solar panels would pay back in 5 years or less. At the same time, political incentives and changes in current legal framework would be necessary to reduce the payback time for solar panels.

There are four factors that influence the return of investment period for solar panels – the solar panel system's efficiency rate, the price of the solar panel system, the government support and the components of the electricity bill. Separate actions, such as the reduction of the price of solar panels or an increased efficiency for solar panels gives only partial effect and would not bring the result of five-year return of investment period. It should be solved in a complex action.

It is also possible to conclude that based not only on the publicly available data on the prices of solar panels, but also on the finding from the model, the price for solar panels in Latvia is at least two times higher than in other European and non-European countries, which is a huge barrier for the households to increasingly install the solar panels. Moreover, the prices for solar panels are not aligned with the efficiency, making the solar panels inadequately over-priced.

References

[1] European Commission. 2020 climate & energy package.
[2] Vaughan A. Renewable energy. Almost 90% of new power in Europe from renewable sources in 2016. The Guardian 2016. Available: https://www.theguardian.com/environment/2017/feb/09/new-energy-europe-renewable-sources-2016
[3] Kannan N, Vakeesan D. Solar energy for future world. A review. Renewable and Sustainable Energy Reviews 2016;62:1092–105.
[4] Kabir E, Kumar P, Kumar S, Adelodun AA, Kim KH. Solar energy: Potential and future prospect. Renewable and Sustainable Energy Reviews 2018;82(1):894–900.
[5] Sun D, Wang L. Research on heat transfer performance of passive solar collector storage wall system with phase change materials. Energy Build 2016;119:183–18.
[6] Herrando M, Markides CN. Hybrid PV and solar-thermal systems for domestic heat and power provision in the UK: techno-economic considerations. Appl Energy 2016;161:512–32.
[7] Mohanty P, Muneer T, Gago EJ, Yash Kotak Y. Solar radiation fundamentals and PV system components. New York: Springer International Publishing; 2015;7–47.
[8] Sampaio PGV, Gonzalez MOA. Photovoltaic solar energy: Conceptual framework. Renewable and Sustainable Energy Reviews 2017;74:590–601.
[9] Regulation of Minister Cabinet No. 73. Par akciju sabiedribas "Sadales tikls" elektroenergijas sadales sistemas pakalpojumu tarifiem. Latvijas Vestnesis 2016;88(5660).
[10] Public Utilities Commission. Par OIK no 2017. gada 1. aprila. Available: https://www.sprk.gov.lv/lapas/par-oik-no-2017gada-1aprila
[11] Photovoltaic software. How to calculate the annual solar energy output of a photovoltaic system? Available: http://photovoltaic-software.com/PV-solar-energy-calculation.php
[12] Huld T, Pinedo-Pascua I. Global irradiation and solar electricity potential: optimally-incline photovoltaic modules. European Commission.

Environmental and Climate Technologies
2020, vol. 24, no. 2, pp. 247–257
https://doi.org/10.2478/rtuect-2020-0070
https://content.sciendo.com

System Dynamics Modelling of Railway Electrification in Latvia

Liga ROZENTALE[1]*, Gjermund Bjørseth MO[2], Armands GRAVELSINS[3], Claudio ROCHAS[4], Jelena PUBULE[5], Dagnija BLUMBERGA[6]

[1, 3–6] *Institute of Energy systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*

[2] *Western Norway University of Applied Sciences, Inndalsveien 28, 5063 Bergen, Norway*

Abstract **– Nowadays the transport sector is one of the most challenging sectors in terms of reducing pollution produced in this sector. It becomes more and more clear that one of the best solutions for mitigating this pollution and the climate change linked to it is the usage of electrified railway. The aim of this article is to evaluate the impact that electrification of the railway will have on the environment from the perspective of pollution. The article shows a system dynamics model, which is based upon factors that affect a newly electrified railway. These include power demand, economics and the environmental impact originating from the railway. This model can be applicable for any country, however in this article Latvia is modelled as an example of how the model works and how the environmental factors will change as a result of an electrification of Latvia' s railway system.**

Keywords **– Climate change; electricity policy; environmental impact; railway electrification; renewable energy sources; system dynamics**

1. INTRODUCTION

The European Commission (EC) has pointed out that mobility of goods is an essential part of the European Union's (EU) internal market and is crucial for the competitiveness of European industry and services. It has a significant impact on economic growth and job creation. In recent years, the annual volume of inland freight transport in the EU (including road, rail and inland waterways) has stabilized at around 2300 billion tonne-kilometres per year, and road transport accounts for about 75 % of this total. [1]

With regard to Latvia, it should be noted that transport and logistics are the second largest sector of the economy, generating more than one billion euros of revenue to the state budget or one eighth of the total state budget and employing up to 70 thousand people directly or indirectly.

Railway transport is one of the most promising modes of land transport, both in safety and in environmental terms. Of the country's total land transport, the share of rail freight is approximately 39 % (as shown in Fig. 1), while passenger transport is 7 %. In the structure of rail freight transport 85 % is transit traffic, mainly from Russia and Belarus to ports in Latvia (East-West transit corridor), inland transport is about 11 % [1].

* Corresponding author.
E-mail address: liga.rozentale@em.gov.lv

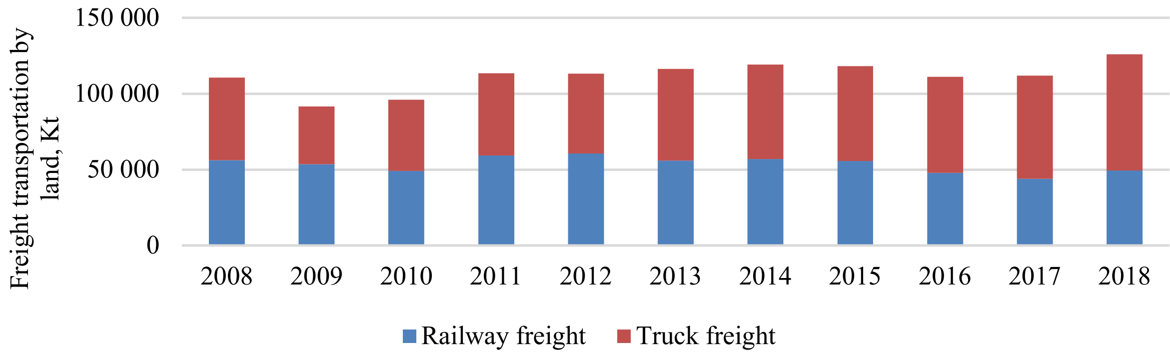


Fig. 1. Freight transportation by land in Latvia [2].

The total length of Latvia's rail network is about 1860 km, of which only about 14 % is electrified (this is substantially lower than the EU average of 55 %). However, at present, electric trains can only be used for passenger transportation, while freight is only carried by diesel trains [3].

The EC has also noted that the transport sector has a negative impact on the environment and the quality of life of EU citizens. The transport sector accounts for about one third of energy consumption and total CO_2 emissions in the EU. Promoting efficient and sustainable transport modes such as rail and inland waterways could help in reducing Europe's dependence on imported oil and reduce pollution [4]. According to the European Environment Agency and as shown in Fig. 2, rail transport produces 3.5 times less CO_2 emissions per tonne-kilometre than road transport [1].

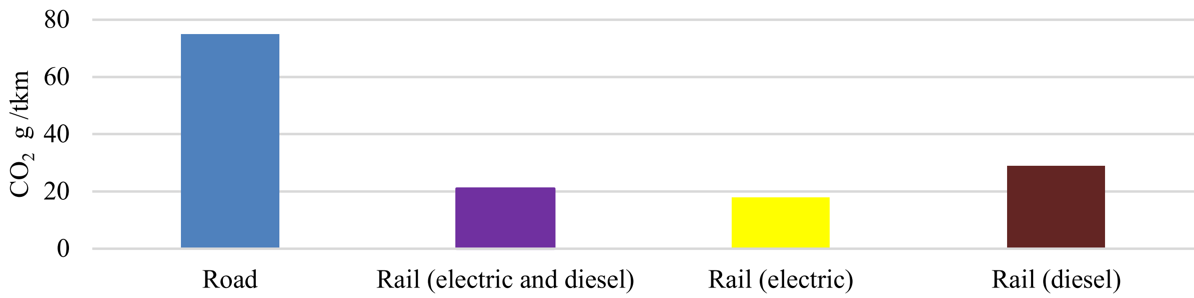


Fig. 2. CO_2 emissions per tonne-kilometre in the EU [4].

However, currently diesel is the main energy source both for truck and railway freight, which is also the main source of emissions (mostly CO_2) in the land transport sector.

The promotion of more efficient and sustainable modes of transport, in particular rail freight, has been an essential element of EU policy for the last 25 years. Already in 1992, the EC set itself the prime objective of achieving a balance between the various modes of transport. In 2001, it reaffirmed the importance of revitalizing the rail sector and set the objective of maintaining rail freight at a 35 % level in the Member States of Central and Eastern Europe by 2010. Finally, in 2011, the EC set a target for 2030 to shift 30 % of road freight transport with a route longer than 300 km to other modes, such as rail or waterways, and by 2050 to shift 50 % [1], [6].

Dependent on the available resources, every country in the regions of Scandinavia and the Baltics are aiming towards the same goal of the EU to decrease the outlet of greenhouse gases

(GHG) with 20 % by 2020 [7] and to reduce CO_2 emissions by 80 % within 2050 [8], as well as to reach the goal of the Paris agreement [7]. This change towards a more sustainable feeding-system for the railway will demand severe resources and cooperation across borders.

There is a reason to believe that the electrification of the railway will have a major positive impact on the economy and a reduction of the emissions originating from the railway. Countries that have implemented electrical railways have generally had an increase in the economy and decrease of emissions coming from the transport sector. It is not only expected to benefit the country at a national level but also in the rural areas, which might experience an increase in tourism and industries. While the developed model is extensive and allows to evaluate railway electrification from different perspectives, including country's economy as a whole, this article focuses on the environment and the main objective of this article is to research how the electrification of the railway will affect the environment from the perspective of pollution.

For system dynamics modelling purposes, the modelling tool Stella Architect has been utilized as this is a great tool for simulations and forecasting of different dynamic scenarios. The authors of the article use this programme to develop a scenario that is appropriate for countries that might want to change the fuel source from fossil to electrical power in regard to the specific country's situation.

2. Methods and Procedures

2.1. Model development

Modelling is defined as an imitation of real-life situation with mathematical equations in order to forecast the future developments of a situation. It is an analytical instrument, which allows to quantify the aspects that may affect the environment. Computer models are often used to forecast the chemical or physical impact of an action on the environment. A model can aid in explaining the environment as a linked system and to research the impact of different environmental components as well as to give forecasts on their behaviour [9]. There are different approaches for modelling, but this particular research is focused on system dynamic modelling, which is an approach to figuring out the nonlinear behaviour of complex systems over time using stocks, flows, internal feedback loops, table functions and time delays [10], [11].

To understand the impact electrification has on the environment as well as the energy supply and production, the model considers the current situation of the electrical supply system and the future development of the system. In the model there are four main factors that must be considered:

- emissions;
- power usage;
- transport opportunities;
- economic influence.

These factors are implemented into the hypotheses. The hypotheses influence each other through the whole simulation period, where the inputs are integrated into the hypotheses before they are further directed into the main model which shows the results.

The model contains a private sector scenario and a government ownership scenario; scenarios can be switched on and off to compare the different results and to understand and compare the benefits of each specific sector, whereby each has its own potential. Each scenario includes the appropriate parameters for the specific scenario. The model also includes such state policies as implementation of railway electrification project and switching from fossil to renewable energy sources.

As the model is built upon several parameters, which can be utilized in any country that considers electrification of the railway, this model is made around a fluent structure, where it is possible to add different scenarios suited for the use of the model. In this model, the main suitable parameters of a private/government owned railway are incorporated to simulate the influence that different scenarios might have on the economy and environment.

In this model the variables influencing the pollution are defined as Pollution units. This covers all the current pollution factors - carbon dioxide CO_2, sulphur dioxide SO_2, nitrogen oxides NO_x, methane CH_4 and particulate matter PM. The reason for these being made in to one unit is to reduce the size of the model and since the overall goal is to be able to observe the pollution from the railway in general these will not affect the model in one way or another.

2.2. Environmental influences

The environmental aspects of the model cover the particulate matter (PM) and greenhouse gases (GHG). The sources for these emissions can be found in both railway and the power generation sector. As these sectors operate in two completely different aspects of industry, they are separated in the model as well - the railway is represented by emissions from Korean locomotives, and the power sector has the emissions originating from power production.

Based on Korean research [12], a diesel-electric locomotive produces 282 g/kWh emissions when idle and as much as 701 g/kWh when at the highest level of performance, N_2O at 0.0181 g/kWh when idle and 0.0107 g/kWh at maximum use, and CH at 0.0394 g/kWh when idle and 0.0103 g/kWh when at maximum use. Dependent on the activity of the motor the emissions rise, when at maximum output the motors in the mentioned Korean research used as much as 2363 kW at notch 8, which is the highest throttle setting for these locomotives.

This means that a diesel-electric locomotive has an hourly demand of 2363 kWh, this results in a maximum hourly carbon dioxide CO_2, methane CH_4 and nitrous oxide N_2O emissions as Eq. (1)–(3).

$$CO_2\left[\text{t h}^{-1}\right] = 701\left[\text{g kWh}^{-1}\right]\cdot 2363\left[\text{kWh}\right] = 1.66\left[\text{t h}^{-1}\right] \tag{1}$$

$$N_2O\left[\text{t h}^{-1}\right] = 0.0107\left[\text{g kWh}^{-1}\right]\cdot 2363\left[\text{kWh}\right] = 25.28\left[\text{g h}^{-1}\right] \tag{2}$$

$$CH_4\left[\text{t h}^{-1}\right] = 0.0103\left[\text{g kWh}^{-1}\right]\cdot 2363\left[\text{kWh}\right] = 24.34\left[\text{g h}^{-1}\right] \tag{3}$$

These are significant amounts of hourly emissions affecting the local and global environment.

PM in the model is a part of the total emissions in the model as it impacts the model at the same rate as the other emissions.

In the current situation, the feeding of the electrical railway is done by both non-renewable energy and renewable energy, which is how the power network is mostly fed throughout Europe.

With most of the electricity coming from non-renewable power sources, the non-renewable energy must be considered in the model as this is an extremely important part of the current electrical feeding system.

2.3. Economical influences

The economical parameters are divided between the private and government sectors. As the electrical railway is believed to be economically sustainable over time for both sectors, the main indicator of when the proposed project can be called a success is when the project has economical surplus. This is however a larger factor in the private sector than in the government one, as the government sector has more funds to operate the railway over time. It is very important to separate the two sectors and to separate what kind of subsidies they are able to incorporate into the budget for the railway.

For the private sector the main obstacle is the ratio between investments and profit from the railway. To get a high profit from the railway, it is crucial to make it visible for the public and the transport firms, as well as it must be a sensible alternative to road transport. To move the transport of goods from road to railway is not easy as road transport is very popular with cheap labour and relatively low fuel cost compared to the cost of operating a freight train. One huge benefit of electrical railway is the implementation of emission quotas, which over time, will limit the fuel resources that are currently used for road transport unless the energy used is renewable. The road transport sector is currently far behind the railway sector in this regard and there are currently no available options for freight companies to use electrical energy as a fuel supply. This has an extensive impact on the model, which can be highly visible towards the end of the simulation.

The emission quotas themselves are one of the most significant parameters for the model as the prices for them are rapidly increasing over time. Since 2014, the price has increased by 265 %, from 6.84 EUR/tCO_2 [13] up to more than 25 EUR/tCO_2 in the beginning of 2020 [14]. The yearly increase for the model is estimated at 5.58 %. This affects the whole model regardless of which sector is run in the model.

Another factor included is the financial stability of the sectors, as the government can take a longer time on the down payment for the railway compared to the private sector which needs annual results that prove the benefits of investment. For both sectors, the goal is to get the railway operations into an economical equilibrium, which will brand it as a success. This is however very difficult to achieve as railway operations require a lot of resources and an even flow of transport. There will be certain delays in the beginning of the railway which will slow the transport down and lead to potential delay in the return of investment from the railway.

Investment costs in the railway will be considered as a negative variable in the model, as this again is used as a measurement for when the railway has reached equilibrium. The initial cost is the same for both scenarios, which in this model is estimated as the cost for a new railway in Latvia.

2.4. Energy influences

The energy supply is very important to be able to reduce the pollution when the railway is finished. This will determine if the investment in the railway has led to improvements to the environment or if the situation is still the same.

The current situation used in the model is that the electrical energy is 50/50 in terms of what source the energy originates in. This means that we can assume that the railway is going to be supplied by electricity from both RES and fossil energy.

In the model there is a separate structure that provides a simulation of the energy sector as well as the railway sector. The model does not include the energy demand for the rest of the country, only the demand relevant for the railway.

3. CASE STUDY

While the model can be used for any country to evaluate and understand the challenges and possibilities provided by an electrified railway, this case study shows the adaptation of the model for Latvia' s transport sector.

The environmental variables for the model are shown in Table 1. These variables give better understanding of how the railway may influence the socio-economic aspects of a country; these variables are then further developed towards the objective of the specific simulation.

The emissions from the locomotives are based on how they are operated throughout the year as the operations may differ from year to year. Thus, the operating time is included as well, as they indicate how the increase of emissions may differ depending on the assignments the railway gets.

The total costs in the railway are a result of wages, taxes and fuel costs. With this and the income from the railway, the total revenue is calculated in the model and the model is structured around these revenues as this is the most important measurement for the interested parties.

One very important aspect of the railway investment is the payback time. As this is a major indicator of the investment success, before and after the project is finished. If it takes too long to make the investment a profitable operation, there will be no desire to invest in it.

The corporate income tax seldom changes over time and is therefore set as a stationary value. The wages on the other hand tend to increase every year by a small percentage. This is also the case in regard to fuel price, as they tend to follow the increase of wages.

Table 1 describes the variables for the revenue. This is an outlay for which variables the economic side of the model needs to run functionally.

The model is built around one structure but have several other sub-models such as pollution sub-model, locomotive change sub-model, economic sub-model, hired workers sub-model and energy sub-model, which all support the main model.

TABLE 1. VARIABLES IN THE MODEL

Environmental variables	Revenue variables	Economic variables	Pollution variables	Hiring variables	Energy variables
Renewable energy sources	Corporate tax rate	Worker salary	Pollution from diesel locomotives	Assumed birth rate	Pollution from fossil-fuel based energy
Non-renewable electrical supply	Wages	Locomotive cost	Pollution from energy sources	Available workers	Change rate from fossil to renewable energy sources
Locomotive power demand	Wage increase	Time to release funding	Pollution from electric locomotives	Retirement rate	
Locomotive emissions	Fuel price	Annual fund use		Wage increase	
Locomotive operating time	Fuel piece increase	Railway funding			
		Investment rate			

There are also economic, pollution, hiring and energy variables in the model that can be mathematically changed based on country specific data which are also summarized in Table 1.

In the Latvia model, there are two policies that produce results from the model. One is the upgrade policy for the railway and the other is the policy demanding a change in electrical power production. The two policies influence but do not depend on each other.

The current policy in accordance with the EU has the target of a carbon neutral energy market by 2050. In the national energy and climate plan of Latvia, the goal is to reach 50 % of total energy from RES within 2030, the current status in Latvia is that the RES is covering 39 %.

According to a study conducted by scientists at the Riga Technical University, the energy demand in Latvia will increase by 1 % each year [15]. This is also considered in the model as this influences the energy sector and policy.

In this model the railway is considered as a part of the energy increase variable as the energy demand from the railway is very dependent on multiple factors that are not included in the model. The energy part of the model also includes an estimate of the energy production over the relevant time span in order to understand how much of the energy is used for the railway and what effect fully electrified railway would have on the energy system in Latvia.

The policy that will change Latvia's railway structure the most is the amount of electrified railway tracks (in kilometres) and not the amount or type of locomotives. However, this research considers the cost of changing the locomotives as well as the time it will take to change them. This is done to get a better understanding of how the new policy will change the railway overall instead of just how many kilometres have been electrified.

As the railway policy depends on the renewable energy policy, the status of this policy is very important to the success for the railway policy. This will show how much pollution has been retracted from the railway sector and the energy demand that the railway needs to reach the policy goals.

The current policy of the railway is to upgrade the railway to an electric one. This is in the first instance for the railway going from Rīga to Krustpils, Krustpils to Daugavpils and Krustpils to Rēzekne. These are the main lines in Latvia's railway and the busiest ones. An electrification of these lines will electrify 308 kilometres of the west-east line. This upgrade will cut the cost for both maintenance and operations of freight transport, increasing the speed to 160 km/h [16]. This will improve the overall economy of the railway as well as reduce the pollution coming from this transport sector.

In the case study of Latvia, the starting point for the model is the year 1990, where there is an assumption on the locomotive stock in the railway as well as an assumption on how long the electrified railway was at that time. To start off, the model has 200 locomotives where the percentage of railway use is determined by the available electrified railway. As described previously, the already electrified railway is at 14 %, which is the starting point. When the policy is implemented in year 2030 (the year in which the new railway electrification project is set to be finished), the amount electrified railway in Latvia will be 30 %.

The model is developed from and explanatory model that highlights the problem model is going to show. The explanatory model in Fig. 3 shows how the emissions affect the emissions over time, adding them to the stock "Pollution from railway".

This variable gives us an indicator of how many locomotives can be changed in order to reach the goal of the policy. With the change rate dependent on the sub-models it will be dynamic towards changes in these models and behave according to the changes done in the testing phase.

Seven different scenarios have been developed for the Latvian case study and are summarized in Table 2.

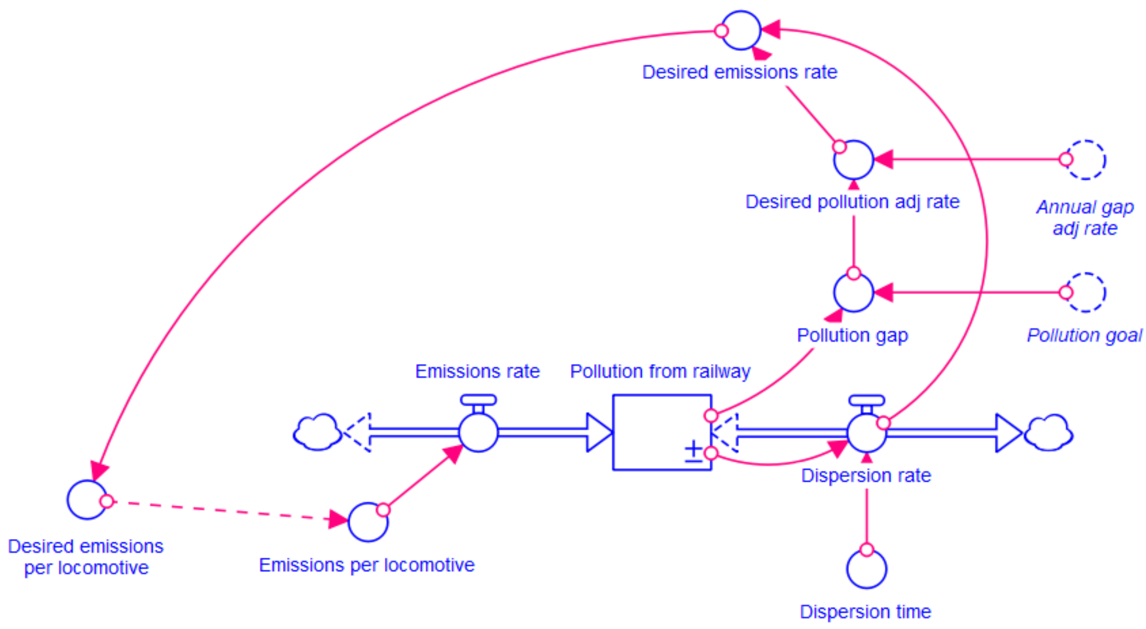


Fig.3. Explanatory model.

TABLE 2. DESCRIPTION OF SCENARIOS UTILIZED IN THE MODEL

Scenario	Main factors	Description of scenarios
1	0 % electrification	Policy switch in the model is turned off (i.e., no policy is implemented), giving the model the same results as before the potential policy is implemented. In this scenario nothing changes, and everything stays the same as it is now, considering that the railway electrification project was cancelled in spring 2020.
2	30 % electrification	The original electrification policy (30 % of the railway is electrified) switch is turned on (i.e., the policy is implemented) with the variables described above.
3	60 % electrification	Electrification of 60 % is introduced, increasing the electric locomotives accordingly. This scenario is run with the desired funding as funding to accommodate the increased need for funding that will occur during the simulation.
4	100 % electrification	The railway is changed to 100 % meaning that the locomotives also will change towards 100 %. The funding is also the desired funding in this scenario.
5	30 % electrification + RES	The results in this scenario have a prerequisite of a fully renewable energy sector giving the electric locomotive emissions only from transfers, mostly PM. This will reduce emissions from the locomotives even further. The railway will be electrified by 30 %.
6	60 % electrification + RES	This scenario has the same assumptions as scenario 5 regarding emissions from electric locomotives. The only thing that has been changed in this scenario is the railway electrification up to 60 %, giving a further increase in electric locomotives and a decrease in emissions. As in scenario 3, the funding is the desired funding.
7	100 % electrification + RES	This is s a scenario where the pollution from the electric railway is 100 % tank-to-wheel (TTW) instead of well-to-tank (WTT). Including the desired funding as basis for the funding of the policy.

In the scenarios where the only thing that is changed is emissions per tonne, the only results that change are the emissions. In the scenarios where the railway is further electrified, the desired funding has been used to feed the model with funding data. This is to give the scenarios optimal conditions and not to hinder the change from diesel to electric locomotives.

4. Results

In scenario 1, the locomotives do not change either and the number of electric locomotives is the same 28, while the diesel locomotives are 172. The results are reflected in Fig. 4 showing that the pollution is still at 43.5 billion pollution units (PU).

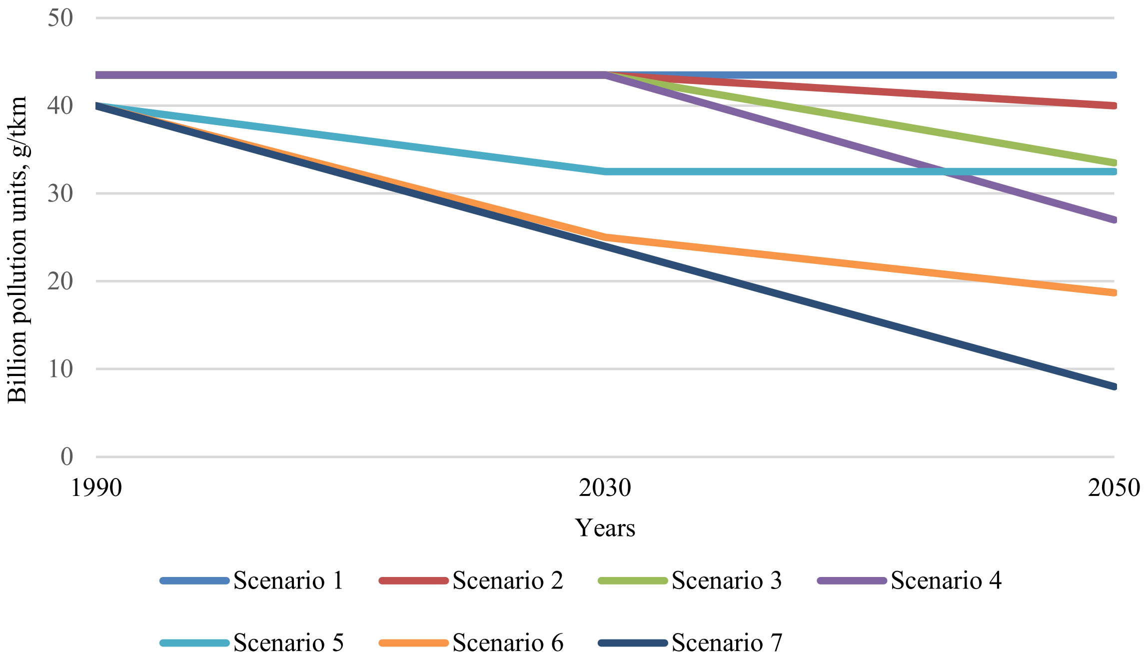


Fig. 4. Pollution units in all seven scenarios.

In scenario 2, the variables mimic the previous Latvian proposal for the new railway. The pollution from the railway drops significantly – from 43.5 billion PU to 40 billion PU, this is a drop of 8.05 % (Fig. 4). It is important to remember that in this scenario, the energy sector has not been incorporated into the model giving the electric locomotives a fuel source that is fossil.

With the reduction in pollution also comes an increase in electric locomotives and by 2040 16 % of the total locomotives have been changed from diesel to electric and that is the maximum amount when 30 % of the railway is electrified, increasing the locomotives from 28 to 60. The model also shows an increase in workers employed as 5 workers are needed to get one locomotive operation within 1 year.

When scenario 3 is implemented (60 % electrification), emissions dropped further to 33.5 billion tonnes PU, which is a 22.99 % decrease. In 2046 there would be more electrified locomotives (121) than diesel fuelled (79). The desired funding changes depending on how much of the railway is electrified. The funding increases from approximately EUR 26.5 million to EUR 53 million once the policy is over.

Scenario 4 comes with 100 % electrification, which means that eventually all locomotives become electric. In the case where the railway is electrified more than the original policy which is 30 % electrification there is a need for more funding, as the original budget supports upgrades for EUR 440 million. Therefore, the desired extra funding is in the model to take account for future upgrades where the necessary extra funding must be added. Here pollution decrease to 27.4 billion PU in 2070 and it is expected that these values will continue to drop as the electric locomotives continue to change after the policy has ended. In this scenario, the number of workers increases to 22.

The desired funding in Scenario 4 is EUR 136 million within the first year. This gradually decreases to EUR 68.7 million when the policy reaches the end in 2050.

In the final three scenarios, the energy supply for the locomotives is "tank-to-wheel", simulating full renewable energy usage, giving the locomotives only pollution from transit. In this case, the renewable energy reduces the starting value for all the electric locomotives, which gives the model a starting value at 40 billion PU. In scenario 5, the pollution would drop to 32.5 billion PU (with a 30 % electrification). The emissions from the diesel locomotives are responsible for most of the pollution coming from the railway and when the railway has been upgraded to electric, the pollution from the diesel sector drops significantly.

In scenario 6 (60 % electrification), the emissions for the electric locomotives are "tank-to-wheel" and for the diesel locomotives "well-to-wheel". When the supply chain is fully based on renewable energy sources and 60 % electrified, emissions drops from 40 billion PU to 18.7 billion PU and, as in the previous scenario, diesel emissions drop significantly. The decrease of emissions continues steadily throughout the time-period of the policy, as well as some years after the policy has ended. When the policy is turned on the funding matches with the desired funding making the model conditions optimal. The employment reaches a peak in 2035, when the employment is 34 workers.

Finally, in scenario 7 the railway is 100 % electrified and energy supply is fully renewable. As could be expected, here the emissions have been reduced the most. The emissions drop according to the locomotive changes, the emissions start at 40 billion PU and drops under 10 billion PU in 2050. The emissions from the diesel locomotives also drop alongside the locomotive changes.

The employment peaks in 2035 with 33 new employed workers. When the policy stops in 2050, the worker employment rate is 25 workers. The funding in this scenario shares a pattern with the other scenarios where the desired funding has been used as a feed for the actual funding. Where the funding is covered during the policy time and increase depending on how much of the railway that has been electrified.

5. CONCLUSIONS

Different scenarios of the system dynamics modelling provided a rather wide range of results showing the real importance of two influential policies – electrification of the railway and switching over to usage of fully renewable energy.

As the results showed, when looking from the perspective of climate change and the possibilities to reduce that, it would be enough to implement scenario 2 in order to already decrease the pollution units by more than 8 % that can be reached already before 2050, which is the year for the major future climate targets.

It's important to understand that all the reviewed scenarios (besides the first one) not only provide climate benefits, but also impact the economy both from the side of investments, as well as employment and indirect economic benefits. Especially in these challenging times of international crisis, it is very topical to discuss future investments for the benefit of economic recovery.

Although scenarios 5 to 7 are very hypothetical, they are excellent tools for showing how renewable energy policy positively affects pollution. However, from a more realistic perspective, scenarios 2 and 3 are both beneficial for the climate and less financially and politically intensive. Especially scenario 2 is very realistic considering that it is based on actual government plans, which are now seemingly cancelled, but hopefully will be introduced again.

The scenarios using full renewable energy policy could be further researched in the future providing a few softened versions, where the renewable energy in Latvia is at the 70 % or 80 % goal, which would have a greater potential for being implemented in state policy.

Overall, system dynamics modelling better explains the benefits of future policies and gives a good understanding of the possibilities and best choices considering the current economic situation and the aspects linked to that.

ACKNOWLEDGEMENTS

The research is funded by the Ministry of Economics of the Republic of Latvia, project "Sustainable and renewable transport policy formulation in Latvia (4muLATe)", project No. VPP-EM-2018/AER-2-0003.

REFERENCES

[1] European Commission. Dzelzceļu kravu pārvadājumi ES: pareizais ceļš vēl nav atrasts. Publications Office of the EU, 2016. (In Latvian). https://doi.org/10.2865/796882

[2] Central Statistical Bureau of Latvia. Dzelceļa kravu pārvadājumi. (In Latvian). [Online]. [Accessed 30.11.2019.]. Available: https://www.csb.gov.lv/lv/statistika/statistikas-temas/transports-turisms/transports/tabulas/tr200c/kravu-parvadajumi-dzelzcela-transporta

[3] University of Latvia. Latvijas Dzelzceļš kravu pārvadājumu tarifa samazināšanas meklējumos. 2018. (In Latvian). [Online]. [Accessed 23.11.2019]. Available: https://www.jf.lu.lv/en/par-mums/ul-media/news/detailed-view/t/43463/

[4] Porubova J., Bazbauers G. Analysis of Long-Term Plan for Energy Supply System for Latvia that is 100 % Based on the Use of Local Energy Resources. *Environmental and Climate Technologies* 2010:4(1):82–90. https://doi.org/10.2478/v10145-010-0022-7

[5] International Energy Agency. CO_2 emissions per tonne-kilometer in the EU, 2015. [Online]. [Accessed 01.12.2019.]. Available: https://www.eea.europa.eu/data-and-maps/figures/specific-co2-emissions-per-tonne-2

[6] Barisa A., Rosa A. A system dynamics model for CO_2 emission mitigation policy design in road transport sector. *Energy Procedia* 2018:147:419-427. https://doi.org/10.1016/j.egypro.2018.07.112

[7] Liobikienė G., Butkus M. The European Union possibilities to achieve targets of Europe 2020 and Paris agreement climate policy. *Renewable Energy* 2017:106:298-309. https://doi.org/10.1016/j.renene.2017.01.036

[8] Egging R., Tomasgard A. Norway's role in the European energy transition. *Energy Strategy Reviews* 2018:20:99–101. https://doi.org/10.1016/j.esr.2018.02.004

[9] Okpala *et al*. A review of modelling as a tool for environmental impact assessment. *IREJEST* 2013:39–46.

[10] Forrester J. W. System Dynamics – The next fifty years. System Dynamics Review, 2007. https://doi.org/10.1002/sdr.381

[11] 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* 2017:128:10–16. https://doi.org/10.1016/j.egypro.2017.09.005

[12] Kim Y-K. *et al*. Country-specific greenhouse gas emission factors of diesel-electric locomotive in Korea. *Transportation Research Part D: Transport and Environment* 2017:57:74–83. https://doi.org/10.1016/j.trd.2017.09.009

[13] Barisa A., Rosa A. Scenario analysis of CO_2 emission reduction potential in road transport sector in Latvia. *Energy Procedia* 2018:86–95. https://doi.org/10.1016/j.egypro.2018.07.036

[14] CO_2 European Emission Allowances. Markets Insider. 2020. [Online]. [Accessed 05.07.2020.] Available: https://markets.businessinsider.com/commodities/co2-european-emission-allowances

[15] Report of research project – Assessment on the use of renewable energy resources in Latvia until 2020. Riga Technical University, 2008.

[16] European commission. The EU invests in a faster, more efficient rail network in Latvia. Brussels, 2019.

Energy Intensive Manufacturers in State Economy

Case study of Latvia

Liga Rozentale, Dagnija Blumberga
Institute of Energy Systems and Environment
Riga Technical University
Riga, Latvia
liga.rozentale@em.gov.lv

***Abstract*—The research focuses on evaluating the impact of large manufacturing enterprises both on country's economy and on environment from the perspective of energy intensity. The case study is based on the situation in Latvia. The research uses the Kaya identity to show the situation that is necessary to obtain in order to achieve the carbon emissions goals of the European Union. The research also provides an analysis on coincidences between Latvia's GDP, energy intensity and carbon intensity, as well as studies the input of the largest industries in Latvia on the country's energy intensity and provides suggestions for improving the manufacturing industry from the perspective of energy savings.**

***Keywords*— energy intensity; GDP; greenhouse gas emissions; Kaya identity**

I. Introduction

Manufacturing industry is sometimes considered to be the backbone of a country's economy. Some of the main benefits include such aspects as increased employment, country's gross domestic product (GDP) and technological advancement. [1] However, it is assumed that large manufacturing also comes together with high energy intensity and high greenhouse gas emissions, as well as it could be argued that manufacturing companies depend on state of the economy. It is argued that increases in energy consumption lead to increased economic growth. [2] [3] During the recess in economy, manufacturing also decreases. That was also the case in Latvia after 2008 when large manufacturers closed their business. Considering the great emphasis on the climate goals in the European Union (EU) in the last years, the goal of this research is to determine to what extent economic growth (i.e. GDP) is related to the increase of energy intensity. This issue has several sub-goals such as to research, how much large manufacturing companies are responsible for high energy intensity and greenhouse gas emissions in Latvia and what would be the best way to foster the manufacturing industry without rapid increase in energy intensity and greenhouse gas emissions in Latvia.

II. Methodology

The case study involves data on GDP, energy consumption and greenhouse gas emissions in Latvia (based on the data by the Statistical Bureau of Latvia), to evaluate the development tendencies of this data. Further on the Kaya identity is applied to analyse more thoroughly the allowed carbon intensity. The Kaya identity can be expresses as:

$$CO_2 = Pop \times \frac{CO_2}{E} \times \frac{E}{GDP} \times \frac{GDP}{Pop} \quad (1)$$

where
CO_2 – the total amount of carbon emissions,
E – the total energy consumption,
GDP – the gross domestic product,
Pop – the population. [4]

The Kaya identity facilitates the understanding of the mechanism that determines the changes in emissions. While it cannot be assumed that an increase in population or GDP will mean that the carbon emissions will increase as well, the Kaya identity provides possibility to estimate quantitively, how different variables in this equation impact other variables such as emissions and energy consumption. [4] [5] The Kaya identity also helps in understanding by how much it is necessary to reduce the carbon intensity to achieve the EU 2020 and EU 2030 goals in reduction of CO_2 emissions and it provides conclusions on how possible it is to achieve the goals and the perspective on the necessary actions. [6]

It is also possible to express the Kaya identity in commonly used terms as shown in Table I.

TABLE I. COMPOSITION OF KAYA IDENTITY

Formula	Description
$\frac{CO_2}{E}$	Carbon intensity
$\frac{E}{GDP}$	Energy intensity
$\frac{GDP}{Pop}$	GDP per capita

The Kaya identity is applied for the case study in Latvia. The results are calculated for the years 2020 and 2030 based on the increase or decrease of the data (population, GDP per capita, energy intensity) relative to 1990. Thus, it is assumed that the base data in 1990 corresponds to 100% and the respective changes in percentage are calculated for 2020 and 2030. Different growth patterns are assumed for the annual GDP based on the past, current and forecasted economic situation and are summarized in Table II.

978-1-7281-3942-5/19/$31.00 ©2019 European Union

TABLE II. ASSUMPTIONS FOR ANNUAL GDP PER CAPITA GROWTH RATE

Time period	**Annual GDP per capita growth rate**
1990 – 1995	1.00%
1996 – 2001	1.50%
2002 – 2007	2.00%
2008 - 2011	1.00%
2012 - 2030	2.50%

The population in 1990 in Latvia was 2,67 million (100%), the forecasts were used for the population in 2020 and 2030, and the respective population was reflected in percentage (72% and 63% respectively). [7]

Finally, based on literature review, it was assumed that the reduction in carbon intensity from 1990 has been about 1,10% annually. [8]

Meanwhile, according to the National Energy and Climate Plan of Latvia, it is planned to reduce the CO_2 emissions by 55% in 2020 and by 57% in 2030 compared to the levels of 1990. [9] Thus, the respective residual CO_2 emissions in comparison with 1990 would be 45% and 43%.

III. Case Study

As can be seen in Fig.1, the deepest economic crisis in Latvia in the last two decades took place in 2009, when the GDP decreased the most. Since then the GDP has increased a lot, but not permanently, it fluctuates a lot. Fig.1 proves that in 2018, the GDP has increased by the largest percentage (compared to previous year) since 2012.

Fig. 1. Changes in GDP in Latvia, % (compared to previous year) [7]

When looking at the energy consumption in Fig. 2, it can be seen that it has actually not fluctuated together with the GDP in the same manner. For example, the GDP increased largely in 2010, 2011, 2015 and 2017 (compared to the previous year), but the energy consumption did not increase by the same level. As it is shown in Fig. 2, the energy consumption in 2011 and 2015 was even lower than a year earlier. In 2012, when the GDP went down by 4%, the energy consumption actually increased and as can be seen in Fig. 2, it increased mostly in the industry and construction sector, which includes the manufacturing companies as well. What is interesting, energy consumption in the industry and construction sector is something that is increasing or just keeping stable during negative shifts of the economy in the country.

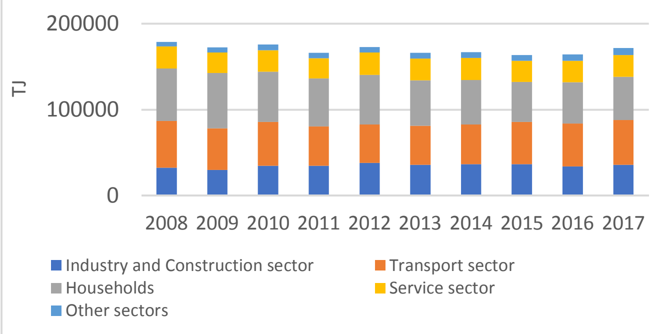


Fig. 2. Energy consumption by sectors, TJ [8]

As can be seen in Fig.2, households' energy consumption and transport sector's energy consumption has decreased over the years, where apparently a large role has been played by energy efficiency measures in households and by shift in transportation habits to more sustainable transport. [12]

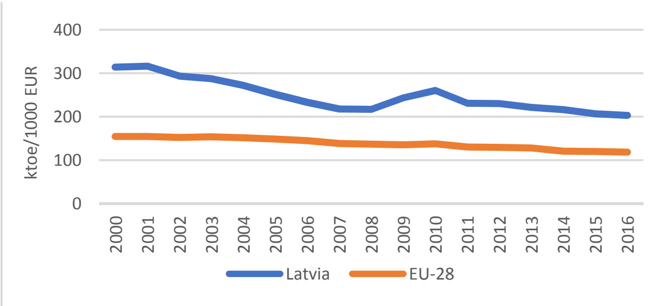


Fig. 3. Energy Intensity of the economy in Latvia and EU-28, ktoe/1000 EUR [13]

Fig. 3 indicates that the energy intensity in Latvia is quite above average in the EU, however, in the recent years the gap is narrowing down. Meanwhile, if energy intensity trends are compared with GDP, they are not always consistent. From 2001 to 2007 the GDP was growing, but the energy intensity was slowly decreasing. At the same time in 2008, when the crisis started to produce loss in GDP, the energy intensity reached the lowest mark in Latvia. When the GDP was at its lowest point in 2009, the energy intensity slowly started to grow. Nevertheless, it can be seen that as the GDP again started decreasing in 2011, the same pattern was found with the energy intensity.

While the consumption of energy in general stays approximately on the same level, Fig. 4 shows that the greenhouse gas (GHG) emissions are slightly decreasing every year since 2010 due to such changes as more and more renewable energy and effective cogeneration in the energy mix and it is supplemented by energy efficiency measures. [14] At the same time, the most impact is left by CO_2 emissions, which are the main emissions in energy intensive manufacturing.

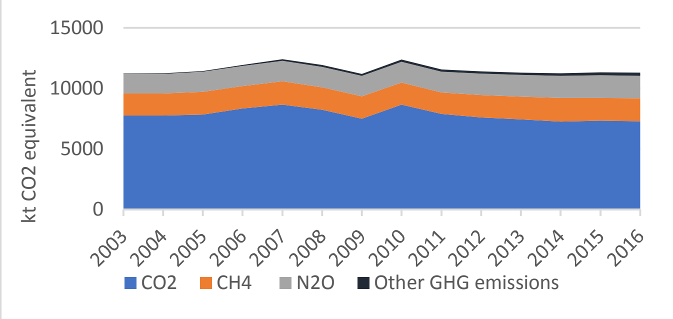


Fig. 4. Greenhouse gas emissions in Latvia, kt CO_2 equivalent [9]

At the same time, when looking through the sectors that produce the most GHG emissions, it can be seen in Fig.5 that industrial processes actually produce the least amount of these emissions, i.e., it could be vaguely argued that manufacturing by itself is not so environmentally unfriendly. However, most of the emissions come from the energy sector, which of course also includes the energy used for manufacturing goods.

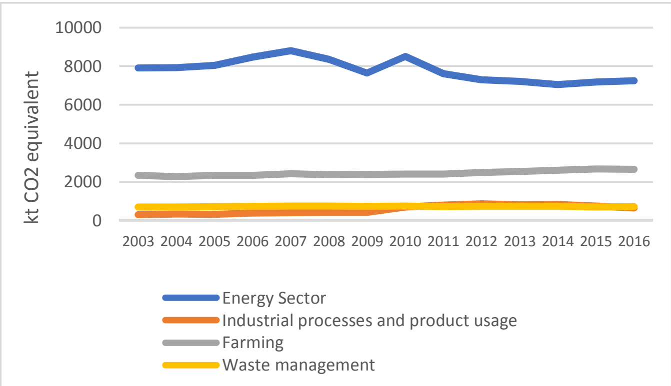


Fig. 5. Greenhouse gas emissions per sector in Latvia, kt CO_2 equivalent [9]

IV. Results and Discussion

When moving further to the Kaya identity, Table III shows the results of the calculations for the optimal carbon intensity in 2020 and 2030 under the assumptions of forecasted GDP, population and energy intensity.

TABLE III. KAYA IDENTITY CALUCLATED TARGET VALUES FOR CASE STUDY IN LATVIA

	Years		
Criteria	1990	**2020**	**2030**
CO_2 emissions	100%	43%	45%
Population	100%	72%	63%
GDP per capita	100%	168%	215%
Energy intensity	100%	72%	64%
Carbon intensity	100%	**49%**	**52%**

Table III shows that the carbon intensity in Latvia in 2020 should be 49% (i.e., the reductions should be by 51%) and 52% in 2030 (i.e. the reduction should be by 48%) in order to achieve the National Energy and Climate Plan's targets in reduction of CO_2 emissions, which will soon be non-negotiable (when the Plan is approved at the end of 2019).

The Kaya identity allows to work with the data and understand, how much, for example, the reduction of energy intensity, would lower the carbon intensity. If the energy intensity is lowered by 5% annually beginning from 2020, the carbon intensity reduction by 2030 would only need to be 20%. Thus, the necessity to reduce carbon intensity would drop by half. This example proves the idea, that it is necessary to urgently develop manufacturing with much lower energy intensity than now.

In order to do that, it is important to understand, what are considered to be the energy intensive industries, and which are non-energy intensive industries.

TABLE IV. INDUSTRIAL SECTORS BY ENERGY INTENSITY [15]

Industry grouping	**Representative industries**
Energy-intensive manufacturing	
Food	Food, beverage, and tobacco product manufacturing
Pulp and paper	Paper manufacturing, printing and related support activities
Basic Chemicals	Inorganic chemicals, organic chemicals, resins, and agricultural chemicals, includes chemical feedstocks
Refining	Petroleum refineries and coal products manufacturing, including coal and natural gas used as feedstocks
Iron and Steel	Iron and steel manufacturing, including coke ovens
Nonferrous metals	Primarily aluminum and other nonferrous metals, such as copper, zinc, and tin
Nonmetallic minerals	Primarily cement and other nonmetallic minerals, such as glass, lime, gypsum, and clay products
Non-energy intensive manufacturing	
Other chemicals	Pharmaceuticals, paint and coatings, adhesives, detergents, and other miscellaneous chemical products, including chemical feedstocks
Other industrials	All other industrial manufacturing, including metal-based durables
Nonmanufacturing	
Agriculture, forestry, fishing	Agriculture, forestry, and fishing
Mining	Coal mining, oil and natural gas extraction, and mining metallic and nonmetallic minerals
Construction	Construction of buildings (residential and commercial), heavy and civil engineering construction, industrial

	construction, and specialty trade contractors

Data from the Central Statistical Bureau of Latvia shows that approximately 25% of net electricity consumption is consumed in manufacturing industries, mainly in 4 particular industry sectors, which consume 85% of the energy consumed in manufacturing. These are:

- Manufacturing of fabricated metal products;
- Manufacturing of wood;
- Manufacturing of food;
- Manufacturing of other non-metallic mineral products. [11]

Before the economic crisis, another energy intensive manufacturing sector was also basic metals production.

There could be various types of possible classifications, but Table IV along with the above-mentioned Latvian manufacturing sectors with high energy consumption illustrates that currently (and during the last decade), the largest manufacturing companies in Latvia (based on their contribution to GDP) are energy intensive. The largest manufacturer in Latvia consumed more than 400 GWh of electricity per year in 2012 – it was steel manufacturer JSC “Liepājas Metalurgs”. While it was the single biggest electricity consumer, it’s impact on the rather small Latvian GDP can also be seen in Fig.1 (in terms of export and social welfare it provided) and measured. The manufacturer went into bankruptcy in 2013, then restarted its’ manufacturing and closed for good in 2016. When it closed down for the first time in 2013, it was estimated by the government that Latvia’s whole GDP reduced by 1.2 – 1.5%. The manufacturer not only paid 0.22% of all the taxes collected in Latvia, but also employed 2800 workers.

There are also other very large manufacturers in Latvia such as Ltd. “Schwenk Latvija” (previously known as Ltd. “Cemex”), which is the sole producer of cement in Latvia and JSC “Valmieras stikla šķiedra”, which specializes in manufacturing glass fibre products. Both of these manufacturers are also categorized as energy-intensive based on Table IV.

About 15-25% of costs for energy intensive manufacturers are composed of costs for energy consumption. [17] Such a large energy consumption is not only unsustainable and against the energy and climate goals of Latvia, but is also very expensive for the manufacturer, which is also one of the reasons why JSC “Liepājas Metalurgs” went bankrupt. And such situation not only leaves negative impact on the GDP, but has other side effects such as increased energy tariffs for the rest of the energy consumers, because when a large energy user stops paying for the electricity or gas connection, the costs of maintaining electricity and gas transmission and distribution systems are redistributed to the remaining energy consumers.

When analysing the energy intensity (and CO_2) intensity, it is important to link it with the concept of decoupling. There are two types of decoupling – resource and impact decoupling, which can be further categorized as relative or absolute decoupling.

Resource decoupling in this case study would be reduced usage of energy per unit of economic activity (GDP), so the production amount is the same, but with less energy resources, which can be labelled as increased resource productivity. Impact decoupling means that the economic output must be increased while reducing the negative environmental consequences such as CO_2 emissions, so the production volume is larger (not at the same level as in case of resource decoupling), but the energy resources are used at the same level as before or less, so it can be labelled as increased eco-efficiency. [12] In case of Latvia, both of the options would be acceptable from the point of view of country’s economic growth. However, considering the trouble with achieving the carbon emissions goals, the only option is the resource decoupling, which is already taking place now, though rather slowly.

Moreover, in a situation of growing economy, it is important to distinguish whether the resource or impact decoupling is relative or absolute. Relative decoupling means that the increase of the environmental indicator, e.g., energy usage, is lower than the growth rate of the economic indicator, e.g. GDP. At the same time, absolute decoupling means that this energy usage will decrease or stay the same, while the GDP will grow. [12] Absolute resource decoupling would be the best-case scenario. However, based on the Figures described above, it is possible to evaluate that the relative resource decoupling would take place in Latvia.

To avoid the energy intensity increase, it would be an option to switch country’s focus to promoting non-energy intensive manufacturing. This would be a possibility in a country, whose largest producers are not energy intensive manufacturers. This is not the case in Latvia, meaning that it would not be possible to exclude the existing large energy-intensive manufacturers who create a large part of the GDP. It is possible that new manufacturers come into the market, but the key for the “old” manufacturers would still be energy efficiency measures. Energy efficiency measures restrict energy consumption, but they do not affect the manufacturer’s gross value added and manufacturer’s energy intensity (which is calculated as the energy costs to gross value added) is decreasing. [13]

V. Conclusions

The research above shows that energy intensity is an overarching problem in Latvia’s manufacturing industry while it is also the cornerstone of the country’s economy as it is strongly linked with the GDP.

As the manufacturing industry plays an important role in Latvia’s GDP, the manufacturing should not be reduced, but it must be improved by introducing new energy efficient and low energy intensity manufacturing with high added value.

However, considering the current structure of the country's manufacturing industry, it is necessary to work on the current manufacturers' energy efficiency as that would be the fastest and most cost-efficient activity to improve the situation. Further research would be essential to understand the best energy efficiency measures for energy intensive manufacturers.

To achieve the EU's goals for reduction of carbon emissions, it is important to put effort in restructuring the manufacturing industry. It is essential to minimize the carbon intensity, which is directly dependent on the energy intensity.

Kaya identity is an excellent tool to consider the possible scenarios for achieving national and EU's climate goals. For example, if a country can manage to reduce the energy intensity at least by 5% annually from now on, the carbon intensity targets would be more realistic to achieve by continuing work on other sectors, such as transport.

References

[1] A. Coad and A. Vezzanic, "Three cheers for industry: Is manufacturing linked to R&D, exports, and productivity growth?," *Structural Change and Economic Dynamics,* vol. 50, pp. 14-25, September 2019.

[2] E.Dogan and A.Aslan, "Exploring the relationship among CO2 emissions, real GDP, energy consumption and tourism in the EU and candidate countries: Evidence from panel models robust to heterogeneity and cross-sectional dependence," *Renewable and Sustainable Energy Reviews,* vol. 77, pp. 239-245, September 2017.

[3] L.Timma, T.Zoss and D.Blumberga, "Life after the financial crises. Energy intensity and energy use decomposition on sectorial level in Latvia," *Applied Energy,* vol. 162, pp. 1586-1592, January 2016.

[4] V.Bianco, F.Cascetta, A.Marino and S.Nardini, "Understanding energy consumption and carbon emissions in Europe: A focus on inequality issues," *Energy,* vol. 170, pp. 120-130, March 2019.

[5] J.A.Duro, "Weighting vector and international inequality changes in environmental indicators: An anallysis of CO2 per capita emissions and Kaya factors," *Energy Economics,* vol. 39, pp. 122-127, September 2013.

[6] A.Tavakoli, "A journey among top ten emitter country, decomposition of "Kaya Identity"," *Sustainable Cities and Society,* vol. 38, pp. 122-127, April 2018.

[7] W. Bank, "Population estimates and projections," [Online]. Available: https://databank.worldbank.org/source/population-estimates-and-projections. [Accessed September 2019].

[8] European Commission, "Greenhouse gas emission statistics - emission inventories," [Online]. Available: https://ec.europa.eu/eurostat/statistics-explained/pdfscache/1180.pdf. [Accessed September 2019].

[9] Ministry of Economics of Latvia, "National Energy and Climate Plan," [Online]. Available: https://em.gov.lv/lv/nozares_politika/nacionalais_energeti kas_un_klimata_plans/. [Accessed September 2019].

[10] CSB, "Gross domestic product in comparisson to previous year," 2018. [Online]. Available: https://www.csb.gov.lv/lv/statistika/statistikas-temas/ekonomika/ikp/galvenie-raditaji/iekszemes-kopprodukts-un-kopeja-pievienota-vertiba . [Accessed 2019 July].

[11] CSB, "Energy consumption by sectors (TJ),2008-2017," 2017. [Online]. Available: http://data1.csb.gov.lv/pxweb/lv/vide/vide__energetika__ikgad/?tablelist=true. [Accessed 2019 July].

[12] J. Makijenko, J. Burlakovs, J. Brizga, M. Klavins, "Energy efficiency and behavioral patterns in Latvia," *Management of Environmental Quality,* vol. 27, no. 6, pp. 695-707, 2016.

[13] CSB, "ENVIRONMENT OF LATVIA IN FIGURES: climate change, natural resources and environmental quality 2017," [Online]. Available: https://www.csb.gov.lv/sites/default/files/publication/2018-12/Nr_24_Vides_raditaji_Latvija_2017_%2818_00%29_LV_EN.pdf. [Accessed September 2019].

[14] Latvian Environment, Geology and Meteorology Centre, "Latvia's National GHG Inventory Report, 1990-2017," 2018. [Online]. Available: https://www.meteo.lv/fs/CKFinderJava/userfiles/files/Vide/Klimats/Majas_lapai_LVGMC_2019_seginvkopsavilkums.pdf. [Accessed September 2019].

[15] U.S. Energy Information Administration, "International Energy Outlook 2016," 2016.

[16] K.Ločmelis, U.Bariss, D.Blumberga, "Latvian energy policy on energy intensive industries," *Energy Procedia,* vol. 113, pp. 362-368, 2017.

[17] I.Kasjanovs, "Latvijas apstrādes rūpniecība šķērsgriezumā," [Online]. Available: https://www.macroeconomics.lv/node/280. [Accessed September 2019].

[18] J. L.Cruz, "Energy and CO2 intensity changes in the EU-27: Decomposition into explanatory effects," *Sustainable Cities and Society,* vol. 26, pp. 486-495, October 2016.

[19] K.Ločmelis, A.Blumberga, U.Bariss, D.Blumberga, "Energy policy for energy intensive manufacturing companies and its impact on energy efficiency improvements. System dynamics approach," *Energy Procedia,* vol. 128, pp. 10-16, 2017.

Liga Rozentale, Ms. sc. ing., is a PhD student in Environmental Engineering at the Riga Technical University. She received Bachelor's degree in Management and Organization of International Economic Relations at Riga Technical University in 2013, a Master's degree in European Studies at the University of Leuven (Belgium) in 2014, as well as a double Master's degree in Environmental Engineering at Riga Technical University and Vilnius Gediminas Technical University (Lithuania) in 2018. Current research focuses on the climate aspects of energy policy in Latvia.

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).
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.

2021 IEEE 62nd International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON) | 978-1-6654-3804-9/21/$31.00 ©2021 IEEE | DOI: 10.1109/RTUCON53541.2021.9711724

Potential role of energy communities in the way towards climate neutrality

Case study of Latvia

Liga Rozentale, Dagnija Blumberga
Institute of Energy Systems and Environment
Riga Technical University
Riga, Latvia
liga.rozentale@em.gov.lv

***Abstract* — Decentralized production of renewable electricity is steadily growing in the European Union. Solar and wind energy power plants are increasingly installed for self-consumption both by households and enterprises and these renewable energy installations could play an important role in the transition towards climate neutrality by 2050. All European Union's member states are required to develop national legal framework to allow energy communities to actively participate in the energy market and to further incentivize the usage of renewable energy. The aim of this study was to research the potential of energy communities in Latvian electricity market considering the developing legal framework and electricity demand and capacity conditions in Latvia. Research showed that currently the planned legislation in Latvia provides a good basic mechanism for energy communities and electricity sharing as well as peer-to-peer trade without harsh restrictions. Considering the future electricity deficit in Latvia, energy communities have a good potential, but further detailed requirements still must be developed in order to ensure the security of electricity grid.**

Keywords — renewable energy community; citizen energy community; active customer; energy sharing; peer-to-peer electricity trade

I. Introduction

The European Union's (EU) climate and energy policy are for the past several years one of the most topical policy fields in the EU. The EU's determination to achieve climate neutrality by 2050 means that the EU member states have to use different tools in order to increase the usage of renewable energy in the countries' energy mix. Latvia is one of the EU member states who fully supports the climate neutrality target and has set several tasks to achieve it. As had been concluded in the report "Latvia's strategy for achieving climate neutrality by 2050", one of the solutions to the challenge of achieving climate neutrality is to increase the share of renewable energy [1]. In the search for the necessary adjustments in the electricity policy in Latvia to pave the path towards climate neutrality, the authors have already analysed the possible stimulations to encourage the development of solar energy installations in Latvia [2]. As can be seen in Fig.1, already now Latvia is in the third place between other EU member states regarding the share of energy produced from renewable energy [3].

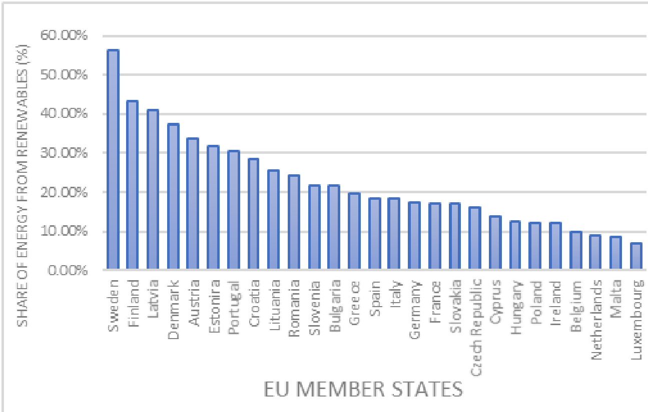


Fig.1 Share of energy from renewable sources in the EU member states, 2019 (%) [3]

Meanwhile, the EU has provided a new legal framework for additional promotion of renewable energy – energy communities. With the increase of decentralized electricity production, creation of energy communities has become more and more topical considering the economical benefit that appears when a group of people engage in an activity that is considered to be more expensive if excercised individually [4]. The concept of energy communities has been developing for more than ten years and there are already operating pilot projects [5]. Energy communities provide the opportunity for consumers to be empowered at different community sizes and forms, produce their own electricity (or other type of energy) and consume it collectively with little or no involvement of an electricity supplier [6][7]. Whereas the legal framework is only now being put in place by all EU member states in order to transpose the requirements of two EU directives that try to empower the consumer, which will be further discussed in this research. The aim of this study is to evaluate how the EU requirements are being transposed in the national regulation and whether this national regulation of Latvia provides a good ground for actually introducing energy communities in Latvia in a cost-effective manner that would encourage both households and enterprises to get involved in such activity.

978-1-6654-3804-9/21/$31.00 ©2021 European Union

II. Methodology

The focus of this research will be a case study analysing and comparing the EU legal framework with the appropriate legislative proposals in Latvia. This will allow to evaluate if the national legal framework is properly transposing the EU legislation without creating barriers for the introduction of energy communities in Latvia. The research will also highlight the electricity generation capacity in Latvia, which will allow to evalute the technical impact that generation capacities owned by energy communities could leave on the electricty system in Latvia.

There are two EU's directives that were developed simultaneously and both set rules for energy communities – Directive 2019/944 of the European Parliament and of the Council on common rules for the internal market for electricity and amending Directive 2012/27/EU [8] (hereafter – Directive 2019/944) and Directive 2018/2001 of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (hereafter – Directive 2018/2001) [9]. Directive 2019/944 introduces the term "citizen energy community" (CEC), but Directive 2018/2001 introduces the term "renewable energy community" (REC). The main difference between CEC and REC is that CEC is specifically meant for electricity production (or storage, aggregation, sharing etc.) and this electricity can also be non-renewable, while REC concerns all types of renewable energy (these can be renewable electricity installings, but they can also be heat pumps, biomethane facilities etc.). Thus, if a group of people makes an energy community to collectively produce electricity from solar panels for their own needs, it will simultaneously be a REC (because of renewable energy) and CEC (because of electricity). Both CEC and REC are created as a legal voluntary entities. Energy communities ar controlled by its members and their main aim have to be creation of benefits for the members of the energy community (instead of gaining financial profit) [10].

Directive 2019/944 uses the term "sharing" to describe the transfer of electricity between the members of the CEC, however it is not explicitly defined or restricted in the articles. The principle of sharing is shortly described only in the recital (which is not a legally binding part of the Directive), setting out a few principles:

- ✓ Sharing is a type of electricity supply method;
- ✓ Sharing does not mean that the power plant has to be in close range to the CEC members, who are receiving this electricity;
- ✓ Sharing is not restricted to single metering point (i.e. members of the CEC can be located at different places);
- ✓ Sharing should not have impact on network charges, when the distribution/transmission system is used for electricity flows.
- ✓ Sharing should not have negative impact on balancing, metering and imbalance settlements.

At the same time Directive 2018/2001 prescribes in one word in Article 22 that REC are also entitled to share energy.

However, to make things more confusing, Directive 2018/2001 also introduces term "jointly acting renewables self-consumers" (that are neitheir CEC, nor REC). This is a group of people, who do not need to create such a legal entity as energy community but who can still produce and share electricity between themswelves (Article 21) if they are located in the same building or apartment block.

Finally, Directive 2018/2001 also slightly touches upon another principle of peer-to-peer trading defining it as trade of renewable energy based on a contractual agreement, which can be either a direct trade or involving a third party. Unfortunately, the Directive 2018/2001 does not specify, how this peer-to-peer trade differs from traditional electricity trade, but it could be assumed that in peer-to-peer trade the electricity seller is not considered an electricity supplier and does not have to comply with the rules set for providers of public utilities' services.

All these final consumers, who produce and consume (or store, sell etc.) electricity that has been generated by themselves are defined in Directive 2019/944 as active customers. Previously these customers were known just as self-consumers, however this was a narrow term and would not include the option of storing and selling electricity, as well as providing flexibility services or participating in energy efficiency schemes. To distinguish active customers from other market participants, it is defined that active customer's actvities shall not be its primary commercial or professional activity.

As has been established in the EU Council's Energy Working Party meetings (author L.Rozentale participated as an expert), the two Directives that were proposed by the European Comission, where not fully coordinated in the developing phase. This has led to partial overlap of the ideas in the Directives (with different terms but similar concepts such as citizens energy community and renewable energy community) while also creating partial gaps and misunderstandings (such as if there is difference between sharing and peer-to-peer trade) [11]. However, there are researches that try to explain the scope of each of the Directives, outlining the differences, restrictions and potentials [12][13].

For the further analysis of the legal framework in Latvia, the authors use the proposals in the national legislation (the legislation has not yet been approved), as well as the expert views expressed in different public consulations in Latvia regarding the future of the energy communities.

III. Case Study

The EU's member states are free to chose the best ways how to tranpose rules set in the Directives in the national regulations. Currently, the Ministry of Economics (MoE) of Latvia is developing the necessary legislation to transpose both Directives [14]. The central energy laws in Latvia is the Energy Law and Electricity Market Law that are both in the amendment process. The view of the MoE of Latvia is to introduce the general regulation of energy communities and RECs in the Energy Law, while the CEC and the linked regulation of sharing and active customers will be further elaborated in the Electricity Market Law.

Considering the overlaps and confusing provisions in the Directives, each member state is trying to provide its own interpretation for a logical mechanism. The concept proposed in Latvia is summarized by authors in Fig.2. The following interpretation of the Directives provides that there are three types of active cutomers: renewables self-consumers, jointly acting self-consumers and energy communities. Jointly acting renewables self-consumers and energy communities can use the electricity sharing option (sharing is not considered trade), while single renewables self-consumers (both households and legal entities) can use net-metering scheme. All three types are allowed to participate in peer-to-peer trade.

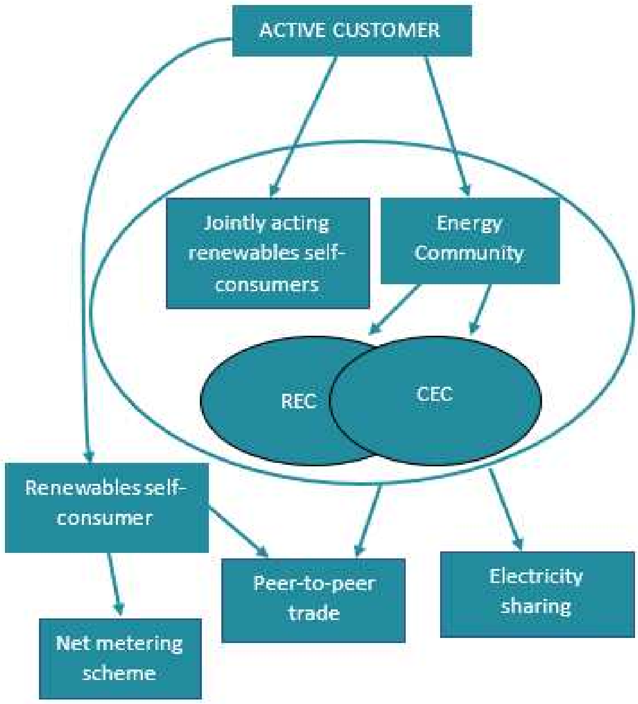


Fig.2. Proposed legislative framework in Latvia for active customers

Though according to the Directives, the primary target shall not be gaining financial benefit from energy community, the directives do not forbid energy communities to receive income, e.g., for the electricity that has been produced in the energy community and has been sold in peer-to-peer trade as the residual electricity that was not necessary for the consumption of the members in the energy community at that time. Thus, energy communities can have income that could be used to pay off the assets and to maintain electricity production installations, which has been stressed by the society as one of important aspects for the energy community to be cost-efficient [15].

As regards net metering scheme, this mechanism has been introduced in Latvia for several years. Already now individual household consumers with microgenerators can feed this self-produced surplus electricity into the grid and take it from the grid later without paying the electricity price (however, they need to pay for using the grid). Still, the proposed improved mechanism will provide a few additional benefits:

- ✓ No more capacity restrictions for renewables self-consumers;
- ✓ Renewables self-consumer can produce electricity in another object (e.g. countryside house) and consume it in a different object if both objects are covered by the same electricity supply agreement;
- ✓ Mechanism will apply also to legal entities as well but in a different manner – legal entities will accumulate virtual money (surplus electricity times the current electricity tariff) and not an amount of electricity in kilowatt-hours. Households will also be able to opt for this type of mechanism if they believe it is better for them.

It can be concluded that the new rules for net metering scheme will provide a more appealing environment for renewables self-consumers. However, it will not be applied to energy communities and jointly acting renewables self-consumers. The second group will have the sharing possibilities, however if there is any surplus electricity, the community would have to arrange peer-to-peer trade.

When an EU member state transposes a directive, it cannot go in contradiction with the directive, but it can expand the scope and adapt it to the actual circumstances in the specific member state. A good example of how to adapt a directive's requirements has been used regarding jointly acting renewables self-consumers as the proposed scope of this term in Latvia would cover not only one building, but also row houses (i.e. houses with a shared wall) and industrial parks. This is a result of discussions with the existing self-consumers and interested parties, which expressed the need for expanding the scope of the definition as there are row houses and industrial parks that would be interested in participating in this mechanism. [15]

Any future state support mechanisms are currently avoided by the government because such support would likely be introduced at the expense of other electricity consumers without electricity generation installations, who would have to pay higher electricity tariffs. However, Latvia's Recovery and Resilience plan envisages EU funding at least for solar installations (specific support program is still to be developed). Such support would be the only specific incentive for developing energy communities as currently the legislative proposals do not provide any other specific benefits for the energy communities. Still, as it was mentioned at the beginning, one of the main reasons to create energy community is to share the costs of electricity generation installations. The proposed regulation of Latvia does not put any barriers to the creation of energy communities.

Both the existing (e.g. existing solar panels of one of the community's members) and potential new power plants can be part of an energy community providing electricity for its members. However, as stated in the Directive, these cannot be profit-oriented power plants. Thus, power plants connected to the transmission grid (such as the large-scale hydroelectric power plants on Daugava river) would not be a typical subject for energy communities.

The existing power plants either already have a final consumer or could provide for the needs of energy community. Considering that there are renewable energy power plants in Latvia that previously received the benefits of compulsary procurement, which has now been canceled for a number of power plants putting them in financial difficulties, there rises a possibility for these power plants to be sold to energy communities [16]. However, in such case the power plant could not be used for selling electricity anymore. And these would not serve for the purpose of increased usage of renewable energy as these power plants are already accounted for.

Meanwhile, the possibility to share electricity in energy community or share electricity in one building/apartment block can be appealing for consumers, who are willing to install electricity generation units, but who can't afford it or don't want to bear the costs of electricity installations fully on one household or one business owner [17]. Such reasoning has been expressed in Latvia during the discussions regarding the potentital benefits of the energy communities, organized by the municiplaity of Riga [15].

At the same time, currently open are questions regarding contractual rights between the members of the energy community or between jointly acting renewables self-consumers, data sharing mechanism, balancing responsibilities and other practical aspects that will be determined in the Regulation of Cabinet of Ministers in a later stage.

Nevertheless, there is already now an existing pilot project of an energy community in one of the municipalities (Marupe) in Latvia. The project involves a row house and an apartment building. The current pilot project is one of the reasons behind evolving the scope of jointly acting renewables self-consumers to cover a larger potential group of self-consumers. In both cases of the pilot project there are installed solar panels. The row houses, for example, have 6 solar systems (each consisting of 4 solar panels) with the total capacity of only 7.92 kW [18]. The lack of national legislation, technical challenges (rooftop repairments, network installations) and difficulties in communication with members of the energy community (not everyone is equally interested in the project) are some of the issues in developing an energy community. But as has been concluded by the project coordinator, as long as there are no support instruments, it will be hard to actually incentivize the creation of energy communities considering the large investments that are necessary and the long pay-back time of solar panels [19]. Thought the costs of the energy community project are not known, in a similar renewables self-consumer project with 7,2 kW capacity, the total costs for the solar panels and their installation were around 6000 EUR. The project owner expects payback in about 10 years-time [20]. The actual payback time is dependent on how much electricity is used momentarily and how much is fed into the grid. The payback time will be longer if more electricity is fed into the grid as you have to pay variable costs for the usage of the electricity grid when you take electricity back from the grid (EUR/kWh). The most common request from the society in terms of support is to introduce grants for installing solar panels. [15] At the same time, it can be argued that a bigger role should also be played by the municipalities, who could be involved in supporting the development of energy communities as has been remarked also in the guidelines CEE Bankwatch Network and Latvian Green Movement [21].

The transmission system operator (TSO) of Latvia has modelled the possible electricity demand up to year 2030 in three scenarios, where the first one is the most conservative and the last one is the most optimistic and provides the highest increse in electricity consumption in Latvia [22]. Nevertheless, all three scenarios as can be seen in Fig.3 shows that the electricity consumption in Latvia in the next years will only rise. The TSO has also compared this demand with the possibilities to provide the necessary capacity from the existing power plants and import. In the base scenario, Latvia would be capable to cover peak demand up to 2024, after that there would be electricity defecit in Latvia [22]. This means that additional electricity generation installations will be needed.

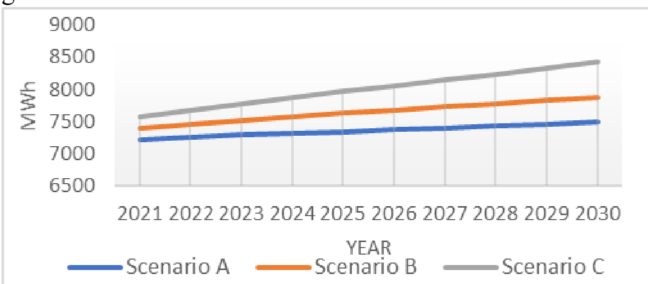


Fig.3. Electricity demand forecast 2021-2030 by electricity transmission system operator

As can be seen in Fig. 4, most of the small-scale renewable electricity (connected to the distribution grid) in Latvia is produced by biomas and biogas combined heat and power (CHP) plants. This is followed by wind parks, small hydroelectric plants and finally solar power plants [23]. Though the increase of small-scale renewable energy production has increased in the last decade, it is still only a little share of the total electricity demand in Latvia.

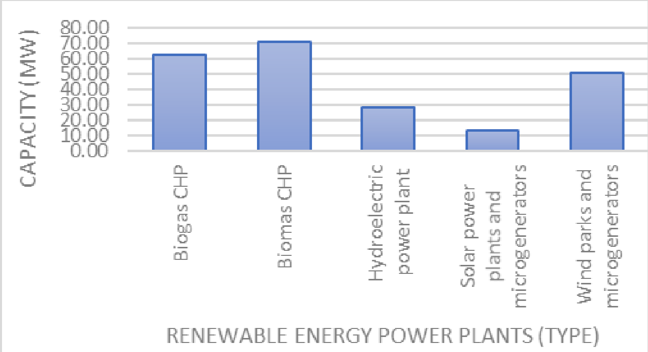


Fig.4. Renewable electricity generation capacity in Latvia in the distribution grid, MW

As per the data of distribution system operator [23], by the end of June 2021 the installed solar capacity for microgenerators (capacity up to 11.1 kW) was 9.12 MW, while the capacity of solar power plants (above 11.1 kW) was 4.44 MW, which adds up to 13.56 MW of solar capacity connected to the distribution grid in Latvia. This is not as impressive as in Germany with about 5 GW of installed solar capacity [24], but it is important to mention that in 2017 the solar capacity in Latvia was around 2 MW, so currently it has grown more than 6 times in the last 4 years.

The concept of energy communities can stimulate this tendency. If we make an assumption that in the next 4 years solar capacity will increase again at least 6 times, those would be more than 80 MW capacity in 2025. With efficiency rate of 16% [2], these would produce around 0.112 TWh/year (considering that these solar panels produce electricity 24/7 or 8760 hours/year). In such case, the solar energy could cover around 1,4% of Latvia's yearly consumption. Currently this share is close to 0% [26]. Though energy communities in short term will likely not become the mechanism that eliminates risk of electricity generation deficit, it can play a good role towards achieving EU renewable energy goals and climate neutrality.

IV. Conclusions

Though the concept of energy communities is much appreciated and can offer many opportunities both for the electricity consumers and the state in terms of increasing generation capacity, the EU Directives have provided a complicated and confusing baseline legislation that creates a knowledge gap.

Research showed that currently the planned legislation in Latvia provides a solid basic mechanism for energy communities and electricity sharing as well as peer-to-peer trade without harsh restrictions.

Considering the future electricity deficit in Latvia, energy communities have a good potential, but further detailed requirements (contracts, electricity data accounting, reporting, balancing) for creating them still must be developed in order to ensure the security of electricity grid.

For further development of the national legislation, it is important to involve public as much as possible to understand the current experiences and possibilities in order to create as efficient legal framework as possible.

The research and development of the legislation is complicated also because of the lack of best practice in the EU. Though pilot projects have been launched in many EU countries, the EU Directives have not yet been transposed by the neighboring countries that otherwise could provide advice.

Financing, such as providing grants, is one of the key measures that would allow energy communities to develop. Financing, appropriate legal framework, cost of technologies and the interlinked payback time, as well as responsiveness from the society will all impact the role energy communities will be able to play in order to avoid electricity deficit from 2024 onwards.

V. References

[1] Ministry of environmental protection and regional development. Report "Latvija stratēģija klimatneitralitātes sasniegšanai līdz 2050.gadam"

[2] Rozentale L., Lauka D., Blumberga D., Accelerating Power Generation with Solar Panels. Case in Latvia. Energy procedia, 2018, Vol. 147, pp.600-606.

[3] Eurostat. Renewable energy statistics. 2020. [Online] Available at; https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable_energy_statistics

[4] De São José D., Faria P., Vale Z., Smart energy community: A systematic review with metanalysis, Energy Strategy Reviews, Volume 36, 2021

[5] Caramizaru A., Uihlein A. Energy Communities: an overview of energy and social innovation, JRC Science for policy report, 2020.

[6] Heleweg M A., Saintier S., Renewable energy communities as 'socio-legal institutions': A normative frame for energy decentralization? Elsevier. Renewable and Sustainable Energy Reviews, Volume 119, 2020

[7] Soeiro S., Dias M.F. Community renewable energy: Benefits and drivers. Elsevier. Energy Reports. Volume 6, Supplement 8, December 2020, Pages 134-140

[8] Directive 2019/944 of the European Parliament and of the Council on common rules for the internal market for electricity and amending Directive 2012/27/EU. 2019. [Online]. Available at: https://eur-lex.europa.eu/legal-content/LV/TXT/HTML/?uri=CELEX:32019L0944&from=en

[9] Directive 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources. 2018 [Online]. Available at: https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32018L2001

[10] Ceglia F., Esposito P., Marasso E., Sasso M, From smart energy community to smart energy muncipliaties. Elsevier. Journal of Cleaner production, Volume 254, 2020

[11] Di Silvestre M.L., Ippolito M.G., Riva Sanseverino E., Sciumè G., Vasile A., Energy self-consumers and renewable energy communities in Italy: New actors of the electric power systems, Renewable and Sustainable Energy Reviews, Volume 151, 2021 [Online] Available at: https://www-sciencedirect-com.resursi.rtu.lv/science/article/pii/S1364032121008431

[12] Hoicka C.E., Lowitzsch J., Brisbois M.C., Kumar A., Camargo L.R., Implementing a just renewable energy transition: Policy advice for transposing the new European rules for renewable energy communities, Energy Policy, Vol. 156, 2021 [Online] Available at: https://www-sciencedirect-com.resursi.rtu.lv/science/article/pii/S0301421521003050

[13] Lowitzsch J., Hoicka C.E., van Tulder F.J., Renewable energy communities under the 2019 European Clean Energy Package – Governance model for the energy clusters of the future?, Renewable and Sustainable Energy Reviews, Vol. 122, 2020 [Online], Available at: https://www-sciencedirect-com.resursi.rtu.lv/science/article/pii/S1364032119306975

[14] Ministry of Economics of Latvia. Discussion papers. 2021. [Online]. Available at: https://www.em.gov.lv/lv/diskusiju-dokumenti

[15] Riga Planning Region, Expert discussion on the legal framework of energy communities and the possibilities of supporting RES projects, 2020 [Online] Available at: https://rpr.gov.lv/eksperti-diskute-par-energokopienu-tiesibu-ietvaru-un-aer-projektu-atbalsta-iespejam/

[16] Jurista vārds (legal journal), Recent case law in disputes over the abolition of support for the mandatory purchase of electricity, 2020 [Online], Available at: https://juristavards.lv/doc/277009-jaunaka-tiesu-prakse-stridos-par-elektroenergijas-obligata-iepirkuma-atbalsta-atcelsanu/

[17] Grzanić M., Morales J.M., Pineda S. and Capuder T., Electricity Cost-Sharing in Energy Communities Under Dynamic Pricing and Uncertainty,*IEEE Access*, vol. 9, pp. 30225-30241, 2021 [Online] Available at: https://ieeexplore.ieee.org/document/9354638

[18] Riga planning region. Atjaunojamās enerģijas kopienu projekts Mārupē. 2020. [Online]. Available at: https://zrea.lv/upload/attach/4_Marupes_energo_kopiena_16dec2020.pdf

[19] Helmane I. Plašākas iespējas pašpatēriņam, kad elektrību ražo saule un vējš. LV portāls, 2021. [Online] Available at: https://lvportals.lv/skaidrojumi/326480-plasakas-iespejas-paspaterinam-kad-elektribu-razo-saule-un-vejs-2021

[20] Kronbergs J. Do solar panels on the roof pay off? Jānis Kronbergs shares his experience. 2020. [Online] Available at: https://kursors.lv/2021/03/07/vai-saules-paneli-uz-jumta-atmaksajas-pieredze-dalas-janis-kronbergs/

[21] CEE Bankwatch Network, Latvian Green Movement, Energy communities' project developement in Latvia. Guidelines for potential project promoters, 2015. [Online] Available at: http://zalie.lv/wp-content/uploads/2014/12/Co-power-vadlinijas-LV_finaldocx.pdf

[22] JSC "Augstsprieguma tīkls", Pārvades sistēmas operatora ikgadējais novērtējuma ziņojums par 2019.gadu. 2020. [Online] Available at: https://www.ast.lv/sites/default/files/editor/PSO_Zinojums_2019.pdf

[23] Ministry of Economics of Latvia. Electricity producers. 2021. [Online] Available at: https://www.em.gov.lv/lv/elektroenergijas-razosana

[24] Solar Power Europe. EU Market Outlook for solar power 2020-2024. 2020. [Online] Available at: https://www.solarpowereurope.org/wp-content/uploads/2020/12/3520-SPE-EMO-2020-report-11-mr.pdf?cf_id=23124

[25] JSC "Augstsprieguma tīkls", Electricity market report. 2021. [Online] Available at: https://www.ast.lv/lv/electricity-market-review?year=2020&month=13

2020 IEEE 61th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON) | 978-1-7281-9510-0/20/$31.00 ©2020 IEEE | DOI: 10.1109/RTUCON51174.2020.9316486

Aggregator as a new electricity market player

(Case study of Latvia)

Liga Rozentale, Antra Kalnbalkite, Dagnija Blumberga
Institute of Energy Systems and Environment
Riga Technical University
Riga, Latvia
liga.rozentale@em.gov.lv

***Abstract*—The research focuses on evaluating the chances of a new electricity market player – aggregator – to come into Latvian electricity market in the nearest future. Electricity market in Latvia has been liberalized since 2015 and there is a wide range of electricity suppliers competing on market basis. It is important to understand, what role could an aggregator play in this market, will it be accepted by other market participants and does it have any chances to survive in a rather small economy with much lower number of electricity consumers than in many other European Union's countries that are currently working on implementing the European Union's legislation that would allow for aggregators to operate in the electricity market.**

Keywords— demand response, aggregator, electricity market, flexibility

I. INTRODUCTION

Nowadays we are living in a world, where the society, governments and other institutional players are looking for ways of achieving climate neutrality in the global economy. There are the usual ways – energy efficiency in buildings, innovative technical solutions for cleaner manufacturing, ecologically friendly cars and many more possibilities of which the population has become more or less familiar in the last decade. Meanwhile, there are also sector specific solutions that are less common and under-utilized. The aim of this research is to look at one specific solution, which has not yet developed in Latvia at all – aggregator – an electricity market player that has been defined at the European Union's level already for some time, but a player, who has been rather incomprehensible for the Latvian electricity market. This research focuses on the legislative and economic aspects of the aggregators in order to understand, how to introduce them in the Latvian electricity market and what kind of benefit would it give.

To understand the role of an aggregator, it is important to start with the concept of demand response. Demand-side response could be described as changes in the usual pattern of electricity consumption by the final consumer. [1] When a consumer decides on its own to use less electricity when it is more expensive (e.g. in the peak hours) and use it more when it is cheaper (e.g. at night) it becomes demand response, i.e., final consumers (demand-side) responds to the market incentives. There are two pre-conditions:

- Consumer must have a dynamic electricity price agreement with its' electricity supplier;
- Consumer must have a smart electricity meter installed.

A dynamic electricity price agreement with the electricity supplier means that the consumer pays for the electricity the real-time power exchange market's tariff. There will be a risk of high electricity price fluctuations, but it can also become very advantageous for the consumer in a longer low-price period. [2]

The smart meter in comparison to conventional meter shows the real-time electricity consumption and can be paired with the hourly electricity price in the power exchange market. Thus, the electricity consumers can follow the electricity price fluctuations and adapt their electricity consumption in order to save money.

It should be noted that demand-response has been defined in European Union's (EU) legislation already since 2012, when it was introduced by Directive 2012/27/EU on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. With Directive 2012/27/EU, the Member states of the EU where required to encourage the development of demand response and to create the necessary legal framework for that. [3]

It is important to also understand the reasons, why demand response is promoted at the EU level. Though one of the reasons is the empowerment of consumers, there is also a more general necessity for a better functioning of the electricity market as the demand response can provide the so-called flexibility. More and more electricity globally is produced by variable renewable energy sources such as hydro, wind, solar power etc. The electricity production is very dependent on the weather conditions, so either there needs to be other flexible generation options that can be turned-on when the weather condition are unfavorable for adequate electricity production from variable renewable energy sources or the demand side should become flexible in its demand. [4][2]

II. METHODOLOGY

The case study is based on researching the legal and economic aspects of demand response and aggregation, and applying them to the situation in Latvia.

As has been noted in a research by J.K. Juffermans [5], it's hard to predict how much of the conventional generation will be able to aid in providing flexibility in the future,

978-1-7281-9510-0/20/$31.00 ©2020 European Union

because it can be thoroughly based on political decisions on whether these conventional generation units will continue to operate (e.g. cogeneration plants from natural gas). Thus, a bigger role will be played by demand side response.

For the purpose of flexibility, demand response cannot be based on unpredictable actions of consumers, because these are not organized actions but based on personal interests of each individual. To make it organized (also known as explicit demand response), a new electricity market player has been introduced – an aggregator. As defined in the new Directive 2019/944 on common rules for the internal market for electricity and amending Directive 2012/27/EU, an aggregator "combines multiple customer loads or generated electricity for sale, purchase or auction in any electricity market". Article 17 further elaborates that:

- all markets (day-ahead, intraday) should be open to demand response, including ancillary services (balancing, reserves etc.);
- any electricity undertakings or consumers may be required to pay compensation to those market participants who are directly affected by demand response;
- compensation, if introduced, shall not be a barrier to demand response and shall only cover the costs incurred by the suppliers or supplier's balance responsible party.[6]

There are two types of aggregators – independent and combined. Combined aggregator means that an electricity supplier or balance responsible party or distribution system operator is also an aggregator, so aggregation is an additional function of an already existing market player. An independent aggregator on the other hand is a separate undertaking working independently from the previously mentioned electricity suppliers, balance responsible parties or system operators. Currently, more common in the EU is the combined aggregator, because it is easier to involve it in the market. It's not only less complex from the legislative perspective, but also from the perspective of the electricity consumers in cases, where the aggregator is the consumer's electricity supplier. [7]

At the same time, authors can argue that an aggregator can be seen as a threat from other market participants such as electricity suppliers. In view of the authors, demand response can be seen as a cost for retailers, because:

- Electricity retailers (balance responsible parties) buy this virtual electricity in the power exhchange market provided by aggregators. It's not actual electricity, but an electricity saving at a particular time. Retailers (balance responsible parties) buy this electricity to fullfill the demand but they cannot bill it to consumers.
- Demand response contributes to physical balancing of electricity market, but it is seen as a financial imbalance by retailers.

Fig.1. reflects all the flexibility mechanisms provided by the agreggators at different wholesale market segments, where aggregator can act as a facilitator for providing flexibility where needed. [8]

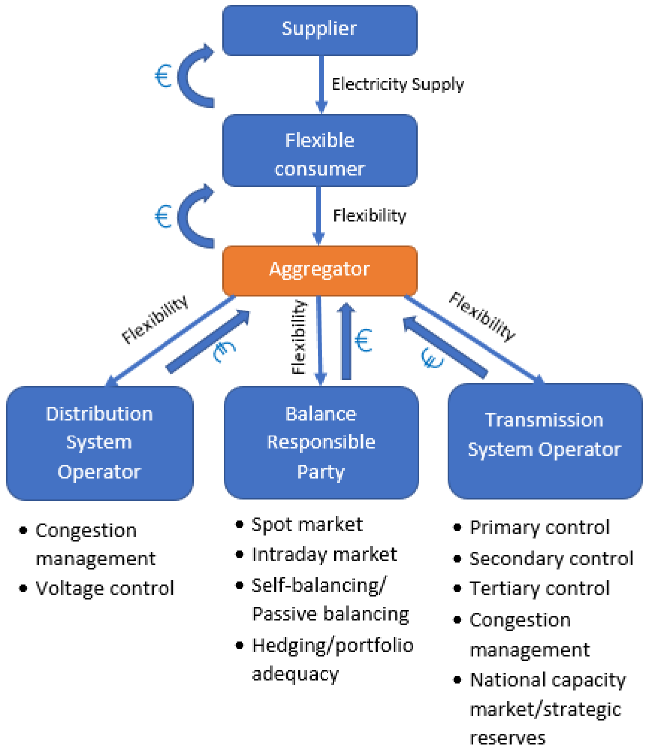


Fig.1. Flexibility services provided by aggregator [8]

There are 6 types of demand-side's electricity consumption management, which are shown in Fig.2. These different types of demand side management, which can be combined all together, allow us to very closely relate to generation. [9]

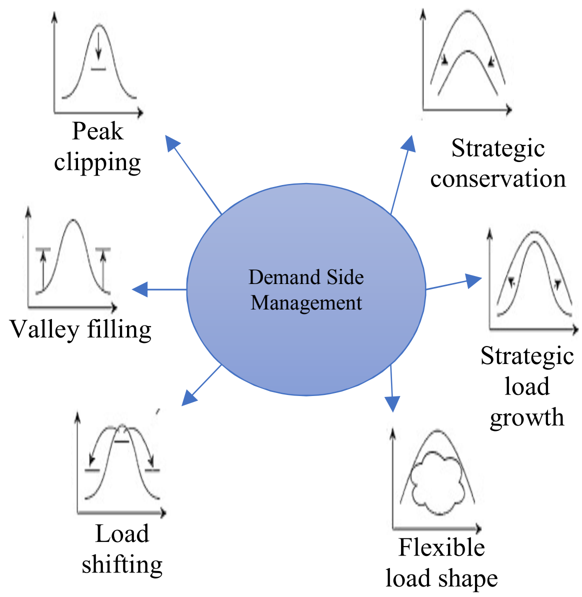


Fig. 2 Types of demand side management [9]

978-1-7281-9510-0/20/$31.00 ©2020 European Union

In growing demand of electricity, this can replace part of the generation that will be needed to fulfil this future demand. These demand side management types show us all the options an aggregator can use – it's not only load shifting to another period of time, but also decrease in electricity consumption in general by using the consumer's appliances more efficiently and thus providing benefits also for the EU's climate policy and climate targets. [9]

III. Case Study

In case of Latvia, most of the local electricity is produced in hydro power plants, where the main three power plants on Daugava river have the capacity of 1558 MW. [10] However, in dry years, the electricity sector is partly dependent on cogeneration from natural gas in two thermal power stations in the city of Riga with the total capacity of 976 MW. Currently, these cogeneration plants generate electricity when the electricity prices in Nord Pool power exchange are high, but they can't compete with cheap electricity and they are subsidized from the state and basically serve for the purpose of security of supply. [10][11] Thus, demands side response with the involvement of aggregation can be a valuable alternative.

Fig.3 shows that as mentioned before, the share of renewable energy in electricity is increasing also in Latvia, this increase is rather persistent for the last 10 years. With this increase, new mechanisms for flexibility in electricity demand are necessary considering the volatile nature of renewable energy sources. As has been mentioned above, when the renewable energy sources fail to provide balance in the electricity system (due to the weather, which impacts the amount of electricity that can be produced by the main renewable energy sources – hydro, wind and sun), aggregators can provide the necessary flexibility (by lowering, shifting or using other previously mentioned demand side management types to change electricity demand) and ensure balance in the electricity system. [12]

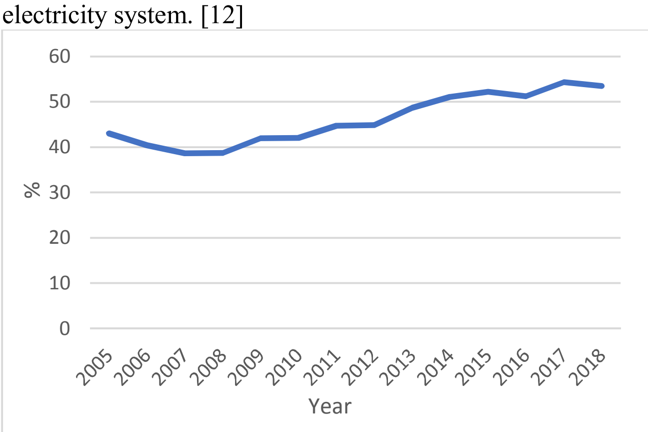


Fig.3. Share of renewable energy in electricity, % [13]

As was explained above, an aggregator should be able to participate in all types of electricity markets. Currently aggregators mostly participate in the balancing market by becoming balancing service provider (BSP). Meanwhile, each electricity supplier has its balancing responsible party (BRP). BRP is responsible for submitting energy generation and consumption schedules to the transmission system operator on the day before electricity delivery. On the other hand, BSP (in this case aggregator) submits balancing service bids to the system operator, who will procure this service. When BRP deviates from the submitted electricity generation and consumption schedule, BSP will activate balancing energy to ensure balance in the electricity system. System operator will pay BSP for its service and allocate these costs to BRP, who will have to pay for the created imbalance. [14]

In the beginning of 2020, following the requirements of the above-mentioned Directive 2012/27/EU, the Cabinet of Ministers of Latvia approved the first rules on the functioning of aggregators in Latvia. [15]

The regulation defines the rights and obligations of aggregators, payments for the services provided by aggregators, as well as define relations between the aggregators and other electricity market's participants. The rules increase the ability of electricity consumers or third parties of their choice to handle electricity consumption information in order to provide a mechanism by which consumption can be adjusted quickly.

Latvian legislation sets that an aggregator is a new type of energy service provider that can increase or decrease the electricity consumption of a group of consumers according to the total electricity demand in the network, thus allowing the consumption to become flexible. It is important to mention that the consumer may be remunerated for participating in the provision of a demand response service. An aggregator may enter into a contract with several customers, on the basis of which it may temporarily reduce their electricity consumption if there is a high demand for electricity. The aggregator then sells this saved electricity to the electricity market. An aggregator can also do the opposite and can increase electricity consumer consumption when electricity prices are favorable. [15]

Fig.4 shows hourly electricity price in the Nordpool power exchange's Latvian price area on 3 August 2020. As can be seen in the figure, the lowest electricity prices are at night between 12 AM and 4 AM, while the highest prices are in the morning hours before work, as well as after the typical working hours at 7 PM.

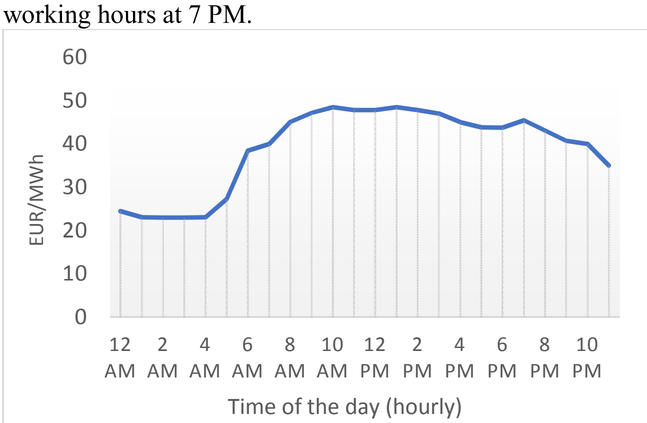


Fig.4. Hourly EUR/MWh in NordPool Latvian price area, 3 August 2020 [16]

978-1-7281-9510-0/20/$31.00 ©2020 European Union

To authors minds we could distinguish between two different approaches to aggregation – household aggregation and aggregation in manufacturing sector. Household sector means that the aggregated electricity amount is much smaller. An aggregator working with households would need to have a large portfolio of households to make an impact and to have a profitable business. As has been explained to authors in an informal interview by an entrepreneur from France working in the field of aggregation and having a pilot project in Estonia, aggregators in households focus on such household appliances as electric heaters, boilers, heat pumps, air-conditioners and thermostats. These can be easily controlled by distance and without disturbing the daily life of consumers, who would not feel discomfort due to limitations in electricity usage. However, as explained by the above-mentioned entrepreneur, the aggregator needs to have at least 10 000 consumers, who save 5 kWh a day to make it a profitable business. For instance, general review of online offers for electrical appliances provides that on average a central air conditioner/heat pump consumes around 5 - 15 kW per hour, so reduction of electricity consumption by 5 kWh a day is actually not so much considering that part of the amount of electricity would still be consumed but at different time of day, when the electricity prices are lower. For example, Fig.5 shows the demand of electricity in Latvia on 3 August 2020. The red line is the actual demand, but the blue line has been drawn by the authors to show how could an aggregator level out the demand in peak hours by shifting it to different time of day.

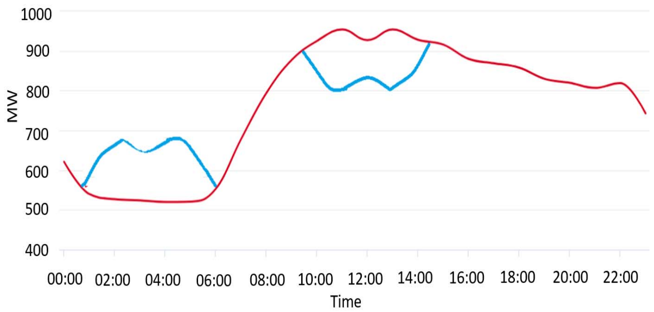


Fig.5. Electricity consumption MWh/hour in Latvia on 3 August 2020 [17]

For example, the state-owned electricity supplier JSC “Latvenergo” has around 700 000 household electricity clients [18], so creating a portfolio of 10 000 consumers that would be ready to engage in the activities of demand response would not be impossible. Moreover, a combined aggregator does not even need so many consumers, because there would be a loop between the aggregator and the electricity supplier, where the income created by an aggregator in substance stays with the same undertaking (the supplier) and thus no actual costs would emerge for the supplier. The second biggest electricity supplier in Latvia JSC “Enefit” has almost 6000 household electricity clients [19], thus also providing an already existing large client basis, where part of them could engage in demand-response.

If an aggregator has aggregation agreements with 10 000 consumer that reduces at least 1 kWh daily (not 5 kWh, because most of the aggregated amount is shifted to another timer period and not reduced), these are 10 MWh a day or 3650 MWh per year by rough calculations. Latvia’s yearly consumption of electricity is around 7 TWh. This means that an aggregator could be capable of reducing the yearly electricity consumption in Latvia by at least 0.05%. This may not seem much, but for one aggregator it is not a bad result and would also serve as means for achieving national energy and climate targets. [20]

However, considering the necessary amount of clients needed for the business of aggregators to be profitable, it does not seem realistic for the time-being for an independent aggregator to come in the market unless this is an international investor coming with its business from another EU country, which already has a large market portfolio. This option of combined aggregator is not only the main possibility currently from the economic perspective that can be advantageous for both aggregator and supplier, but also the only technical possibility. The current national legislation does not allow for an independent aggregator to come into the market because there is a requirement for the aggregator to be associated with the same balancing service provider as the consumer’s object which is intended to be used in the demand response service. And this balancing service provider should give authorization for aggregation. [15] Basically, it means that the aggregator needs to coordinate its actions with consumer’s electricity supplier, which is also the balance responsible party. Thus, if the consumer’s supplier disagrees, aggregator cannot participate in aggregation. However, this is not in accordance with the previously mentioned Directive 2019/944, which provides that neither the consumer, nor the independet aggregator has to coordinate their mutual agreement and the use of the demand response with electricity supplier and/or its balancing service provider. The provisions of Directive 2019/944 have to be implemented by 31 December 2020, so it shall change in the nearest time.

The ammended national regulation shall enable aggregators to participate not only in the balancing market, but in intra-day and day-ahead markets as well and the EU legal framework allows member states to introduce a compensation mechanism for suppliers. The question is, how to set a fair compensation, so that the supplier is not pushed in a disadvantageous position by aggregators.

TABLE 1. ECONOMIC ASPECTS OF AGGREGATION

A. No demand response	B. Demand response without compensation
1. Supplier forecasts consumption of 20 MWh	1. Supplier forecasts consumption of 20 MWh
2. Supplier buys on NordPool 20 MWh electricity x 50 EUR/MWh = 1000 EUR	2. Supplier buys on NordPool 20 MWh electricity x 50 EUR/MWh = 1000 EUR
3. Supplier sells 20 MWh electricity to consumers for 50 EUR/MWh = 1000 EUR	3. Aggregator activates demand response and reduces consumers’ consumption by 2 MWh

978-1-7281-9510-0/20/$31.00 ©2020 European Union

	4. Supplier sells 18 MWh electricity to consumers for 50 EUR/MWh = 900 EUR
	5. Supplier loses 100 EUR (2 MWh x 50 EUR/MWh) due to demand response

Table 1 shows a hypothetic example of the economic aspects of aggregation. Scenario A have the usual circumstances – supplier buys the forecasted amount of electricity from Nordpool power exchange and supplies it to consumers. Scenario B however introduces demand response. Supplier forecasts the same amount of consumption and buys on Nordpool power exchange the amount of electricity that would normally be necessary for consumers. However, due to agreement with aggregator, consumers eventually consume less than it was forecasted. So, supplier has bought 20 MWh, but it can sell only 18 MWh, in result the supplier has lost 100 EUR. This is approximately the same amount that the aggregator will gain (assuming the aggregator has also sold his aggregation services by 50 EUR/MWh x 2 MWh = 100 EUR). While understanding the situation of supplier, if we asked the aggregator to compensate the losses, there would basically be no business case for the aggregator.

However, here is another option that can be considered fair. It has been observed by some studies, that when aggregator provides its services to the electricity market, the overall electricity price in the Nordpool power exchange lowers, because the more expensive generation units are excluded from bidding. [8] As a result, the supplier gains because he has paid less for the 20 MWh than he would have paid if there was no demand response.

As an example, NordPool's price without demand response could be 55 EUR/MWh. Thus, the supplier would have bought the same 20 MWh for 1100 EUR (by 100 EUR more). In this case, the supplier does not lose anything – he paid at NordPool 100 EUR less, which is the same amount that he lost due to demand response by not selling 2 MWh (Scenario B). As a result – there is no net loss for the supplier and the aggregator should not pay any compensation to supplier.

Another example would be, where NordPool's price without demand response is 52 EUR/MWh. In this case, supplier would have paid 1040 EUR for 20 MWh (by 40 EUR more). Here, the supplier has gained 40 EUR at NordPool, while losing 100 EUR by not selling 2 MWh. So, the supplier's net loss is 60 EUR. This is the amount that should be compensated to supplier by the aggregator.

Considering the above-mentioned, it would be fair for both supplier and aggregator to introduce such a compensation mechanism. However, the challenge here is to determine what the NordPool price would have been without aggregation. The possible solution would be for NoordPool to provide such data and for transmission system operator to calculate the settlement amount. That would lead to a central settlement model, where the compensation mechanism is managed by the transmission system operator.[21]

Meanwhile, another detail needs to be considered, that not all electricity consumers currently would be able to make an agreement with an aggregator as not all electricity consumers are equipped with smart electricity meters that were mentioned in the introduction part as a prerequisite for receiving demand response services. Currently about 60% of all electricity meters in Latvia are smart meters, but it is planned that all electricity meters will be updated to smart meters by 2022. [22]

IV. Conclusions

It can be argued that the entry of aggregators into the electricity market can have several benefits, such as:

- aggregators help transmission system operators to ensure a continuous balance of electricity generated and consumed;
- energy savings are achieved both in the final energy consumption phase and in the better use of networks and means of production in the energy production, transmission and distribution phases;
- electricity consumption time can be adjusted according to changes in electricity prices - reduced when prices are highest, but increased when prices are lower without changing the volume of consumption;
- more efficient use of resources while reducing system load.

Thus, the aggregators and demand response can provide benefits not only for the electricity policy of Latvia, but also can serve for the good of climate policy, when reducing the electricity consumption in Latvia.

However, currently the existing electricity market players have not yet engaged in understanding and using the possibilities currently provided for the electricity suppliers who could combine their role of supplier with the role of aggregator. This model can be financially beneficial under the existing market conditions.

Meanwhile, independent aggregators are yet to develop in Latvia. Even if the technical barriers in the legislation are resolved, it will not be enough for independent aggregators to immediately enter the electricity market from the economic perspective as an aggregator would need a rather big client portfolio.

It is important to develop a regulation, which introduces compensation mechanism for suppliers, but there needs to be a middle ground in order not to destroy any business possibilities an aggregator may have,

As this research mainly focused on the residential household area and the aggregators role in it, research could be further developed focusing on the potential that could be provided to aggregators by large manufacturing enterprises.

Acknowledgment

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-EM2018/AER-1-0001

978-1-7281-9510-0/20/$31.00 ©2020 European Union

V. References

[1] A.A.Tellidou, Agent-based analysis of capacity withholding and tacit collusion in electricity markets, IEEE, Transactions on Power Systems, vol. 22, no. 4, pp. 1735-1742, 2007.

[2] Zvirgzdiņa, M., Bogdanova, O., Spiridonovs, J. Aggregator as Cost Optimization Tool for Energy Demand. 17th International Scientific Conference "Engineering for Rural Development": Proceedings, Volume 17, Latvia University of Life Sciences and Technologies Faculty of Engineering, 1781.-1786., 2018.

[3] European Commission, Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC, 2012. [Online] Available at: https://eur-lex.europa.eu/eli/dir/2012/27/oj/?locale=LV [Accessed on 25 July 2020].

[4] Ponds K.T., Arefi A., Sayigh A., Ledwich G. Aggregator of demand response for renewable integration and customer engagement: strengths, weaknesses, opportunities, and threats. Energies, vol.11, pp.2391, 2018.

[5] Juffermans J.K., "Aggregators and flexibility in the Dutch electricity system" Industrial Engineering & Innovation Sciences; Eindhoven Univerity of Technology, 2018.

[6][6] European Commission, Directive 2019/944, 2019. [Online] Available at: https://eur-lex.europa.eu/legal-content/en/TXT/HTML/?uri=CELEX:32019L0944&from=en [Accessed on 10 August 2020].

[7] De Clercq S., Schwabeneder D., Corinaldesi C., Bertetti O., "How to create value through aggregation: a business model review for multiple regulatory environments in Europe" 8th International Workshop on Integration of Solar Power into Power Systems, Stockholm, 2018.

[8] Ziegler H., Mennel T., Hulsen C. Eurelectric. Short study on Demand Response activation by independent aggregators as proposed in the draft Electricity directive, 2017. [Online] Available at: https://www.eurelectric.org/media/2155/eurelectric_dr_aggregation_final_report-2017-2521-0002-01-e.pdf [Accessed on 5 September 2020].

[9] K. A. Linas Gelazanskas, "Demand side management in smart grid: A review and proposals for future direction," Elsevier, Sustainable Cities and Society, vol. 11, pp. 22-30, 2014.

[10] JSC "Latvenergo", Generation capacity in thermal power stations and hydro power stations, 2020[Online] Available at: https://latvenergo.lv/lv/par-mums/razosana [Accessed on 12 August 2020].

[11] Ministry of Economics of Latvia, National Energy and Climate Plan, 2019. [Online] Available at: https://em.gov.lv/lv/nozares_politika/nacionalais_energetikas_un_klimata_plans/. [Accessed 2 September 2020].

[12] Essiet I.O., Sun Y. Maximizing demand response aggregator compensation through optimal RES Utilization: Aggregation in Johannesburg, South Africa. Department of Electrical and Electronics Engineering Science, University of Johannesburg, Johannesburg, 2006.

[13] Central Statistical Bureau of Latvia, Share of renewable energy in electricity, 2019 [Online] Available at: http://data1.csb.gov.lv/pxweb/en/vide/vide__energetika__ikgad/ENG051.px/table/tableViewLayout1/ [Accessed on 15 August 2020].

[14] Van der Veen R., Hakvoort R.A. The electricity balancing market: Exploring the design challenge. Elsevier, Utilities Policy, Volume 43, Part B, pp.186-194, 2016.

[15] Cabinet of Ministers of Latvia, Rules on aggregation, 2020 [Online]. Available at: https://likumi.lv/ta/id/313461-agregatoru-noteikumi [Accessed on 1 September 2020].

[16] NordPool Power exchange, Electricity price EUR/MWh, 2020 [Online]. Availabe at: https://www.nordpoolgroup.com/Market-data1/Dayahead/Area-Prices/LV/Hourly/?view=table [Accessed on 16 August 2020].

[17] Transmission system operator JSC "Augstsprieguma tikls", Power system state, 2020. [Online] Available at: https://ast.lv/lv/content/situacija-energosistema [Accessed on 20 August 2020].

[18] JSC "Latvenergo", Trade operations, 2020 [Online]. Available at: https://latvenergo.lv/lv/par-mums/tirdzniecība [Accessed on 1 September 2020].

[19] Ltd "Enefit", Enefit has increased its client portfolio by three times, 2020. [Online] Available at: https://www.enefit.lv/majai/zinas/Enefit-triskart-palielina-savu-klientu-portfeli [Accessed on 17 august 2020].

[20] Burger S., Chaves-Avila J.P., Batlle C., Perez-Arriaga I.J. A review of the value of aggregators in electricity system. Elsevier, Renewable and Sustainable Energy Reviews, Vol. 77, pp.395 – 405, 2017.

[21] Kurevska, L., Junghāns, G., Sauhats, A., Broka, Z., Baltputnis, K., Lavrinovičs, V. Case Study - Assessing Economic Potential for Demand Response in Baltic Balancing Market. IEEE: 59th International Scientific Conference on Power and Electrical Engineering of Riga Technical University, 2018.

[22] JSC "Sadales tikls", Smart and other electricity meters. 2020. [Online] Available at: https://www.sadalestikls.lv/en/to-customers/electricity-meters/about-electricity-meters/ [Accessed on 22 August 2020].

978-1-7281-9510-0/20/$31.00 ©2020 European Union

energies

Article

Will Aggregator Reduce Renewable Power Surpluses? A System Dynamics Approach for the Latvia Case Study

Ieva Pakere *, **Armands Gravelsins**, **Girts Bohvalovs**, **Liga Rozentale and Dagnija Blumberga**

Institute of Energy Systems and Environment, Riga Technical University, LV-1048 Riga, Latvia; armands.gravelsins@rtu.lv (A.G.); girts.bohvalovs@rtu.lv (G.B.); liga.rozentale@rtu.lv (L.R.); dagnija.blumberga@rtu.lv (D.B.)
* Correspondence: ieva.pakere@rtu.lv

Abstract: Power demand-side management has been identified as one of the possible elements towards a more flexible power system in case of increased capacities of variable renewable energy sources—solar and wind energy. The market coordinators or aggregators are introduced to adjust the electricity consumption by following the market situation. However, the role of aggregators is mainly analysed from the economic perspective, and the demand side management is performed to maximise the utilisation of low price power during off-peak hours. However, this research focuses on analysing the introduction of aggregators as a future player to increase the total share of renewable power and decrease the surplus solar and wind electricity occurrence. An in-depth system dynamics model has been developed to analyse the hourly power production and power consumption rates at the national level for the Latvia case study. The results show that introducing aggregators and load shifting based on standard peak shaving can increase the share of surplus power and does not benefit from increased utilisation of solar and wind power. On the contrary, demand-side management based on available RES power can decrease the surplus power by 5%.

Keywords: demand-side management; aggregator; variable renewable energy sources; system dynamic modelling; Latvia

Citation: Pakere, I.; Gravelsins, A.; Bohvalovs, G.; Rozentale, L.; Blumberga, D. Will Aggregator Reduce Renewable Power Surpluses? A System Dynamics Approach for the Latvia Case Study. *Energies* **2021**, *14*, 7900. https://doi.org/10.3390/en14237900

Academic Editor: David Borge-Diez

Received: 26 October 2021
Accepted: 23 November 2021
Published: 25 November 2021

1. Introduction

On the European Union's (EU) way towards climate neutrality, the role of renewable energy sources (RES) keeps growing. However, the volatile nature of the RES, which depends on the wind speed, solar radiation, water inflow in rivers, also requires a higher level of flexibility in the energy demand. One of the solutions for providing flexibility is to involve demand response. As has been defined in the EU Directive on standard rules for the internal electricity market (Electricity Directive), demand response (DR) is "*the change of electricity load by final customers from their normal or current consumption patterns in response to market signals*" [1]. Thus, in DR, electricity consumers provide adjustments in their regular electricity consumption.

There are four main reasons for DR [2]:

(1) To reduce the total electricity consumption;
(2) To reduce the need for more power generation;
(3) To change the demand pattern to stimulate the potential of renewable energy generation;
(4) To reduce the congestion risks in the electricity grid.

DR is usually facilitated by a new electricity market participant—an aggregator who performs aggregation [3,4]. As has been defined in the Electricity Directive, aggregation is "*a function performed by a natural or legal person who combines multiple customer loads or generated electricity for sale, purchase or auction in any electricity market*" [1]. In reality, it means that this electricity market player—the aggregator—has agreements with electricity consumers, who should adjust their electricity consumption following the instructions of the aggregator, who follows the market situation and requests energy consumption to be decreased when the electricity demand and price is high (during the peak hours) and the consumption to be increased when the electricity demand and price are lower. In return, it provides financial savings for the consumer [5]. Meanwhile, demand response provides both financial benefits for the consumer and security of energy supply due to the uncertain nature of RES and the necessity to optimise the energy consumption [6,7].

DR can be applied both to residential and industrial consumers; however, the electricity consumption load from a residential consumer is relatively minor. Therefore, aggregators need to involve a high level of residential participation in the DR to impact the electricity market [8]. This aspect has also been overviewed in the case study for Latvia while discussing that currently, there are no active aggregators in the Latvian electricity market [4]. Research from Germany shows that 80% of the electricity is consumed by around 2–10% of the industrial consumers [9]. A similar situation has been identified in Latvia, where 85% of electricity is consumed by 25% of the industrial consumers, specifically by the manufacturing sector, providing good opportunities for aggregation [10]. For industrial consumers, the most typical high electricity load to control is considered air conditioning and heating, ventilation, and air conditioning systems, which are simple to control by distance (i.e., with smart metering) and provide large load DR at once in comparison to individual household loads [9]. Some studies differentiate between DR aggregator for residential, commercial, industrial, and agricultural activities and DR by prosumers, small energy producers, producing for their consumption [11].

Though DR has not yet been developed in Latvia, the corresponding national legislative framework has been developed. Nevertheless, it is not fully compliant with the Electricity Directive and provides barriers for independent aggregators to enter the market, as they have to coordinate their actions with electricity suppliers [12].

Aggregators can be assigned into different categories depending on the source of aggregated energy, as shown in Figure 1. but they are not limited to that. Demand aggregator can be the electricity supplier and aggregate electricity from all its consumers. The load aggregator aggregates flexibility. The production aggregator aggregates electricity from a group of generators, i.e., electricity producers are asked to increase or reduce generation loads at their power plant [13]. Electric vehicles can participate in aggregation by charging or discharging their batteries into the grid [14]. The same goes for energy storage. The location of the consumers is not essential [8].

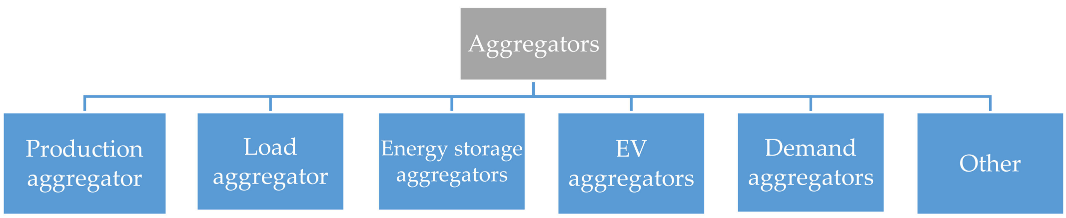


Figure 1. Types of aggregators [8].

Aggregators can play a large set of roles in providing flexibility in the energy market, as they can aid different electricity market players, such as reducing imbalances in the electricity system or avoiding congestions in the electricity grid [15].

A study shows that an aggregator in principle can have three types of contracts with its consumers:

(a) Fixed load—a load that cannot be reduced or shifted by the aggregator and has to be constant during a specific time frame to keep the consumers' activities intact;
(b) Load curtailment—a load that has to be reduced when aggregator requests it;
(c) Duration differentiated loads—a load has to be provided at certain time frames for a specific duration in a certain amount of time. Thus, it is not a continuous load, which differs from a fixed load [16].

The types of contracts mentioned above can be further elaborated into specific strategies. Aggregators can provide DR by implementing different demand-side management strategies [4,17]. For example, while peak clipping reduces the energy consumption, valley filling stipulates the consumption at other times of the day, most commonly by charging batteries such as for the EV [18]. The strategies can be combined to adjust to the electricity generation at a given time. The most common strategy is load shifting, where high electricity demand is lowered by shifting it to another time of the day. Thus, the peak demand is curtailed while this demand is shifted. The load can be shifted as a whole, but it can also be subdivided into smaller loads and spread across a specific period.

For aggregators to provide their services, the consumer should have a smart meter. Though system operators provide gradual roll-out of smart meters, aggregators provide their technologies to control the consumer's appliances from a distance [19]. Thus, the consumer technically does not have to control its appliances. The aggregator can do it on behalf of the consumer, e.g., switching off the air-conditioner at a certain point and turning it back on after a short period so the consumer cannot feel discomfort.

Two types of DR programs can be distinguished as providing consumer benefits–incentive-based and price-based programs. An incentive-based program pays a fee to consumers for reducing the electricity demand at peak hours. But price-based program provides different electricity prices at different times. Thus consumers would choose to consume electricity at times when the prices are lower [17]. If the consumer has a dynamic price agreement with its electricity supplier, it gains a monthly fee from the aggregator (as per their agreement) and lowers the monthly electricity bill costs.

Aggregators can participate both in the day-ahead market by providing a bid on how much DR it is willing to provide on the next day and in the balancing market to ensure the real-time stability in the electricity market after other market participants have failed to fulfil their commitment in the day-ahead market. However, it needs to be noted that aggregators themselves can also fail to fulfil their bids and can provide imbalances in the market. Moreover, aggregators can cause imbalance to other market participants due to their activities [4,20].

To provide services in the electricity market, aggregator uses decision-support tools. These can be optimisation models that show the day-ahead bids and real-time optimisation algorithms that allow the aggregator to follow the flexibility and provide the load trade by aggregators in the day-ahead markets. If an aggregator plans to provide multiple products (balancing energy, reserves etc.) to the market, there are also tools to support that by controlling in real-time diverse, flexible resources [21]. Research shows that a support vector machine (statistical learning approach) can be used with relatively high accuracy to forecast the loads aggregated from households [22]. Different game models have been developed (both with regulated and unregulated competition and using Nash equilibrium) to model the competition between multiple aggregators, which provide each aggregator with the best bidding strategy to benefit the most [21]. The same game models have also been used to show the benefit for system operators arising from aggregators' services [23]. Meanwhile, the mathematical modelling of DR algorithms shows the effect of DR activation at different levels—household level, grid level, and wholesale market level [24]. There have also been researched particular methods for using DR for residential consumption in smart grids with a high level of renewable energy coming into the market, providing the optimal usage of renewable energy, where consumption with the aid of aggregators could follow the renewable energy production load [25,26].

The above reviewed EU legal framework and academic research provides us with the general concept of DR and outline the role aggregators could play in the energy market. However, the actual effect of aggregation depends on the circumstances in the specific EU country, where the aggregation is applied considering such previously mentioned aspects as electricity consumption patterns, electricity generation loads, availability of smart meters, consumers' willingness to participate in DR (including policy incentives), national legal framework, etc. Thus, the article focuses on analysing the possible benefits of DR on reaching a higher renewable power share in the power market of Latvia. An in-depth system dynamics model compares the hourly power consumption and RES power production rates to identify the potential flexibility increase through the introduction of aggregators and obtained environmental benefits from the increased utilisation of RES power in Latvia.

2. Materials and Methods

The system dynamics modelling method evaluates the dynamic effects of DR and its future role in the national energy sector. Modelling is performed by using the Stella Architect software (Stella Architect 2.1. developed by isee systems, Lebanon, NH, USA). This method is broadly applied to analyse different aspects of the energy sector, including energy efficiency increase, RES support policies, and innovative heat supply techniques [27–29].

Figure 2 shows the overall concept of the study. The research algorithm is shown in Figure 3. The first step includes the analysis of an existing situation in the power sector and developing a system dynamics model on an hourly basis. The hourly RES power generation and demand submodel is soft-linked to the national energy system model by providing the annual input data regarding the RES power. The national model represents the overall situation in the Latvia case study and includes different energy consumers and producing units. The installed capacity of the RES power systems has been obtained from the national energy sector model, which also included different support policies promoting RES installations. The hourly solar and wind power generation has been compared with the average power demand profile in the household, industrial and service sectors by identifying the periods when surplus power occurs.

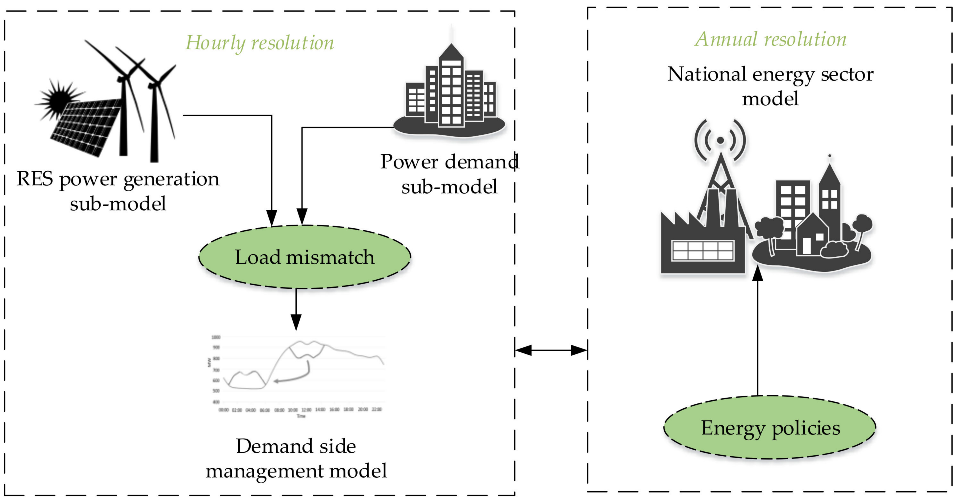


Figure 2. Research framework.

Further, the load mismatch has been analysed, and different scenarios for demand-side management strategies and aggregator roles in the energy sector have been evaluated. The aggregator has been introduced within the study to increase the overall system flexibility towards higher integrated RES power share. The surplus power amount is recalculated for the scenarios with aggregator introduction. The results are compared with the base scenario without demand-side management. Finally, the conclusions and recommendations for power sector flexibility increase are identified.

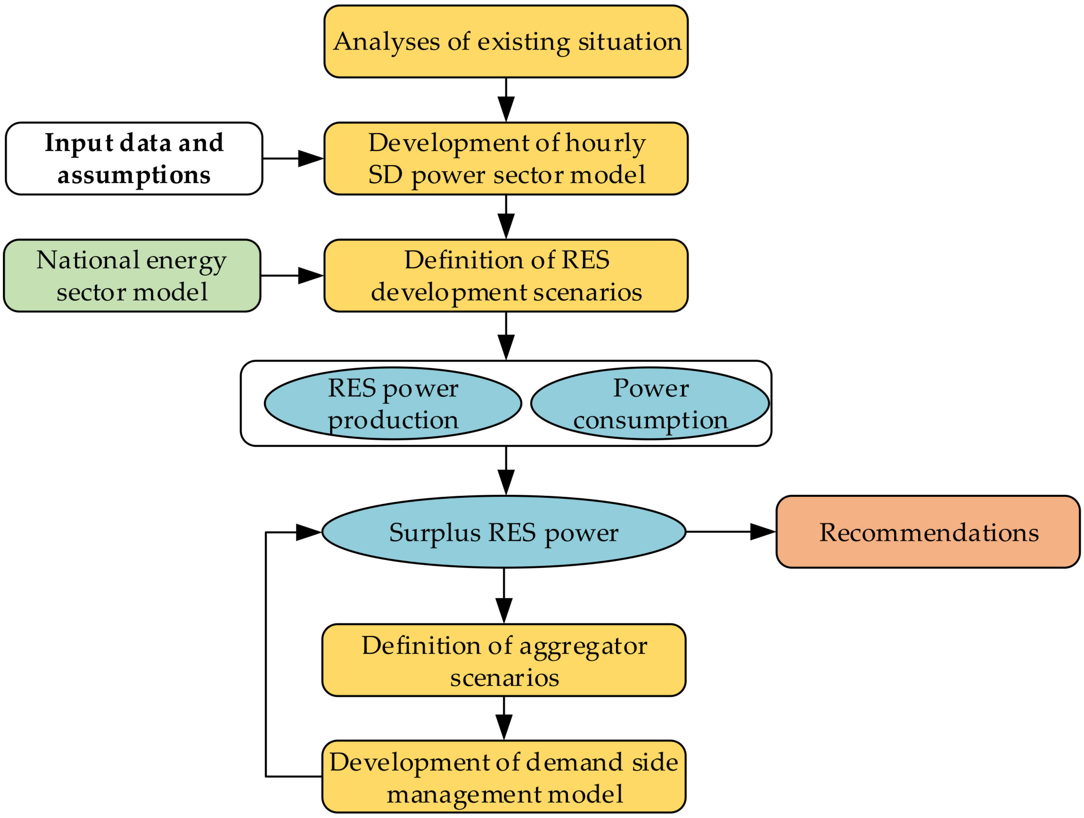


Figure 3. Research algorithm.

2.1. Power Sector in Latvia

The most significant sources of electricity generation in Latvia are two natural gas thermal power plants with a total installed capacity of 976 MW and large hydroelectric power plants along the river Daugava with a total installed capacity of 1558 MW. Other sources consist of a total of 212 MW installed capacity, including smaller producers with 203 MW installed capacity such as cogeneration plants, hydroelectric power plants, solar power plants, and wind turbines [30]. An additional amount of power is produced in microgeneration that mainly consists of solar power plants with nine MW of installed capacity [30]. By producing electricity locally, Latvia had around a 15% shortage in 2018, covered by power imports.

Power consumption mainly consists of three sectors, production, services, and households. The services sector has the highest electricity consumption share of 42%, following production with 30% and households with 28% in 2020. From 2008 to 2020, household electricity consumption has been decreasing, while electricity consumption from services has fluctuated [31].

Latvia participates in the Nord Pool day-ahead market, an auction where power is traded for delivery each hour of the next day [32]. Nord Pool markets are divided into several bidding areas. Based on the submitted orders bidding area prices are calculated and published. Therefore, power is always transferred from the low price area to the high price area. The resulting energy prices and demand indicate how much electricity should be produced locally, exported, or imported [33].

2.2. Power Consumption Modelling

The primary variable for successful aggregator operation is power consumption. Therefore, the hourly power consumption data have been used as the main parameter to model the potential load shifting. Hourly consumption profile for different consumers is acquired from the electricity distribution operator of Latvia [34]. The model uses the average hourly power consumption from 70 households with total annual power consumption ranging from 1.8 MWh to 18 MWh per year and 50 industrial and service consumers in 2018. The industrial consumers include wood processing, the food industry and other industrial plants, with the annual power consumption ranging from 189 MWh to 8060 MWh per year. The consumers from the service sector include 25 different public and private utilities, including banks, hospitals, shopping malls, educational buildings etc. As a result, the annual consumption in the service sector varies from 54 MWh per year to 1972 MWh.The average profile is calculated from the provided sample of consumption profiles for each consumer group (see Figure 4.). Then, the average profile is attributed to all consumers in each group to calculate total electricity consumption in household, industry and services sectors.

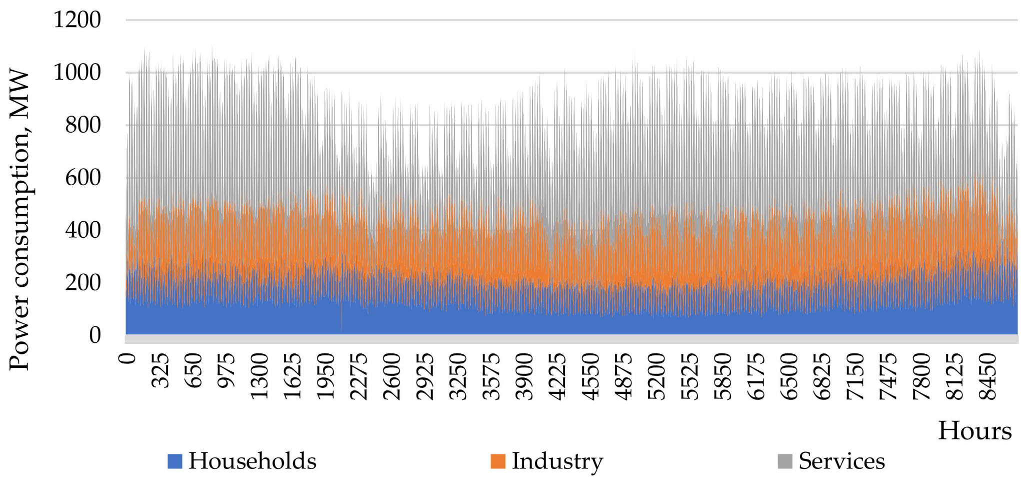


Figure 4. Hourly power consumption by consumer type.

The final results are compared to the statistics of electricity consumption in each sector at the national level. Annual consumption of electricity for different consumers are taken from official statistics [35]. Figure 5. displays the accumulated electricity consumption based on hourly consumption profiles.

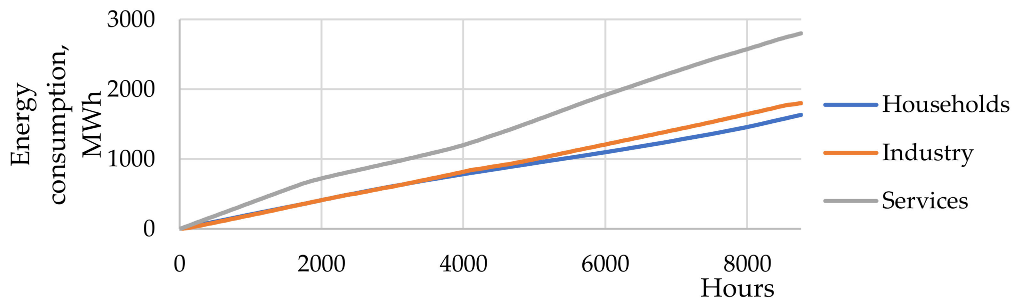


Figure 5. Annual accumulated electricity consumption for different consumer groups.

From the actual power consumption data, the peak hours and the power consumption at night have been estimated.

2.3. RES Power Production Sub-Model

The RES power production sub-model (see Figure 6.) estimates the hourly power production rates from wind farms and solar power plants based on climatic conditions in Latvia.

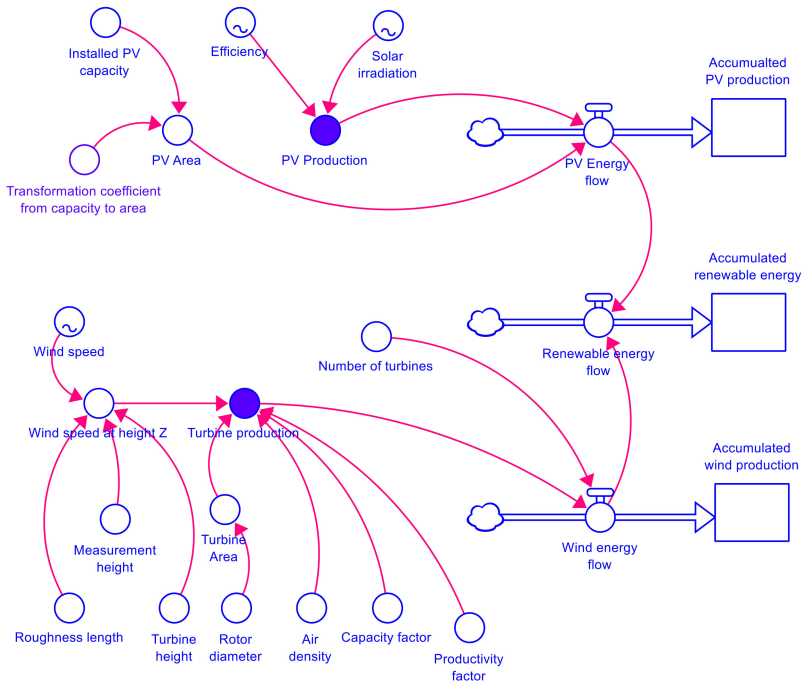


Figure 6. RES power production sub-model.

The solar power production rates are based on the average solar irradiation data and assumptions on average photovoltaic (PV) panel efficiency [36]:

$$E_{PV} = \eta_{PV} \cdot SI \quad (1)$$

where E_{PV}—PV power production, MW/h; S_{PV}—installed area of PV, m^2; η_{PV}—PV efficiency, %; SI—solar irradiation, MW/m^2/h.

The data regarding average solar irradiation rates from 2018 have been used within the model obtained from the national meteorological database. More in-depth analysis regarding solar profiles in Latvia has been described in previous research by Polikarpova et al. [37]. In July, the maximal hourly solar irradiation reaches 799 W/m^2, but the average annual solar irradiation is 1002 kWh/m^2.

The hourly production rates of wind power are based on the average hourly wind speed and general estimations on technical parameters of typical wind turbines. The hourly wind power capacities are calculated according to (2):

$$E_{WT} = \frac{0.5 \times C_f \times \eta \times \rho_{air} \times A \times {v_z}^3}{1,000,000} \quad (2)$$

where E_{WT}—turbine production, MW/h C_f—capacity factor; η—productivity factor; ρ_{air}—air density, kg/m^3; A—Rotor area, m^2; v_z—wind speed at wind turbine height, m/s.

The hourly wind speed data from the year 2018 have been used for the calculation. The average wind speed in Latvia at measured 2 m height is 3.4 m/s. As it can be seen in Figure 7, higher wind speed fluctuations are observed during autumn and winter periods. In addition, the limitations have been added for the hours above the cut-off speed above 6 m/s as the wind turbines should be stopped in order to prevent unnecessary strain on the rotor [38].

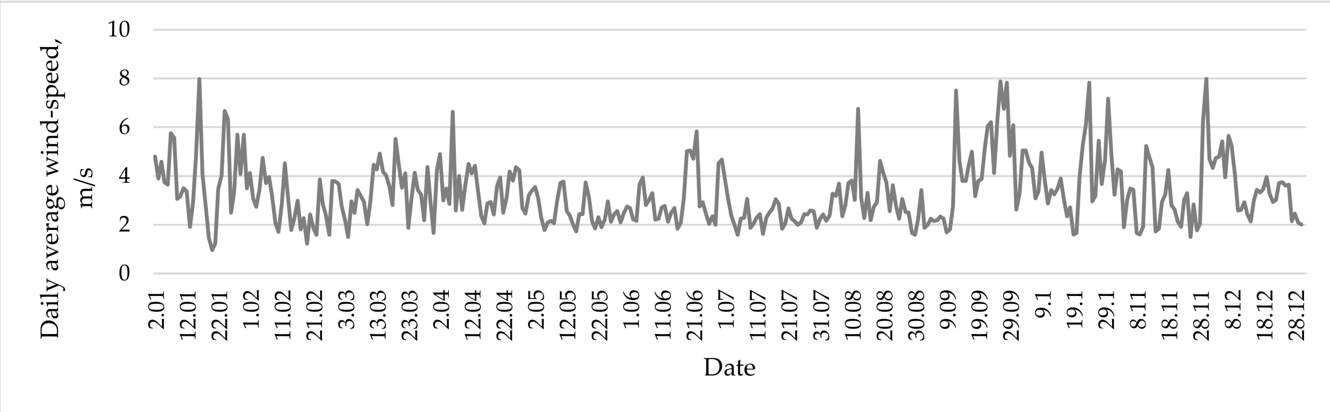


Figure 7. Hourly measured wind speed.

The following equation calculates the wind speed at wind turbine height:

$$v_z = \frac{v_{ref} \cdot ln\frac{z}{z_0}}{ln\frac{z_{ref}}{z_0}} \tag{3}$$

where v_{ref}—wind speed in reference height, m/s; z—wind turbine height, m; z_{ref}—the height of wind speed measurements, m; z_0—roughness length, m.

The following equations calculate the flow of the hourly production from installed wind and solar technology capacities:

$$E_{Wind} = E_{WT} \cdot N_{WT} \tag{4}$$

$$E_{Solar} = E_{PV} \cdot S_{PV} \tag{5}$$

$$E_{RES} = E_{Wind} + E_{Solar} \tag{6}$$

where E_{Wind}—hourly wind energy production, MW/h; N_{WT}—number of turbines installed; E_{Solar}—hourly solar energy production, MW/h, S_{PV}—installed area of PV, m^2; E_{RES}—hourly RES production, MW/h.

Accumulated production stock value for each of the renewable technology at any given time can be calculated by the following equation:

$$St_i(t) = \int_{t_0}^{t} (Fl_i)dt + St_i(t_0) \tag{7}$$

where St_i—accumulated energy production of specific technology, MWh; Fl_i—hourly energy production of specific technology, MW/h.

The main technical assumptions for RES power estimations are summarised in Table 1 based on the average values from technical catalogues of different technologies [39]. Based on the specifications of ongoing development projects in Latvia, it has been assumed that wind turbines with a height of 70 m and a rotor diameter of 60 m could be the most reliable solution. In addition, the climatic data regarding hourly wind speed rates and solar irradiation have been obtained from the national meteorological data centre database [40].

Table 1. The main technical assumptions for RES technologies.

Parameter	Assumption
PV efficiency, η_{PV}	0.18
Capacity factor, C_f	0.4
Productivity factor, η	0.4
Rotor diameter, m	60
Wind turbine high, m	70
High for wind speed measurements, m	2.5
Roughness length, m	0.15

The total area of installed solar panels and wind turbines is estimated based on the forecasted amount of national RES capacities. Overview of installed capacities of variable RES technologies is displayed in Table 2.

Table 2. Installed capacities of variable renewable energy (VRE) sources in different scenarios.

	Solar Capacity, MW	Wind Capacity, MW
Scenario 1	0	77
Scenario 2	100	500
Scenario 3	149	964
Scenario 4	964	149

In this study, four different solar and wind technology capacity combinations were tested. Scenario 1 describes Latvia's current situation when no large solar power plants are installed, and only a few wind farms are operating. Scenario 2 and 3 values represent the medium and optimistic forecast of Latvia's solar and wind technology development until 2050. The forecast was obtained by using the previously developed national scale energy sector model [41]. The model forecasts the future development of RES technologies based on the existing situation, as well as analyses driving forces (development of technologies and price reductions, increase of fossil fuel prices, energy efficiency increase) and barriers (high investment costs, energy source availability, lack of information, insufficient building capacity). In addition, the model includes the main support policies identified within the National Energy and Climate Plan for 2030, such as subsidies for RES technologies, an increase of tax rates etc. Finally, scenario 4 is an inverted version of Scenario 3 in which forecasted solar and wind capacities are reversed to highlight the impact of the increased capacity of PV panels.

The simulated and real wind generation rates in Scenario 1 (existing situation) in 2018 have been compared to validate the modelling results. The results (see Figure 8) shows that the monthly wind power production rates are similar to those obtained from the system dynamics model. The system dynamics model's annually generated wind power difference is 2% compared to the actual production rates, which shows the high accuracy of the developed model.

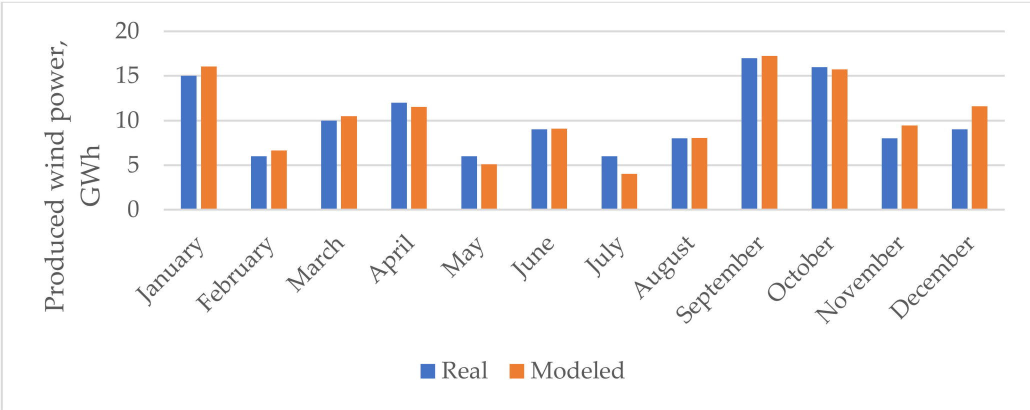


Figure 8. Validation of wind power production rates.

2.4. Modelling of Demand-Side Management and Aggregator

Demand-side management has been introduced to align the RES power production and power consumption profiles. Within the research, two different types of aggregators and demand-side management mechanisms have been tested and compared:

- Load aggregator to balance the power load by shifting peak load to the night hours—Aggregator (Hours);
- Flexibility aggregator to decrease the RES surplus power occurring by shifting the power load to the periods with higher RES production rates—Aggregator (RES).

For each type of aggregator, different approaches have been used for demand-side management.

The load aggregator submodel (aggregator hours) has been shown in Figure 9, in which the shifted load has been calculated by considering the hourly power consumption differences and potential for power increase or decrease.

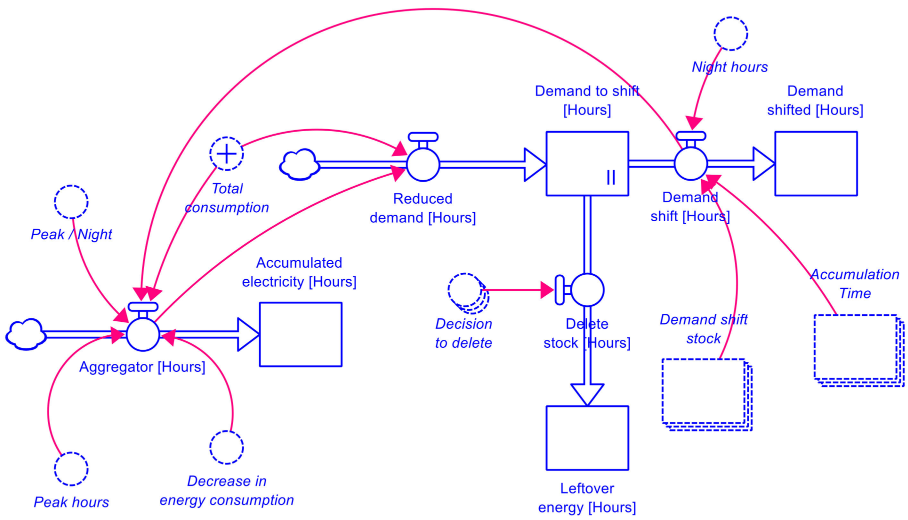


Figure 9. Load shifting sub-model for Aggregator (Hours).

The potential aggregated and shifted power consumption is determined by analysing power consumption in particular periods. In addition, the peak-to-night ratio is introduced to shift electricity from peak hours to night hours in the aggregator (hours) scenario. Finally, the shifted power flow "aggregator (hours)" is determined by calculating the potential aggregated amount of power using the following *if* function:

$$A_H = if(f_P = 1;\ E_{CONS} \cdot (1 - E_{DECR}); E_{CONS} + T_{DS} \cdot f_{P/N}) \quad (8)$$

where A_H—aggregated power for aggregator (Hours), MW; f_P—peak hour rate; E_{CONS}—power consumption, MW/h; E_{DECR}—potential power consumption decrease, MW/h; T_{DS}—potential demand shift, hours; f_{PN}—peak/night hour ratio;

When the time reaches the night hour value, the reduced electricity consumption is fed into the electricity consumption stream, thus shifting the electricity consumption from peak hours to the night hours:

$$E_{SHIFT} = IF(f_N = 1,\ \frac{ES_{SHIFT}}{E_{TIME}},\ 0) \tag{9}$$

where E_{SHIFT}—demand shift, MW; f_N—night hour factor; ES_{SHIFT}—accumulated demand; E_{TIME}—accumulation time.

The power consumption decrease rate depends on the share of power consumption that can be shifted, expresses what part of the total electricity consumption can be reduced, and the share of aggregator customers. The higher the share of aggregator customers, the more significant reduction of electricity consumption can be achieved. The study assumes that the 10% of total power consumption could be shifted to another period which is determined according to previous studies of several authors [42,43].

$$e_{DECR} = e_{DS} \cdot f_{AC} \tag{10}$$

where e_{DS}—shiftable power consumption rate; f_{AC}—share of aggregators' customers.

The share of aggregators' customers in the variable and calculated, depending on how much electricity can be reduced and shifted. Two stocks "installed capacity without aggregator service" and "installed capacity with aggregator service" are considered.

$$E_{AGG} = \int_{t0}^{t} E_{AGG}(t_0) + E_{AGG+} \cdot dt \tag{11}$$

where E_{AGG}—consumption capacity with aggregator service, MW; E_{AGG+}—a shift of capacity with aggregator services, MW/Hours.

Exceeding the 50% share of aggregator customers reduces the growth rate because acquiring new customers for the aggregator service is more complicated. In addition, there is a limiting parameter, the "boundary fraction", which determines how many customers of all can connect to the aggregator service.

In addition to the potential to shift the power demand, there is also an outgoing flow for deleting the shifted power consumption because of the assumption that electricity can only be shifted within 12 h period. Therefore, before the start of the peak hour, the shifted stock is cleared and has a value of zero:

$$E_{SHIFT,\ DEL} = IF(T_{24\text{h}} > T_{N,END},\ INF,\ 0) \tag{12}$$

where E_{DEL}—Deleted shifted power consumption, MW; $T_{24\text{h}}$—Modelling time described in 24 h period, h; $T_{N,END}$—end of night hours, h.

The flexibility aggregator sub-model (aggregator RES) has a similar operating structure as the aggregator (hours) sub-model (see Figure 10).

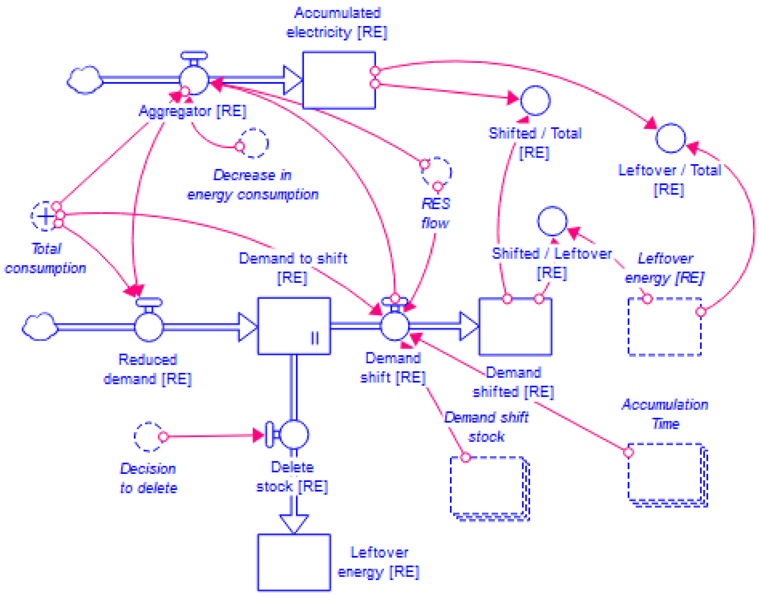


Figure 10. Load shifting sub-model for flexibility aggregator.

The main difference is that the power load is shifted based on the available RES energy flow or how much electricity was produced from RES each hour. Therefore, when the amount of RES produced is higher than the electricity consumption, the electricity consumption is increased by the same rate as the power reduction rate described previously:

$$A_{RES} = if(E_{RES} > E_{CONS};\ E_{CONS} \cdot (1 + E_{INCR}); E_{CONS} - T_{DS} \cdot f_{P/N}) \quad (13)$$

where A_{RES}—aggregated power for aggregator (RES), MW; E_{RES}—RES power production, MW/h; E_{INCR}—power increase rate, MW/h.

2.5. Combining Production and Demand-Side, Surplus Calculation

The last part of the modelling is to compare production and consumption sub-models to evaluate the effect of different renewable capacities and demand-side management options on surplus energy from renewable energy sources.

In Figure 11, the hourly production amount is compared to consumption in case of shifting the load based on RES availability, but the same structure is also used for calculating the energy surplus when the load-shifting based on demand is in place. The hourly flow of surplus is calculated based on the following equation:

$$IF((E_{RES} + E_{HES} + E_{Base} - E_{CONS}) > 0; E_{RES} + E_{HES} + E_{Base} - E_{CONS}; 0) \quad (14)$$

where E_{HES}—hourly hydro energy production, MWh/hour; E_{Base}—hourly baseload from small producers, MWh/hour. The accumulated energy surplus for a specific period is calculated based on Equation (7).

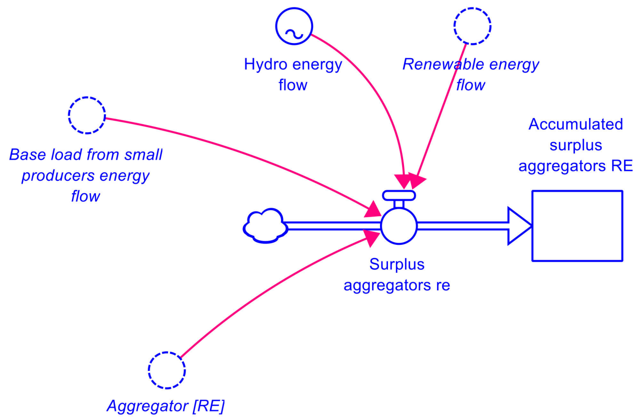


Figure 11. Calculation of surplus energy.

3. Results

The section presents the main hourly and annual results regarding RES power production and possible surplus power reduction through aggregator introduction.

RES Power Production

As described in Section 2.2, 4 different power capacities of variable RES (VRES) combinations were analysed. Figure 12 presents the annual accumulated power production rate for different installed VRE capacities based on the previously built SD model to forecast the future trends of RES technologies installation. Scenario 1 shows the existing situation without solar electricity production and a small amount of wind power, which reaches only 160 MWh. In Scenario 2, when installed solar plant capacity reaches 100 MW, but the capacity of wind farms is 500 MW, the total solar power production is almost 100 MWh per year, but accumulated wind power reaches 1042 MWh per year. This amount is almost doubled in Scenario 3 with additional support policies for wind and solar plants, with total accumulated solar power of 148 MWh and 2008 MWh of wind power. Finally, the increase of solar power production rates is simulated in Scenario 4 when installed solar power capacity reaches 964 MW and produces 948 MWh per year, but the wind power plants provide only 310 MWh of electricity.

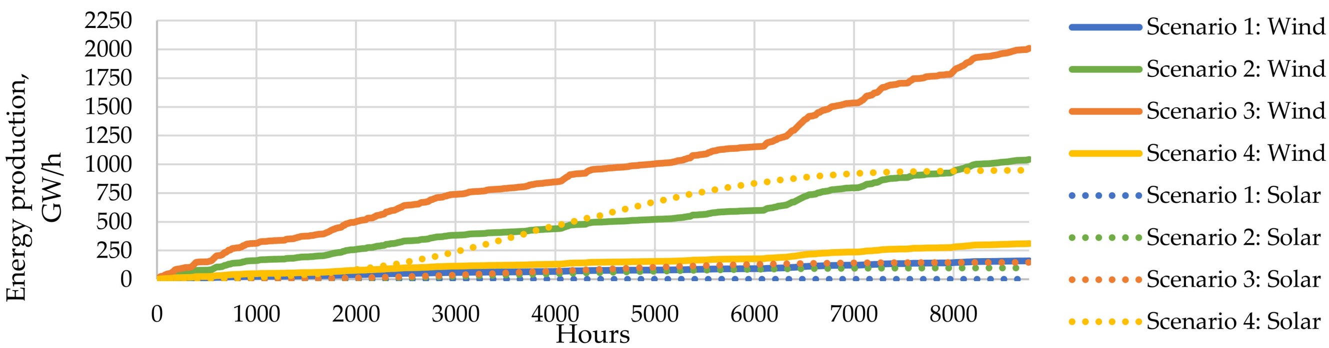


Figure 12. Annual accumulated VRE electricity production for different scenario.

The hourly power production in each scenario can be seen in Figure 13. The production includes the hydropower plants with a nominal capacity of 1000 MW and the baseload provided by biomass cogeneration plants (30 MW) to present the national energy balance accurately. Thus, hydro generation hourly and baseload profiles are constant in all scenarios, and only solar and wind profiles change based on installed capacities.

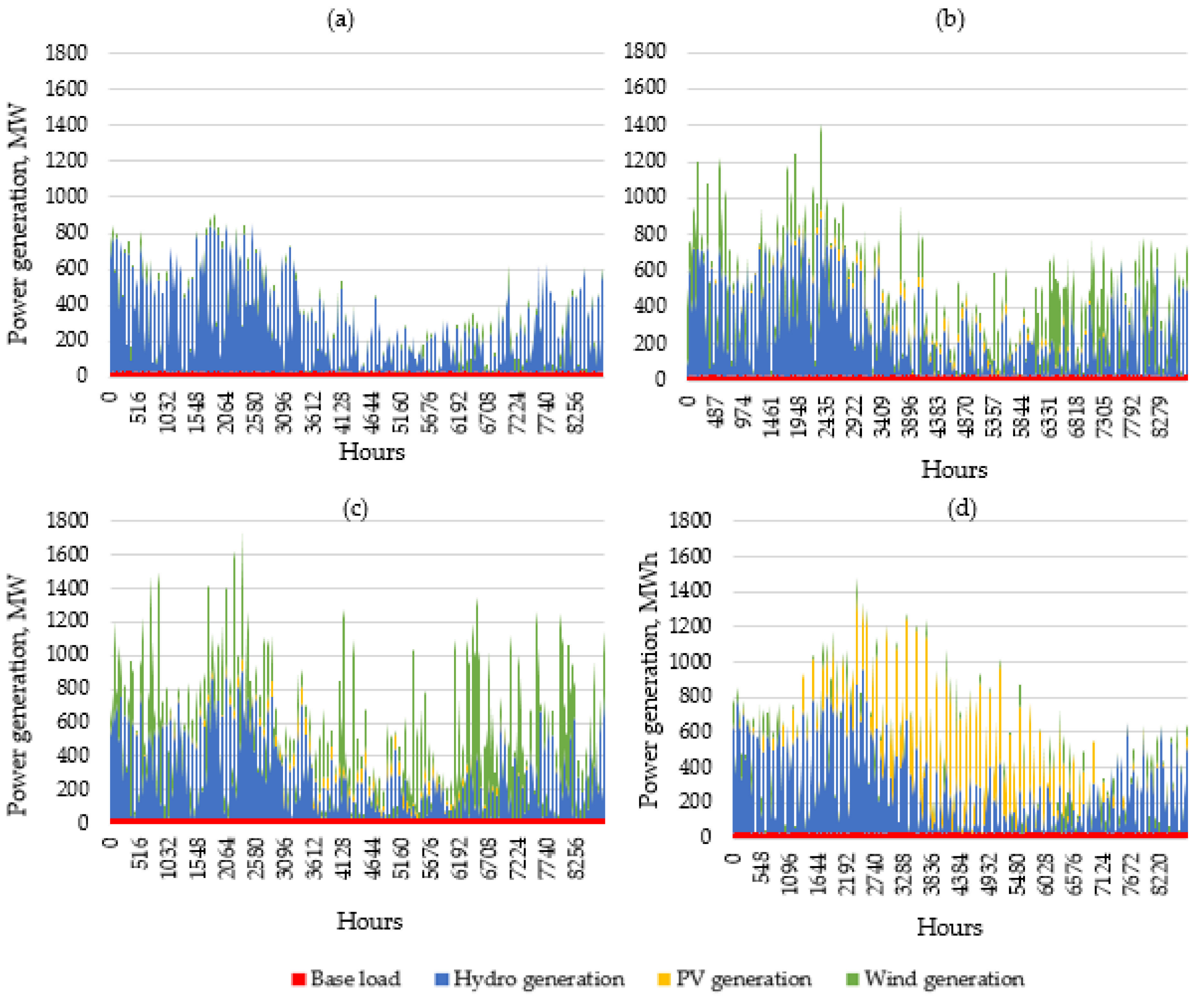


Figure 13. Hourly electricity production by resource type for different scenarios. (**a**) Scenario 1; (**b**) Scenario 2; (**c**) Scenario 3; (**d**) Scenario 3.

As shown in Figure 13, most of the power in Scenario 1 and Scenario 2 is produced by hydropower, but in Scenario 3 significant additional amount is provided by installed wind turbines. In Scenario 4, a high share of power is produced during the late spring and summer periods when there is higher solar irradiation due to the high capacity of installed solar power plants. Further, the hourly production rates are compared with the power consumption to estimate the surplus VRE electricity amounts.

In Figure 14, the ratio between power production and consumption are displayed. When the ratio is 1, the production rate for a particular hour is equal to consumption. However, when the ratio exceeds 1, the production rate is higher than the consumption rate. In Scenario 1, there are only a few hours when production exceeds consumption, but in Scenario 2 and 3, the ratio exceeds 1 significantly more due to the higher wind capacities. Scenario 4 also shows improvement in production and consumption ratio. However, it is not as significant as in Scenario 3. Although Scenario 4 used the same capacity for PV panels as for wind in Scenario 3, less energy is generated due to lower energy conversion efficiency for PV panels. In addition, PV technologies are significantly affected by seasonality and weather conditions.

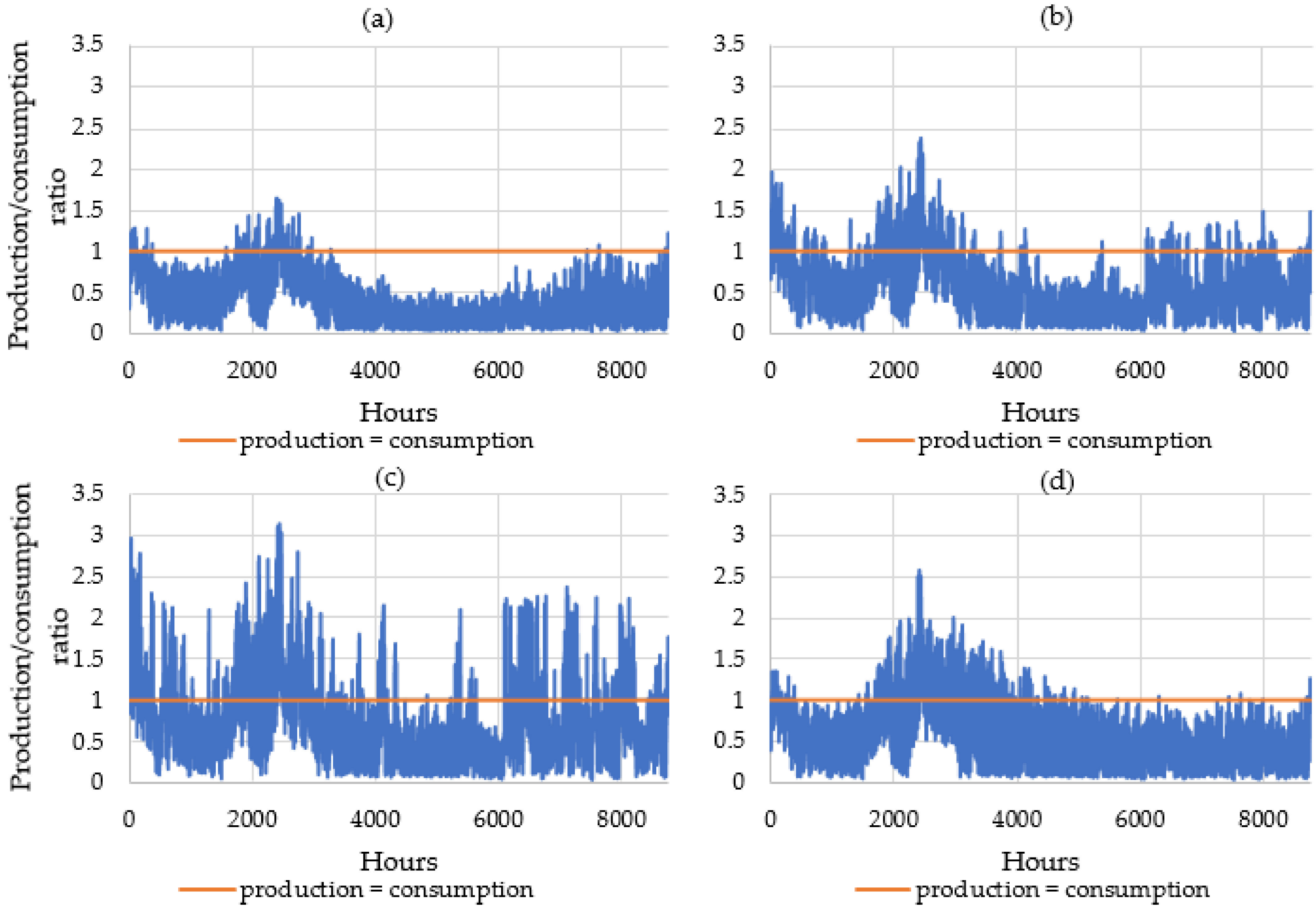


Figure 14. Hourly electricity production by resource type for different scenarios. (**a**) Scenario 1; (**b**) Scenario 2; (**c**) Scenario 3; (**d**) Scenario 4.

When the ratio exceeds 1 and production is higher than consumption, surplus power occurs. Based on the hourly graphs displayed in Figure 14, the total amount of accumulated surplus power can be calculated. In Figure 15, the accumulated surplus is displayed to measure the amount of energy that can be redirected or exported over the year. Scenario 3 shows the highest amount of surplus VRE power—over 600,000 MWh per year.

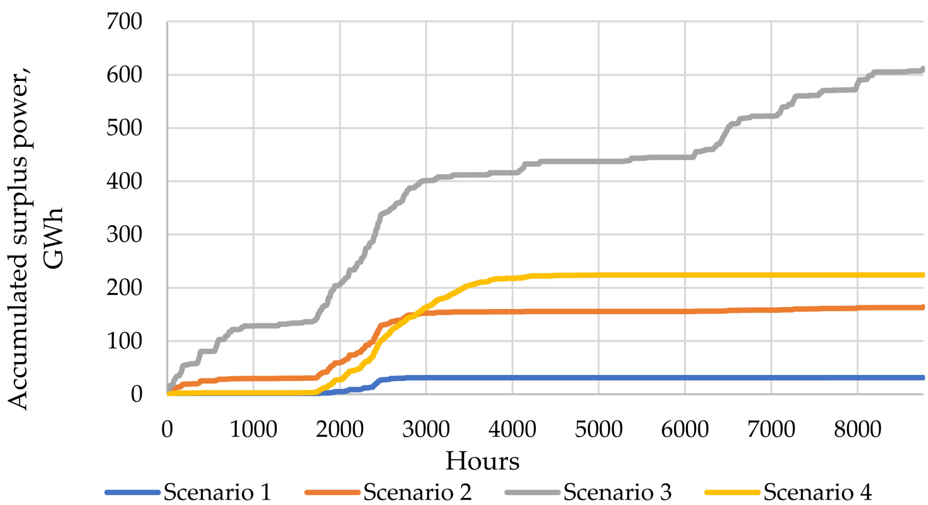


Figure 15. Accumulated surplus power.

In Figure 16, the different perspective of surplus energy is revealed. In the case of low installed capacity, only a small amount of surplus power occurs. For example, in Scenario 1, only around 6 % of total electricity produced from RES (excluding hydro energy) cannot be consumed immediately. However, in Scenario 3, this number increases to 30% from total energy produced from RES. These results are in line with similar previous research. Andresen et al. [44] have analysed the impact on high shares of installed wind and solar power capacities. In the case of 100% of wind power scenario, 30% of surplus power occurs. However, the surplus power for low solar and wind capacities are insignificant.

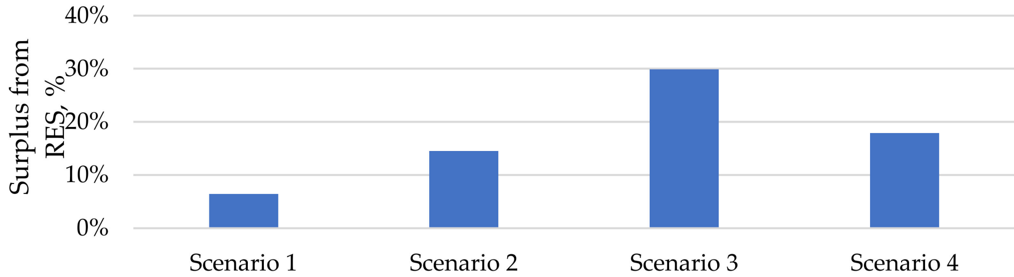


Figure 16. Percentage of surplus from total VRE power.

Aggregators and potential load shifts have been introduced to decrease the amount of occurred surplus power. As described in Section 2.3, two types of aggregators have been tested. The aggregator (hours) smoothens the power consumption load by shifting the peak consumption to off-peak hours during the night while the aggregator (RES) shifts the power consumption load to the hours with higher VRE power production hours. The example of power consumption changes as a result of introducing two different aggregator types has been shown in Figure 17. The graph shows the total hourly RES production and total power consumption for two weeks in March. As seen in the case of the aggregator (RES) introduction, the power consumption is shifted to the periods when there are higher solar and wind power production rates. On the contrary, when the aggregator (hours) is operating, the peak power consumption is reduced but does not follow the RES production rates.

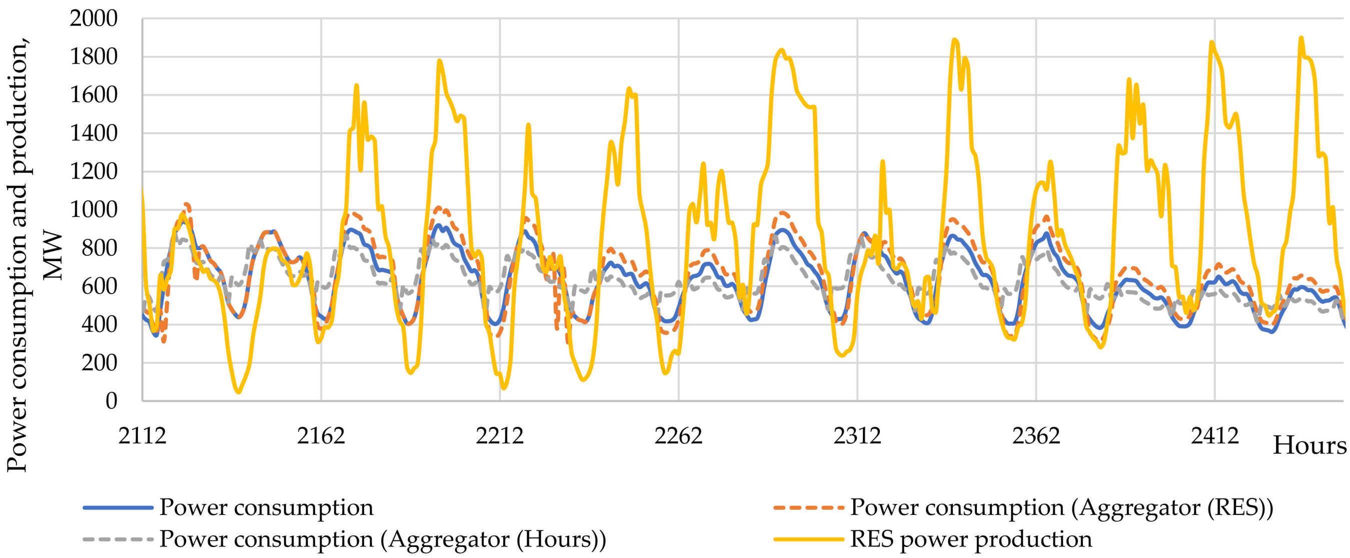


Figure 17. Example of power consumption shift in different aggregator types for Scenario 3 when all of the consumers use aggregator services.

The results also depend on the total share of consumers with aggregator services. Therefore, several shares of connected consumers have been tested in Figure 14. The percentages represent the diffusion level of aggregators in the system. For example, 0% means that no consumer is using the service of aggregators. However, 100 % means that all consumers who are eligible use the service of aggregators. From Figure 18, when load shift is introduced according to available RES power, the surplus power can be eliminated in Scenario 1. In Scenarios 3, surplus power reduces from 30% to 24% when all consumers shift their power load with the help of aggregator services. However, the surplus power amount increases when shifting load from peak hours to off-peak hours and not considering the RES energy availability. The highest increase from 6% to 23% is seen in Scenario 1 when few wind capacities are installed. In Scenario 3, the surplus power could increase by 3% if the power load is smoothed. On the other hand, the smoothened power load can benefit from decreased installed capacities and primary energy savings when operating in baseload conditions. Further investigation could be performed to compare the obtained costs and savings from the economic perspective.

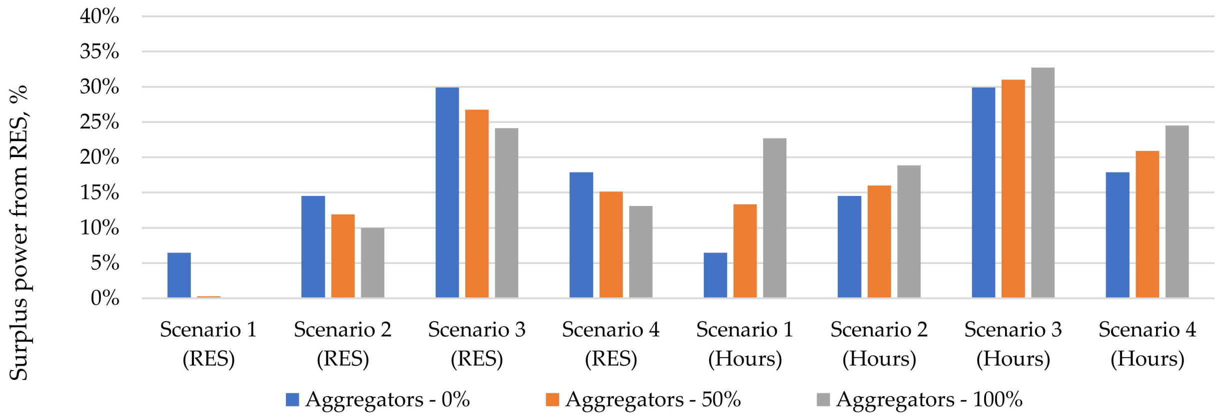
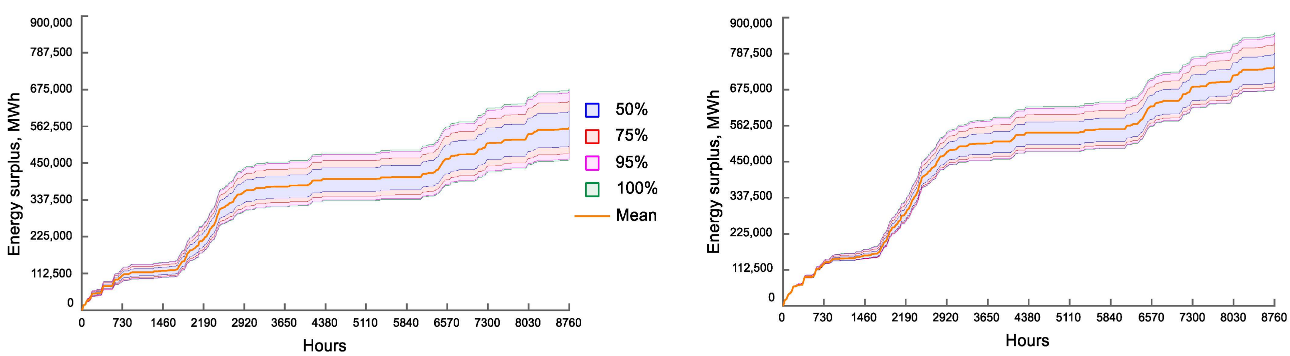


Figure 18. RES surplus power and RES capacity ratio for different aggregator scenarios.

The sensitivity analyses have been performed to analyse the impact of the main variable on the obtained results. As can be seen in Figure 19, the changes of shiftable load can either increase or decrease the obtained results of surplus power. For example, if the assumed shiftable load is increased from 10% to 20%, which could be the case if the most significant power consumers adjust their power consumption and increase the flexibility, the aggregator (RES) can decrease the surplus power by 16% in case of high wind share scenario (Scenario 3). On the other hand, the opposite situation occurs in the case of the aggregator (hours) scenario, which could significantly (by 22%) increase the surplus power from VRES if the share of shiftable loads increases.



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

Figure 19. Sensitivity analyses for shiftable load changes impact the surplus power in case of (**a**) aggregator (RES) and (**b**) aggregator (hours) in Scenario 3.

4. Discussion

This section discusses the limitations of the results, the methods and materials, and the assumptions made for the analyses. The results presented in this paper indicate that power balancing issues due to large shares of VRE in power generation mixes could be decreased and, to some extent, prevented by the possible load shift and integration of aggregators as a market player. Therefore, the results should be considered applicable for the national scale analyses where different power consumers and additional power loads are present. Even though there are other possibilities to utilise the occurred surplus power from VRES, such as the power-to-x concept, power and heat accumulation systems, in-depth analyses are performed for the impact of power load flexibility analyses. However, further studies could compare different scenarios for surplus power utilisation by determining the cost-effectiveness and overall impact on reached renewable power shares.

A limitation of this study is that it has a technical approach and does not consider economic or policy aspects that might influence the system performance. The introduction of aggregators previously is mainly highlighted from the economic perspective. It is associated with power cost reduction potential when power consumption is increased in low power price periods. However, the preliminary analyses on historical market prices of electricity did not show the relation with the increased penetration of VRES due to relatively low market shares of wind and solar power electricity in the Baltic states. Therefore, different load shift mechanisms were introduced without focusing on hourly market prices. The particular article analyses the benefits from higher renewable power utilisation perceptive.

The obtained results on surplus power and shiftable loads are highly dependent on the modelled power capacities, added base loads, and power consumption patterns. Therefore, even though the presented methodology can be applied to other countries, the results can differ for countries without significant hydropower or biomass cogeneration as baseload.

Also, the power consumption patterns could be different for countries with significant power-intensive industries, which is not the case in Latvia. Furthermore, power loads might vary between years due to differences in average outdoor temperatures or changes in consumer habits. For example, working from home increases power consumption in households and reduces the consumption in office buildings in different periods. However, as the study includes different types of consumers (by size, type and location), the average consumption patterns are valid for the detailed analyses.

The power demand and solar and wind generation used in the calculations represent data for 2018. It means that the VRE production profile and, thus, the power balancing profile reflected the wind and solar power generation conditions in 2018. The power generation will differ between years due to varying weather conditions—hourly solar irradiation and wind speed. Also, the balancing load of hydropower is based on the data from the year 2018. However, there are variations in a hydrologic regime each year which reflects the produced hydropower. Therefore, the surplus power can slightly change year by year due to several climatic conditions.

5. Conclusions

The research analyses the potential impacts of demand-side management on the utilised power from RES—solar and wind power plants. The system dynamics modelling merges the forecasted variable power capacities from the national scale forecasting model with the hourly solar and wind production profiles. The results show that when there are large installed wind capacities, around 30% of the generated power occurs in periods without sufficient demand profile, and surplus power occurs.

The results show that the utilised VRE power share does not increase when introducing aggregator, which shifts the peak demand to off-peak periods. On the contrary, the demand shift results in higher power surpluses. However, when the load shift follows the RES power production rates, the surplus power can be reduced by around 5%. However, in this case, all consumers should have participated in the demand shift and have an aggregator service, which would probably not be feasible in reality.

The proposed methodology can be applied and tested internationally to evaluate the future perspectives of flexible power production and consumption in countries with similar power market structures, for example, Baltic and Scandinavian countries. Obtained results can be further used in other energy policy testing and as a support for the definition of the legislative framework of aggregators. Results show that their future role should also focus on renewable share increase, providing financial benefits from shifting demand to lower electricity price periods.

The presented research will be continued by analysing the economic and environmental benefits of demand-side management and load shifting. Furthermore, the model allows testing different policy frameworks, which could be further investigated for the successful performance of aggregators towards carbon-neutral energy production.

Author Contributions: Conceptualization, I.P. and A.G.; Data curation, I.P. and G.B.; Formal analysis, L.R., A.G. and G.B.; Investigation, I.P., G.B. and A.G.; Project administration, I.P. and D.B.; Resources, D.B.; Supervision, D.B.; Visualization, A.G. and I.P.; Writing—original draft, I.P., A.G. and L.R. 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, the project "Assessment of Latvia's renewable energy supply-demand economic potential and policy recommendations", project No. VPP-EM2018/AER_1_0001.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: No publicly available database is generated during this study.

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

References

1. Directive 2019/944 of the European Parliament and of the Council of 5 June 2019 on Common Rules for the Internal Market for Electricity and Amending DIRECTIVE 2012/27/EU. Available online: https://eur-lex.europa.eu/legal-content/en/TXT/HTML/?uri=CELEX:32019L0944&from=en (accessed on 26 October 2021).
2. Vardakas, J.S.; Zorba, N.; Verikoukis, C.V. A Survey on Demand Response Programs in Smart Grids: Pricing Methods and Optimisation Algorithms. *IEEE Commun. Surv. Tutor.* **2015**, *17*, 152–178. [CrossRef]
3. SEDC. Explicit and Implicit Demand-Side Flexibility. Position Pap. no. September 2016. Available online: http://www.smartenergydemand.eu/wp-content/uploads/2016/09/SEDC-Position-paper-Explicit-and-Implicit-DR-September-2016.pdf (accessed on 24 November 2021).
4. Rozentale, L.; Kalnbalkite, A.; Blumberga, D. Aggregator as a new electricity market player: (Case study of Latvia). In Proceedings of the 2020 IEEE 61th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), Riga, Latvia, 5–7 November 2020; pp. 1–6. [CrossRef]
5. Carreiro, A.M.; Jorge, H.M.; Antunes, C.H. Energy management systems aggregators: A literature survey. *Renew. Sustain. Energy Rev.* **2017**, *73*, 1160–1172. [CrossRef]
6. Li, B.; Wang, X.; Shahidehpour, M.; Jiang, C.; Li, Z. Optimal DR Activation Strategy for Risk Aversion Considering Hourly Loads and Locational Prices. *IEEE Trans. Smart Grid* **2019**, *10*, 6203–6213. [CrossRef]
7. Burger, S.; Chaves-Ávila, J.P.; Batlle, C.; Pérez-Arriaga, I.J. A review of the value of aggregators in electricity systems. *Renew. Sustain. Energy Rev.* **2017**, *77*, 395–405. [CrossRef]
8. Lu, X.; Li, K.; Xu, H.; Wang, F.; Zhou, Z.; Zhang, Y. Fundamentals and business model for resource aggregator of demand response in electricity markets. *Energy* **2020**, *204*, 117885. [CrossRef]
9. Paterakis, N.G.; Erdinç, O.; Catalão, J.P.S. An overview of Demand Response: Key-elements and international experience. *Renew. Sustain. Energy Rev.* **2017**, *69*, 871–891. [CrossRef]
10. Rozentale, L.; Blumberga, D. Energy Intensive Manufacturers in State Economy: Case study of Latvia. In Proceedings of the 2019 IEEE 60th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), Riga, Latvia, 7–9 October 2019; pp. 1–6. [CrossRef]
11. Iria, J.; Soares, F.; Matos, M. Optimal supply and demand bidding strategy for an aggregator of small prosumers. *Appl. Energy* **2018**, *213*, 658–669. [CrossRef]
12. Cabinet of Ministers. Aggregator Regulations. Cabinet Regulation No. 157. 2020. Available online: https://likumi.lv/ta/id/313461-agregatoru-noteikumi (accessed on 25 October 2021).

13. Parvania, M.; Fotuhi-Firuzabad, M.; Shahidehpour, M. Optimal Demand Response Aggregation in Wholesale Electricity Markets. *IEEE Trans. Smart Grid* **2013**, *4*, 1957–1965. [CrossRef]
14. Aldik, A.; Khatib, T. EV Aggregators and Energy Storage Units Scheduling into Ancillary Services Markets: The Concept and Recommended Practice. *World Electr. Veh. J.* **2020**, *11*, 8. [CrossRef]
15. Villar, J.; Bessa, R.; Matos, M. Flexibility products and markets: Literature review. *Electr. Power Syst. Res.* **2018**, *154*, 329–340. [CrossRef]
16. Henríquez, R.; Wenzel, G.; Olivares, D.E.; Negrete-Pincetic, M. Participation of Demand Response Aggregators in Electricity Markets: Optimal Portfolio Management. *IEEE Trans. Smart Grid* **2018**, *9*, 4861–4871. [CrossRef]
17. Gelazanskas, L.; Gamage, K.A.A. Demand side management in smart grid: A review and proposals for future direction. *Sustain. Cities Soc.* **2014**, *11*, 22–30. [CrossRef]
18. Deng, R.; Yang, Z.; Chow, M.; Chen, J. A Survey on Demand Response in Smart Grids: Mathematical Models and Approaches. *IEEE Trans. Ind. Inform.* **2015**, *11*, 570–582. [CrossRef]
19. Gkatzikis, L.; Koutsopoulos, I.; Salonidis, T. The role of aggregators in smart grid demand response markets. *IEEE J. Sel. Areas Commun.* **2013**, *31*, 1247–1257. [CrossRef]
20. Okur, Ö.; Voulis, N.; Heijnen, P.; Lukszo, Z. Aggregator-mediated demand response: Minimising imbalances caused by uncertainty of solar generation. *Appl. Energy* **2019**, *247*, 426–437. [CrossRef]
21. Iria, J.; Soares, F. Real-time provision of multiple electricity market products by an aggregator of prosumers. *Appl. Energy* **2019**, *255*, 113792. [CrossRef]
22. Wang, F.; Xiang, B.; Li, K.; Ge, X.; Lu, H.; Lai, J. Smart Households' Aggregated Capacity Forecasting for Load Aggregators Under Incentive-Based Demand Response Programs. *IEEE Trans. Ind. Appl.* **2020**, *56*, 1086–1097. [CrossRef]
23. Abapour, S.; Mohammadi-Ivatloo, B.; Hagh, M.T. Robust bidding strategy for demand response aggregators in electricity market based on game theory. *J. Clean. Prod.* **2020**, *43*, 118393. [CrossRef]
24. Patnam, B.S.K.; Pindoriya, N.M. Demand response in consumer-Centric electricity market: Mathematical models and optimisation problems. *Electr. Power Syst. Res.* **2021**, *193*, 106923. [CrossRef]
25. Hakimi, S.M.; Hasankhani, A.; Shafie-khah, M.; Catalão, J.P.S. Demand response method for smart microgrids considering high renewable energies penetration. *Sustain. Energy Grids Netw.* **2020**, *21*, 100325. [CrossRef]
26. McPherson, M.; Stoll, B. Demand response for variable renewable energy integration: A proposed approach and its impacts. *Energy* **2020**, *197*, 117205. [CrossRef]
27. Forrester, J. Road Maps: A Guide to Learning System Dynamics. 1996. Available online: http://web.mit.edu/sysdyn/road-maps/D-4500-3.pdf (accessed on 23 November 2021).
28. Aslani, A.; Helo, P.; Naaranoja, M. Role of renewable energy policies in energy dependency in Finland: System dynamics approach. *Appl. Energy* **2014**, *113*, 758–765. [CrossRef]
29. Blumberga, A.; Cilinskis, E.; Gravelsins, A.; Svarckopfa, A.; Blumberga, D. Analysis of regulatory instruments promoting building energy efficiency. *Energy Procedia* **2018**, *147*, 258–267. [CrossRef]
30. The Ministry of Economics. Electricity Generation. 2021. Available online: https://www.em.gov.lv/lv/elektroenergijas-razosana (accessed on 16 November 2021).
31. National Statistical System of Latvia. Energy Balance, TJ, Thsd Toe (NACE Rev.2) by Indicator, Energy Resources, Unit and Time Period. Available online: https://data.stat.gov.lv/pxweb/en/OSP_PUB/START__NOZ__EN__ENB/ENB060/ (accessed on 16 November 2021).
32. Nord Pool. About Us. Available online: https://www.nordpoolgroup.com/About-us/ (accessed on 16 November 2021).
33. Nord Pool. Bidding Areas. Available online: https://www.nordpoolgroup.com/the-power-market/Bidding-areas/ (accessed on 16 November 2021).
34. Sadales Tīkls. Homepage. Available online: https://www.sadalestikls.lv/en/homepage/ (accessed on 16 November 2021).
35. Central Statistical Bureau of Latvia. Energy Balance. Available online: https://www.csb.gov.lv/en/statistics/statistics-by-theme/environment-energy/energy/tables/metadata-energy-balance (accessed on 25 October 2021).
36. Gravelsins, A.; Pakere, I.; Tukulis, A.; Blumberga, D. Solar power in district heating. P2H flexibility concept. *Energy* **2019**, *181*, 1023–1035. [CrossRef]
37. Polikarpova, I.; Kakis, R.; Pakere, I.; Blumberga, D. Optimising large-scale solar field efficiency: Latvia case study. *Energies* **2021**, *14*, 4171. [CrossRef]
38. Hassan, A.Y.; Soliman, A.M.; Ahmed, D.; Saleh, S.M. Wind cube optimum design for wind turbine using meta-heuristic algorithms. *Alex. Eng. J.* **2021**, in press. [CrossRef]
39. Energistyrelsen. Technology Data. Available online: https://ens.dk/en/our-services/projections-and-models/technology-data (accessed on 16 November 2021).
40. Latvian Centre for Environment Geology and Meteorology. Meteorology/Data Search. Available online: https://www.meteo.lv/meteorologija-datu-meklesana/?nid=461 (accessed on 26 October 2021).
41. Gravelsins, A.; Bazbauers, G.; Blumberga, A.; Blumberga, D. Power Sector Flexibility through Power-to-Heat and Power-to-Gas Application—System Dynamics Approach. *Environ. Clim. Technol.* **2019**, *23*, 319–332. [CrossRef]
42. Corradi, O.; Ochsenfeld, H.; Madsen, H.; Pinson, P. Controlling Electricity Consumption by Forecasting its Response to Varying Prices. *Power Syst. IEEE Trans.* **2013**, *28*, 421–429. [CrossRef]

43. Ruiz, N.; Cobelo, I.; Oyarzabal, J. A Direct Load Control Model for Virtual Power Plant Management. *IEEE Trans. Power Syst.* **2009**, *24*, 959–966. [CrossRef]
44. Andresen, G.B.; Rodriguez, R.A.; Becker, S.; Greiner, M. The potential for arbitrage of wind and solar surplus power in Denmark. *Energy* **2014**, *76*, 49–58. [CrossRef]

Electricity policy solutions in Latvia from climate perspective

Liga ROZENTALE[1], Dagnija BLUMBERGA

[1,2] *Institute of Energy systems and Environment, Riga Technical University, Azenes street 12/1, Riga, LV-1048, Latvia*

***Abstract* – The European Union's (EU) regulation stipulates that every member state must have a National Energy and Climate Plan (NECP) that sets a range of goals and activities in order to reach the EU 2030 energy and climate targets. An EU regulation has provided guidelines for preparing the NECP, however member states makes their own decisions on what type of goals to introduce and include in their NECP. This research looks at some potential electricity policy solutions that where overlooked in the NECP of Latvia. By using theory-based approach, the authors argue that these outside-NECP solutions could aid in reaching the 2030 energy and climate targets by reducing greenhouse gas (GHG) emissions by a measurable amount and thus should supplement the NECP in its review in 2023.**

***Keywords* – Electricity policy; National Energy and Climate Plan; Theory based approach; Energy transition; GHG emissions**

1. INTRODUCTION

EU's energy and climate policy has been one of the major priorities on the EU agenda for the last decade. While the EU member states try to implement the goals and rules stipulated in EU level documents, new legislative proposals keep coming up and member states need to elaborate new national actions to fulfil the common EU plans.

The new Regulation of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999, which is also knows as the European Climate Law has created a binding goal to achieve climate neutrality in the EU by 2050. The European Climate Law also sets a midway target of reducing GHG emissions by 55% by 2030 compared to the levels in 1990.[1]

At the same time, the EU member states continue to implement NECPs for the period 2021-2030 that have been adopted on the basis of the Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action.[2] Initial NECPs were developed with previous GHG reduction targets in mind, i.e. 40% reduction by 2030.[3] Thus, the GHG reduction target for 2030 has increased by 15%. Thus, more than ever it is important to perform national activities that could provide more support in the way towards reducing GHG.

As can be seen in Fig.1, the most GHG emissions comes from the energy supply sector. This is closely followed by transport sector and industry sector. Both transport and industry sectors have high GHG emissions due to fossil energy consumption. Thus, altogether, changes in energy production and consumption strategy are the ones that will impact the GHG emissions in the future.

* Corresponding author.
E-mail address: liga.rozentale@em.gov.lv

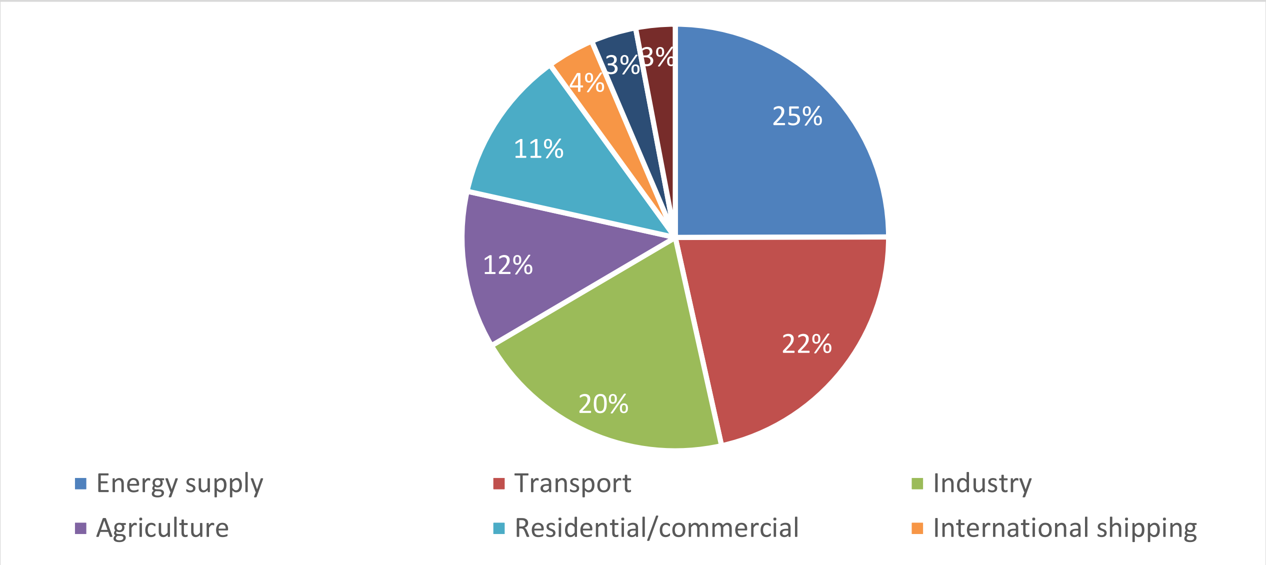


Fig. 1. GHG emissions in the EU by sector in 2019, %[4]

In this research the authors specifically focus on electricity policy measures that either have not been mentioned in the Latvian NECP at all or have been mentioned but without defining specific goal. The aim of the research is to evaluate the possible impact on reduction of GHG when stimulating electricity policy activities that are currently outside of NECP by using theory-based approach. This approach allows to draw conclusions on whether these activities could provide sufficient contribution in achieving the 55% GHG reduction goal and should be included in the revised NECP with adequate funding possibilities. Since the NECPs will be updated in 2023, authors provide a research on the activities that have been overlooked in the NECP of Latvia and could provide substantial input in reducing GHG if appropriate goals are set.

2. Methods and Procedures

This research combines the evaluation of NECP with the theory-based analysis method in order to provide conclusions on whether and how to improve the current NECP of Latvia for achieving the best possible results in terms of reducing GHG emissions.

2.1. Theory-based analysis

Theory-based analysis approach to evaluation is a method that allows to estimate the effects of a range of systemic activities, e.g. a policy program in one field to achieve certain results.[5] Theory-based evaluation aims to find out why and how a specific policy measure works.[6] Theory-based approach includes the theory of change, which allows to trace the changes over time and their causal relationships.[7] Theory of change creates a model that allows to test, which activities will bring the planned outcome.[8] Another possibility is to trace the process of policy implementation, where part of the process can be attributed to some part of the result instead of the overall results.[9] Thus, the policy activities can be measured in their intermediate results and in their final results.[10]

Theory-based evaluation provides a tool for improving a program's design based on the inputs. Fig.2 shows the main benefits that such an approach can provide in policy planning. Theory-based evaluation can be applied at different stages of the policy planning or implementation process.[11]

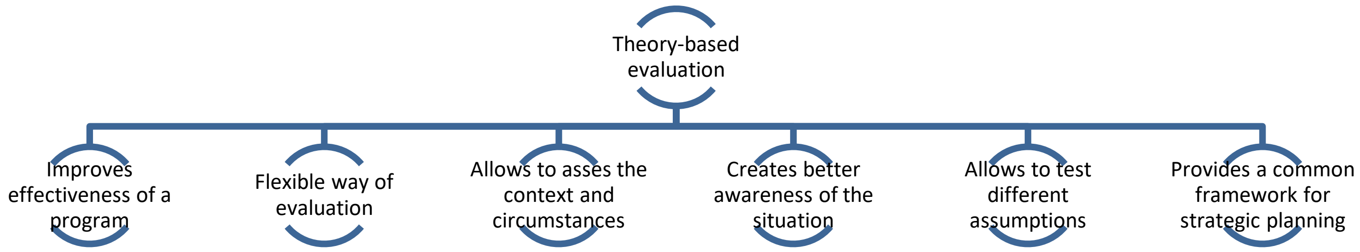


Fig.2. Benefits from using theory-based evaluation method [11]

If applied at an earlier stage, it will aid in creating the specific strategy or program. Nevertheless, if applied after the program is already in action, the theory-based approach will aid in post-evaluation of the program and reviewing it to improve it in the process, showing the flexible nature of this method.[12]

2.2. Electricity policy in NECP

As has been stated in the introduction of this research, energy sector provides the largest GHG emissions in the EU. Meanwhile, it has been noted that the electricity sector is the key sector to be improved in order to achieve the GHG reduction goals in a cost-effective manner.[13] As the authors have summarized in Fig.3, electricity policy is one of the gears in the NECP that plays an important role on the amount of GHG emissions in the energy sector.

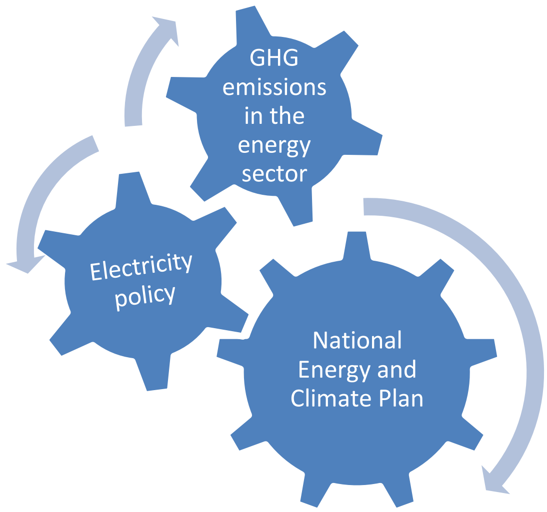


Fig. 3. Causal relationship between the GHG emissions and the NECP

In the previous researches, the authors have looked at different electricity policy perspectives in Latvia – electricity generation from solar panels [14], wind parks [15], collective electricity production and consumption in energy communities [16], reconfiguration of electricity consumption patterns by aggregators [17][18], benefits from railway electrification [19], energy efficiency for energy intensive manufacturers [20], as well as evaluated the current electricity policy initiatives and their link with climate policy. Thus, there is a sound level of research on different potential activities in the electricity policy. However, it is important to assess, what are the current electricity policy measures defined in the NECP.

NECP has been devised into several dimensions with specific targets in each of the dimensions. This scheme is summarized in Fig. 4.

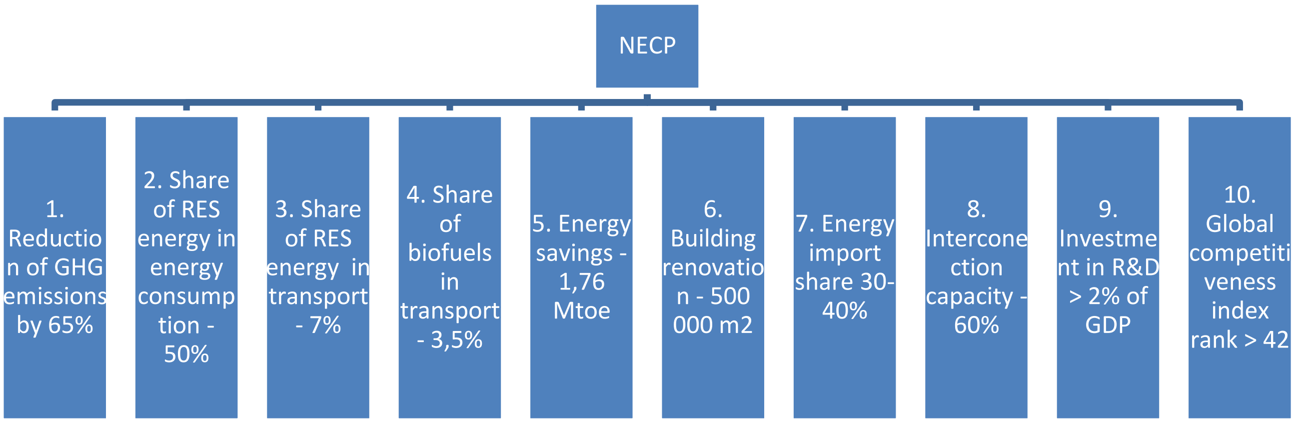


Fig.4. Different dimensions and their targets in NECP of Latvia

There is wide range of activities under each of the dimensions. Though the research is focusing on the electricity policy action for reducing GHG emissions, which is the 1.1. target in Fig.4., it is important to look also at the electricity policy activities under other NECP dimensions as they are closely interlinked. Energy savings and increase of RES energy in energy consumption and transport sector will also affect the GHG emission goal as part of electricity policy. Considering the fields of previous researches, the authors paid their attention to whether NECP has specific electricity policy goals for 2030 in the following areas:

- ✓ Electricity production from solar panels;
- ✓ Electricity production from wind energy;
- ✓ Electricity saving requirements for energy intensive manufacturers;
- ✓ Railway electrification;
- ✓ Electricity savings by aggregation (demand-response);
- ✓ RES electricity production in energy communities.

Though NECP [21] includes the goal to speed up and simplify the procedural process for introducing RES electricity generation installations, there is no specific goal (in megawatt hours) for the installed capacity of solar power plants. In fact, Latvia is the only EU member state without a goal for installed solar capacity. As regards wind energy, NECP has a goal of introducing at least one offshore wind park of 800 MW capacity and at least 1600 GWh electricity production from wind yearly. NECP stipulates that a solution for onshore wind parks should also be elaborated, however, there is not a specific separate target for onshore wind capacity.

As regards energy efficiency measures, there is no specific target defined in terms of reducing energy (electricity) intensity in the manufacturing sector. The measures are descriptive and aimed at assessing whether entrepreneurs should be obliged to compare different alternatives (e.g. manufacturing facilities with higher and lower energy consumption) when making investment decisions. NECP also requires policy planners to amend legal acts that covers EU funding rules to determine certain energy efficiency requirements, as well as requires additional studies to be made, e.g. regarding possible review of the scope of current energy efficiency obligations. Currently, energy intensive manufacturers must carry out an energy audit (once every 4 years) or implement a certified energy/environmental management system. Energy intensive manufacturers must implement at least 3 energy efficiency improvement measures that provide energy savings.[22] However, neither the pre-NECP legislation, nor NECP does not implement any specific measurable energy saving goals for energy intensive manufacturers.

The goals in transport sector includes electrification of certain railway lines by 2023. However, NECP does not explain, what is the electrified percentage of the railway. Meanwhile, public information of JSC "Latvian Railway" sets out a plan to increase the railway electrification up to

30% until 2023, thus we can assume that railway electrification technically has an electrification goal of 30% by 2023, however there is not a specific 2030 goal.

NECP does include vision of aggregators, prescribing the need for legislation that would set the rights and duties of the aggregators, however there is no specific goals for their actions, e.g. yearly electricity savings.

Finally, NECP touches upon creation of energy communities in terms of creating the necessary regulation and possible funding, however there are no specific goals for creating a certain number of energy communities. Though it could be argued that electricity production goals for solar or wind energy could overlap with RES electricity production in energy communities, however it can also be argued that there is a certain amount of RES electricity generation capacity that will only be installed if there is an efficient regulation (incl. financing provisions) for energy communities allowing for a group of electricity self-consumers to combine their efforts in electricity generation, consumption and sharing and selling.

Considering the emphasis on the RES electricity generation and consumption measures, it is also important to recognize the topicality of energy storage facilities. As has been noted by the European Commission, energy storage solution will be crucial for integrating RES electricity into the grid in a cost-effective manner. [23] Battery energy storage systems (BESS) is considered to be a good option for short-term flexibility needs.[24] Currently there are no goals for energy storage capacity in Latvia.

3. RESULTS

All the outside-NECP activities that have been described in the previous chapter have been assigned with a goal. The goals have been developed based on the following considerations:

- ✓ The installed capacity target for solar energy is calculated as the average installed capacity goal between Estonia (324 W/cap) and Lithuania (338 W/cap)[25], considering the regional similarities like solar intensity and the size of territory. If the watt per capita goal is 331 W/cap, the respective installed capacity goal based on the Latvian population (1.9 million) is 629 MW.
- ✓ The installed capacity target for onshore wind is equated with the offshore wind energy goal of 800 MW, which is also the capacity of electricity transmission line "Kurzemes loks" and corresponds to already currently issued wind electricity generation permits by the Ministry of Economics of Latvia. These potential wind energy producers have expressed their interest (and so have received the permit from the Ministry of Economics) but have not yet installed the wind parks due to financial or legal constraints.
- ✓ Considering the current goal of 30% railway electrification by 2023, the goal for 2050 is set to 59% as has been historically set in the policy planning documents "Railway environment protection policy 2012-2020".[26]
- ✓ Energy Efficiency Directive provides that member states must achieve annual energy savings of 0.8% NECP suggests that the voluntary energy efficiency agreements could include the same requirement. Thus, the goal for the energy intensive manufacturers is based on the same concept.
- ✓ According to the study ordered by the electricity transmission system operator's JSC "Augstsprieguma tīkls", the optimal capacity of BESS for 2050 is 240 MW in the Baltic States if all the electricity is generated from RES. This means that around 80 MW of BESS capacity would be needed in Latvia alone. The authors assume that in 2030 at least 1/3 of the total BES capacity should be installed. This has been rounded up to 30 MW by 2030.
- ✓ European countries usually set a threshold for an aggregator to be able to become a market participant. Larger countries like Spain, Germany, United Kingdom has set a

threshold of 50 MW, while smaller or more flexible countries set a threshold of 5 – 10 MW. [27] Currently there is no threshold in Latvia and there are also no aggregators in Latvia. But it can be assumed that an aggregator would need a portfolio of at least 5 MW to make a profitable business. The goal for 2030 could be aggregators (one or more) with the total portfolio size of 50 MW. Considering the virtual operations performed by aggregator, this would mean that the aggregators would provide an equivalent of 50 MW RES electricity.

- ✓ Energy (in particular electricity) communities would produce RES electricity and work towards achieving the solar and wind energy goals. Thus, the installed electricity capacity in energy communities cannot be calculated separately when measuring their input in reducing GHG emissions. However, there will be electricity generation installations that are existing only because of the opportunities provided by the energy community. Thus, it makes sense to create a goal for energy communities while at the same time it should not be calculated in GHG reduction results. Considering that the electricity production in a energy community must not be a commercially motivated activity, based on the average size of solar power plants and small size wind parks, the goal for energy communities in 2030 is suggested to be 100 MW.

If the above-mentioned goals are reached, the activities will have different impacts. The installed new electricity generation capacities as well as aggregators and BESS will replace import or production of electricity from fossil fuels. Electrified railway will replace the diesel used in rail freight transportation. At the same time energy savings of energy intensive manufacturers will reduce energy consumption in total. Though all outside NECP electricity policy activities have different impacts, they can all be tied together with a common indicator, which is the guiding theme of this research, i.e., reduction of GHG emissions. In this case, GHG emissions have been narrowed down to CO_2 emissions that will be measured in kilotons per year. In case of new electricity generation installations, aggregators and BESS, the reduction of CO_2 emissions is calculated by considering that natural gas would instead create CO_2 in the amount of 185 kg/MWh. Diesel rail freight would create CO_2 in the amount of 18g/tk. As regards energy intensive manufacturers, weighted average CO_2 emission factor of 101.9 kg/MWh was used to estimate the reduction of CO_2 emissions per year if the electricity consumption is lowered.

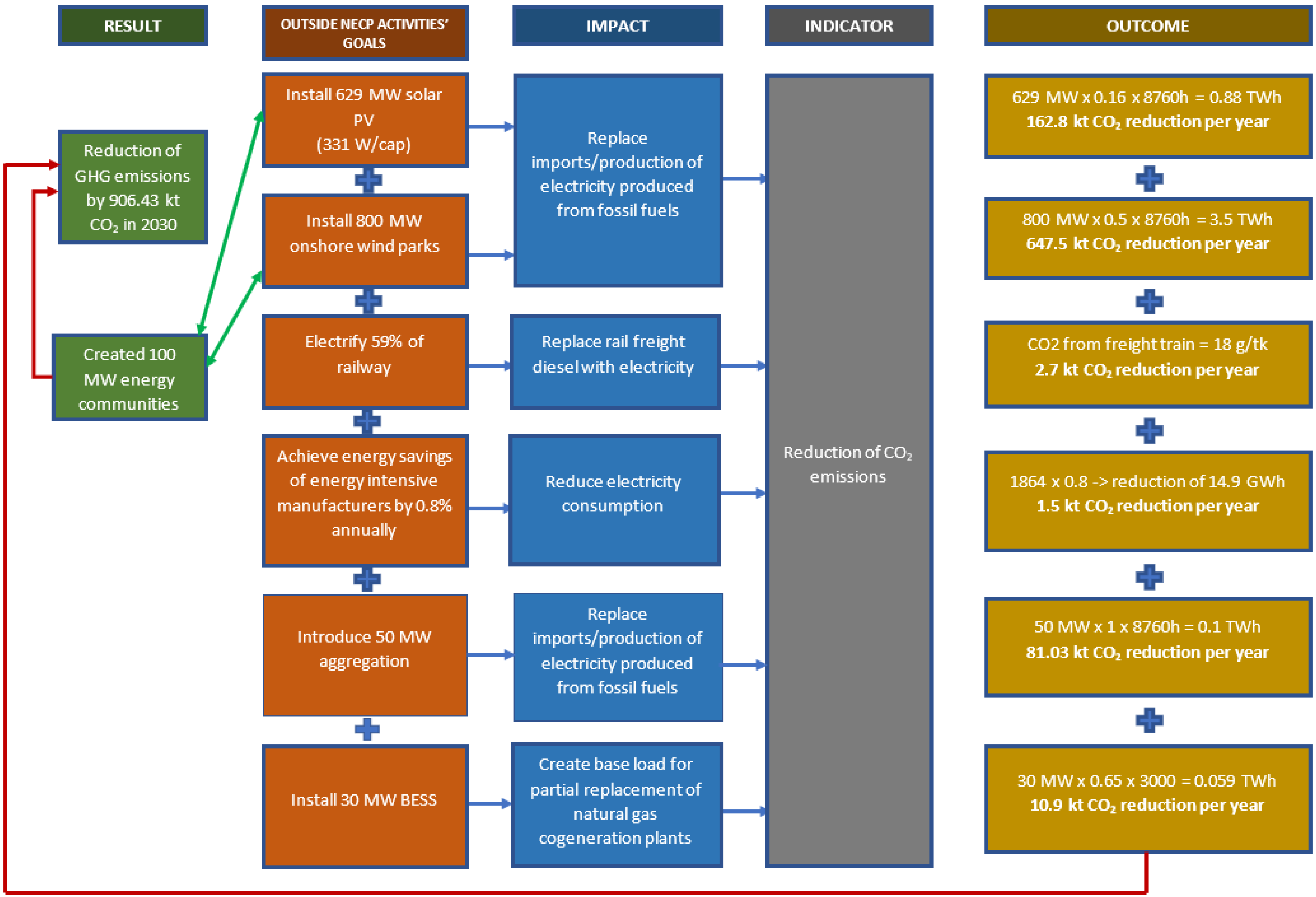


Fig.5. Summary of the results of outside NECP activities and their contribution to reduction of GHG emissions

The results of the outside NECP activities are shown in Fig.5., providing that the total CO_2 savings if the goals are achieved in 2030 would be additional 906.43 kt. For comparison, according to the NECP, total GHG emissions in 2018 were 11 800,2 kt CO_2-eq. It follows that outside NECP activities overviewed in this research could provide the reduction in GHG emissions by around 8%.

If we look at the input of each outside NECP activity, Fig. 6 provides a clear view on which measures have the most impact on the final CO_2 savings.

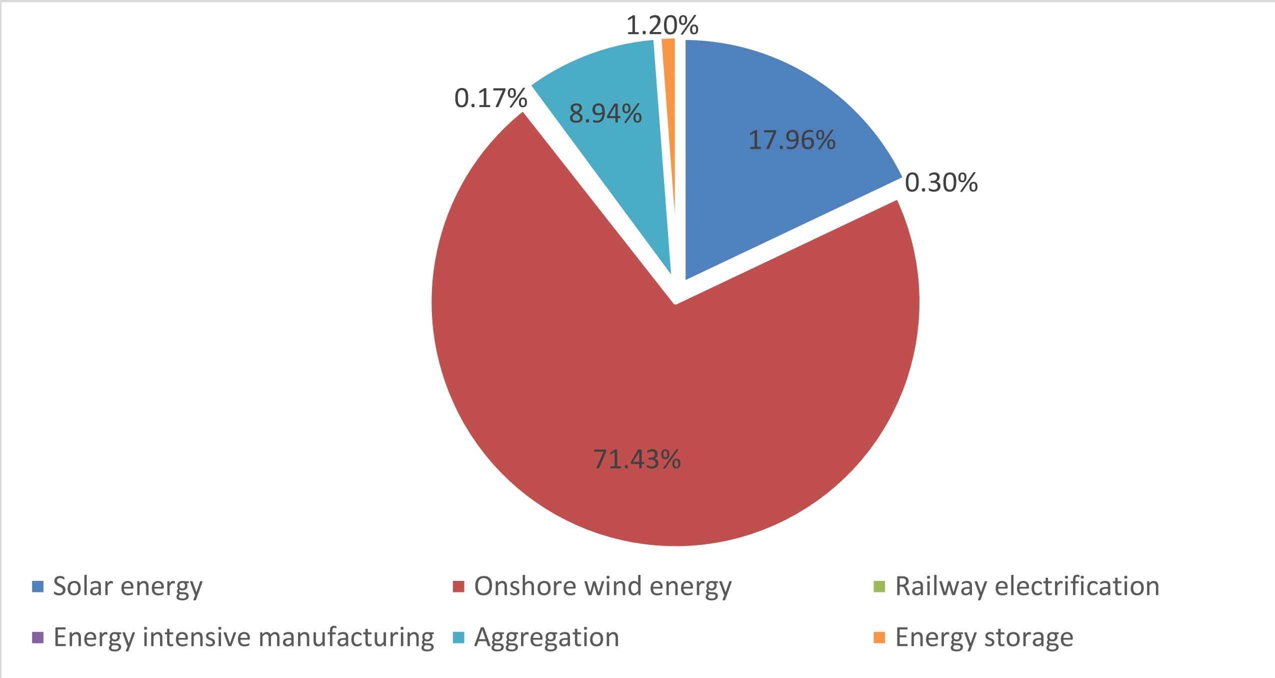


Fig.6. Impact of each outside NECP activity on the reduction of GHG emissions

Onshore wind energy provides the highest potential in reducing GHG emissions as a replacement for electricity generation from fossil fuels. This is followed by the benefits from installing solar energy capacities. Aggregators may also provide an effective amount of CO_2 reductions. At the same time energy storage, railway electrification and finally reduction of electricity consumption in energy intensive manufacturing would actually play a very small role in the efforts of reducing GHG emissions.

4. Conclusions

The electricity market is constantly developing providing new mechanisms, technical opportunities and solutions. The current NECP of Latvia is not using the full potential of these solutions and excludes solutions that may provide a substantial benefit in the work towards reduced GHG emissions. Thus, the general conclusion would be that the current NECP is not focusing on the electricity policy measures from climate perspective as much as needed.

The research overviewed seven additional activities that are not part of the NECP and provided six new goals that could be added in the reviewed NECP of Latvia. If achieved, three of the goals would create significant input in reduction of GHG emissions.

Though all of the activities could be included in the revised NECP, it is important to take into account the actual input of each activity when deciding on funding opportunities as it would not be wise to grant more intensive funding for activities that provide much less output in terms of reducing GHG emissions but are much more expensive, such as railway electrification in comparison to support in the development of solar energy capacities.

Although the research focused on the reduction of GHG emissions, the discussed outside NECP activities creates additional benefits in the energy sector, e.g. if the electricity production by solar or wind energy is increased nationally, Latvia becomes more self-sufficient and avoids electricity imports no only from the EU, but also from the third countries, which is also an issue of energy security. The outside NECP activities allows to create a complex solution for energy security issues considering not only the local electricity production increase but also by including the battery storage and aggregation solutions, which allow to shift the electricity demand.

Outside NECP activities may also provide additional socio-economical benefits considering the employment and investment opportunities, however these aspects could be further studied in additional researches.

When the NECP is reviewed in 2023, it should focus not only on the improvements of the existing measures in the plan, but all the possible additional activities, i.e. not only the ones reviewed in this research, but also considering other trends and possibilities in the market in 2023. This would also include taking an example from neighboring countries to avoid similar circumstances as in the solar energy field, where Latvia is the only EU member state without a solar energy capacity target.

References

[1] Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law') [Online]. [Accessed 12.10.2021]. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32021R1119

[2] Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action, amending Regulations (EC) No 663/2009 and (EC) No 715/2009 of the European Parliament and of the Council, Directives 94/22/EC, 98/70/EC, 2009/31/EC, 2009/73/EC, 2010/31/EU, 2012/27/EU and 2013/30/EU of the European Parliament and of the Council, Council Directives 2009/119/EC and (EU) 2015/652 and repealing Regulation (EU) No 525/2013 of the European Parliament and of the Council [Online]. [Accessed 18.12.2021.] Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?toc=OJ:L:2018:328:TOC&uri=uriserv:OJ.L_.2018.328.01.0001.01.ENG

[3] European Commission. 2030 climate & energy framework. [Online]. [Accessed 04.01.2022.] Available at: https://ec.europa.eu/clima/eu-action/climate-strategies-targets/2030-climate-energy-framework_en

[4] Business data platform Statista. Annual greenhouse gas emissions in the European Union from 1990 to 2019, by sector. [Online]. [Accessed 18.12.2021.] Available at: https://www.statista.com/statistics/1171183/ghg-emissions-sector-european-union-eu/

[5] McConnell J., Adoption for adaptation: A theory-based approach for monitoring a complex policy initiative, Evaluation and Program Planning, Volume 73, 2019, Pages 214-223, ISSN 0149-7189, https://doi.org/10.1016/j.evalprogplan.2019.01.008.

[6] Chen H.T., Theory-driven evaluations. Thousand Oak, Sage, London, 1990

[7] Thusi J., Lucas B., Methodologies for measuring influence, GSDRC helpdesk research report 905, GSDRC, University of Birmingham, Birmingham, UK, 2013 [Online]. [Accessed 06.01.2022.], Available at: https://assets.publishing.service.gov.uk/media/57a08a0040f0b64974000384/hdq905.pdf

[8] Taplin D.H., Clark H., Collins E., Colby D.C. Theory of Change. 2013. ActKnowledge. [Online]. [Accessed 15.12.2021.] Available at: http://www.actknowledge.org/resources/documents/ToC-Tech-Papers.pdf

[9] Mayne J. Making causal claims. Institutional Learning and Change (ILAC) Initiative, 2012. [Online]. [Accessed 16.12.2021.]. Available at: https://cgspace.cgiar.org/bitstream/handle/10568/70211/ILAC_Brief26_Making%20causal%20claims.pdf?sequence=1&isAllowed=y

[10] Funnell S.C., Rogers P.J., Purposeful Program Theory: Effective Use of Theories of Change and Logic Models, John Wiley & Sons, Hoboken, 2011

[11] Vogel I., Review of the use of "Theory of Change" in international development, 2012. [Online]. [Accessed 12.01.2022.] Available at: https://www.theoryofchange.org/pdf/DFID_ToC_Review_VogelV7.pdf
[12] 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(15):4467. https://doi.org/10.3390/en14154467
[13] Egenhofer C., Gazzoletti F., Electricity sector holds the key for the EU's low-carbon economy. CEPS, 2019. [Online]. [Accessed 10.01.2022.] Available at: http://aei.pitt.edu/100394/1/Priorities_elecrticity-sector.pdf
[14] Rozentale, L., Lauka, D., Blumberga, D. Accelerating Power Generation with Solar Panels. Case in Latvia. Energy Procedia, 2018, Vol. 147, pp.600-606. ISSN 1876-6102. Pieejams: https://doi.org/10.1016/j.egypro.2018.07.077
[15] Rozentale L., Blumberga D., Cost-benefit and multi-criteria analysis of wind energy parks' development potential in Latvia, Environmental and Climate Technologies, vol.25, no.1, 2021, pp.1229-1240. https://doi.org/10.2478/rtuect-2021-0093
[16] Rozentale L., Blumberga D., Potential role of energy communities in the way towards climate neutrality
[17] Rozentale L, Kalnbalkite A and Blumberga D., "Aggregator as a new electricity market player: (Case study of Latvia)," 2020 IEEE 61th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), 2020, pp. 1-6, 10.1109/RTUCON51174.2020.9316486
[18] Pakere I., Gravelsins A., Bohvalovs G., Rozentale L., Blumberga D. Will Aggregator Reduce Renewable Power Surpluses? A System Dynamics Approach for the Latvia Case Study Energies 2021, 14(23), 7900; https://doi.org/10.3390/en14237900
[19] Rozentale, L., Mo, G., Gravelsins, A., Rochas, C., Pubule, J., Blumberga, D. System Dynamics Modelling of Railway Electrification in Latvia. Environmental and Climate Technologies, 2020, Vol. 24, No.2, pp. 247-257. doi: https://doi.org/10.2478/rtuect-2020-0070
[20] Rozentale, L., Blumberga, D. Energy Intensive Manufacturers in State Economy: Case study of Latvia. 2019 IEEE 60th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), Riga, Latvia, 2019, pp. 1-6, Pieejams: https://doi.org/10.1109/RTUCON48111.2019.8982318
[21] Ruling of the Cabinet of Minister No.46, "Par Latvijas Nacionālo enerģētikas un klimata plānu 2021.-2030. gadam", 2020. [Online]. [Accessed 10.12.2021.] Available at: https://likumi.lv/ta/id/312423-par-latvijas-nacionalo-energetikas-un-klimata-planu-20212030-gadam
[22] Blumberga A. et al, Project "Energoefektivitātes rīcībpolitikas novērtējums un analīze", 2021. [Online]. [Accessed 03.01.2022.] Available at: https://videszinatne.rtu.lv/wp-content/uploads/2021/01/2_Datu-v%C4%81k%C5%A1ana-un-anal%C4%ABze-par-eso%C5%A1ajiem-Latvijas-energoefektivit%C4%81tes-politikas-instrumentiem-ar-ex-post-metodi-un-eso%C5%A1%C4%81s-energoefektivit%C4%81tes-monitoringa-un-ietaup%C4%ABjumu-v.pdf
[23] Andrey C., Barberi P., Nuffel L., et al, *Study on energy storage: contribution to the security of the electricity supply in Europe*, European Commission, Directorate-General for Energy Publications Office, 2020. [Online]. [Accessed 03.01.2022.] Available at: https://data.europa.eu/doi/10.2833/077257
[24] BATSTORM, Batter-based energy storage roadmap, European Commission, 2018. [Online]. [Accessed 03.01.2022.] Available at: https://ec.europa.eu/energy/sites/default/files/report-_battery_storage_to_drive_the_power_system_transition.pdf
[25] Schmela M et al, EU Market Outlook for Soalr Power 2021-2025, SolarPower Europe. [Online]. [Accessed 10.12.2021.] Available at: https://www.solarpowereurope.org/wp-content/uploads/2021/12/EU-Market-Outlook-for-Solar-Power-2021-2025_SolarPower-Europe.pdf?cf_id=48751
[26] Latvijas Republikas Valsts dzelzceļa administrācija. Dzelzceļa vides aizsardzības politika 2012.-2020.gadam. [Online]. [Accessed 05.01.2022.] Available at: https://www.vda.gov.lv/lv/media/49/download
[27] Bertoldi P., Zanzanella P., Boza-Kiss B. Demand response status in EU Member states., 2016. [Online]. [Accessed 16.12.2021.] Available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC101191